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

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(Current version: January 2007)

Abstract

This paper 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 model of the government bond rate is identified as the transition variable that controls the smooth transition from high volatility regime to low volatility regime. The break 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, volatility shock has profound effects on shorter maturity spreads, while the term structure shock plays an important role in impacting longer maturity spreads. Our results also show noticeable differences between the non-linear and linear impulse response functions.

JEL classification: G15, E43

Keywords: Japanese yen interest rate swap, smooth transition VAR, regime switching.

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This paper 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 model of the government bond rate is identified as the transition variable that controls the smooth transition from high volatility regime to low volatility regime. The break 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, volatility shock has profound effects on shorter maturity spreads, while the term structure shock plays an important role in impacting longer maturity spreads. Our results also show noticeable differences between the non-linear and linear impulse response functions.

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

1. Introduction

This paper provides an empirical examination of the dynamic behavior of the Japanese yen interest rate swap spreads[1] (hereafter swap spreads) and relevant risk factors within a smooth transition vector autoregressive (STVAR) framework. The non-linear, state-dependent model better characterizes the Japanese swap market since the late 1990s, and it uncovers asymmetric and regime-shifting movements in swap spreads.

Being the price of interest rate swaps, swap spreads constitute an important research topic as swap contracts have experienced exponential worldwide growth over the past decade with the widespread use by corporations, hedge funds, and other financial institutions for risk management. Increasingly municipal governments have also entered interest rate swap agreements to manage their debt. In addition to the growing popularity of interest rate swaps for risk management, financial market in the US increasingly has adopted the swap curve for bonds and derivative securities pricing due to the dwindling liquidity in the Treasury market.[2] 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

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[1] They are the spreads between Japanese yen interest rate swaps and Japanese government bonds with comparable maturities.

[2] One-year T-bill was phased out in 2000, while the issuance of 30-year T-bonds was stopped in 2001.

undertaken the task of seeking an appropriate explanation of the Japanese swap market dynamics.[3]

This research thus contributes to the literature in a number of aspects. First, we study the behavior of Japanese swap spreads whose importance is second only to the US counterpart, yet are much ignored and under-studied. 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 non-linear STVAR model allows for a smooth transition from one regime of swap spreads to the other, controlled by an underlying economic determinant.

Third, our sample spans from 1997 to 2005, which not only offers the most updated dataset, but also encompasses the Japanese banking crisis as well as a period of banking mergers and financial reforms. We are thus in a good position 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 also permits us to obtain 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 non-linear framework, the transition variable responsible for the shift of regimes is identified to be the volatility variable based on a GARCH

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[3] To the best of our knowledge, so far only two studies have examined Japanese yen interest rape 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.

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, two-year swap spreads are sensitive to the volatility shock than five- or ten-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 the soundness of our results.

The rest of the paper is organized as follows. In Section 2, we touch on the issue of swap pricing and provide a literature review along with a discussion of the determinants of swap spreads. Data sources and variable definitions are presented in Section 3. Section 4 discusses statistical methodologies while empirical results are reported in Section 5. Section 6 concludes.

2. Swap Pricing, Literature Review, and Determinants of Swap Spreads

2.1 Swap pricing

A plain vanilla interest rate swap is a contractual agreement for one party to pay a fixed rate interest (swap rate) in exchange of a stream of variable cash flows based upon a floating rate of interest such as London Interbank Offered Rate (LIBOR) for a certain amount of notion 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 zero at the initiation of the contract. Let $F(t_0 , t_i)$ 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. Since floating-rate payments could be hedged using forward rate contracts, a hedged swap paying fixed rate, S_{t_0}, having zero net present value, requires that

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

Rearranging equation (1), we obtain the swap rate as:

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

Therefore, swap rate, S_{t_0}, can be regarded as a weighted average of the forward rate agreement paid-in-arrears rates during the life of the swap:

$$S_{t_0} = \omega_1 F(t_0, t_1) + ... + \omega_{n-1} F(t_0, t_{n-1}) \tag{3}$$

with the weight being

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

Since swap spread is measured by the difference between the swap rate, S_{t_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. We will observe a non-zero swap spread, however, when the financial markets are less than perfect, hence counterparty default risk exists. Since the swap spread changes over time, it is important that we understand what drives the dynamics of swap spread.

2.2 Literature review

Only 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) 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 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 (2002) 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 US 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 impact on the US 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 et al. (1994), Lang et al. (1998), Sun et al. (1993), and Fehle (2003). In addition to default and liquidity premiums, other economic determinants of swap spreads by prior researches consist of interest rate volatility and slope of the yield curve as they are alternative proxies of financial market risks (e.g., In et al., 2003; Lekkos and Milas, 2001, 2004).

While most of the studies focus on the US 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 US and UK data. Lekkos and Milas (2004) model US and UK 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 time period that is before the Japanese banking crisis and subsequent financial system reforms. Most importantly, the majority of the swap rate studies rely upon OLS and linear VAR analyses. Non-linear models in recent years have been proved to outperform the linear ones, such as Lekkos and Milas (2004) and Lekkos et al. (2006), which find more flexible interpretation of the results and provide better predictive power on swap spreads.

3. Data and Variables

Based upon the swap pricing model and the findings of extant literature, we define and present relevant data in this section. Weekly data from August 8, 1997 to April 15, 2005 are collected from Datastream and Bloomberg. 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 two-year maturity.

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

SS10 — ten-year maturity swap spread; computed as the differential between the swap rate and the Japan government bond rate of ten-year maturity.

SLOPE — slope of the term structure; computed as the differential between the two-year and the ten-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]

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 spread to measure credit risk. In a similar fashion, we collect yield data on Japanese government bonds (JGB), AAA-rated, and BBB-rated corporate bonds. However, since AAA-rated bonds have significant number of missing data, we employ the spread between BBB-rated corporate bonds and JGB yields to proxy the default premium.

We also include interest rate volatility generated by a GARCH model and the slope of the term structure of interest rates in our empirical model because these two variables determine the value of the option to default in the Sorensen and Bollier's (1994)

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[4] An EGARCH model is discussed in In (2006).

model. Since 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) we measure liquidity premium by subtracting 6-month JGB yield from similar maturity TIBOR rate. Since increasing convenience yield implies that the market requires a higher premium to compensate for the decrease of liquidity in 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 US 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, it is the unprecedented collapse of major banks that 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 JAPAN PREMIUM diagram, 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 post banking crisis period.[5]

Shown in the VOLATILITY diagram, 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

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[5] For detailed discussions of the Japanese banking crisis, see Nakaso (2001), Miyajima and Yafeh (2003), and Krawczyk (2004).

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 1 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. Considering the Japanese economic conditions, the ex post patterns of swap spreads and their economic determinants discussed above, we further partition the whole sample into two subperiods. Panel B shows the statistics for the subperiod between August 1997 and December 2000, while Panel C presents the same statistics for the second subperiod between January 2001 and April 2005.[6] Consistent with Figure 1, default premium, Japan premium, 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 tenfold 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.

4. Methodology

4.1. The baseline model

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

Since 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, we consider the VAR extension of the smooth transition autoregressive (STVAR) model in Camacho (2004), which is also employed in Lekkos and Milas (2004), and Lekkos et al. (2006). The model permits a smooth transition of regimes based upon an empirically chosen economic factor. Let

$$Y_t = A + B(L)Y_{t-1} + \left(C + D(L)Y_{t-1}\right)F\left(Y_{i,t-d}\right) + u_t, \qquad (5)$$

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 Ω.

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

In order 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:

$$F\left(Y_{i,t-d}\right)=\{1+\exp[-\gamma\left(Y_{i,t-d}-c\right)]/\sigma\}^{-1}, \tag{6}$$

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

$$F\left(Y_{i,t-d}\right)=1-\exp[-\gamma\left(Y_{i,t-d}-c\right)^2/\sigma^2]. \tag{7}$$

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 $Y_{i,t-d}$, but the model turns linear if either $\gamma \to 0$ or $\gamma \to +\infty$. In both models, the smoothness parameter γ, which is restricted to be positive between zero and one, controls the speed of adjustment across regimes.

4.2. Linearity tests and the transition function

We follow the specification suggested in Camacho (2004), which adapts the univariate proposal of Granger and Terasvirta (1993) to a multi-equation 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. Since 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 non-linear models.

Next, some linearity and model selection tests are conducted. Maximum likelihood method is employed for the estimation, in which (2 × the log likelihood under the alternative − the log likelihood under the null) will follow asymptotically a χ^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:

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

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, we consider just one lag for each candidate of the transition variable. Linearity

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[7] See Camacho (2004) for technical details about maximum likelihood estimation.

tests are applied for each of these lagged variables. In case of multiple rejections of the null, we follow Terasvirta (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.

Our results of linearity tests appear in Table 2. 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 non-linear model better fits our Japanese swap data. The following step is to choose the transition variable. In order to select just one transition variable that is responsible for the regime shift in the nonlinear model, we also show the ratio of the linearity test statistic 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 sequentially applied to the auxiliary regression (i.e. H_{01}, H_{02}, and H_{03}, respectively) and subsequent decisions are illustrated in Table 3. Using lagged volatility as the transition variable, the *p*-values of Test 1, Test 2 and Test 3 are all about 0.000. Therefore, we conclude that the appropriate transition function is logistic.

5. Empirical Results

5.1. Regime identification

The logistic transition function model is now estimated using the maximum likelihood method.[8] For the ease of presentation and to shed some lights 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 (γ) 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 (γ), 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 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.

5.2. Generalized impulse response analysis

In this subsection, we explain the estimation procedure of the generalized impulse response function (GIRF), and report associated empirical results for our STVAR

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[8] Parameter estimates are not reported to save space. They are available from the authors upon request.

models. Since 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), we define the generalized impulse response function of variable i for an arbitrary shock to variable j denoted by $\varepsilon_{jt} = \delta_j$ and history w_{t-1} as:

$$GIRF\left(h,\delta_j,w_{t-1}\right)=E\left(Y_{i,t+h}/\varepsilon_{jt}=\delta_j,w_{t-1}\right)-E\left(Y_{i,t+h}/w_{t-1}\right). \qquad (9)$$

In the empirical application, δ_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.[9] In order to deal with the problem of shocks in intermediate time periods, we follow the bootstrap procedure suggested by Weise (1999). We first obtain 5000 draws with replacements from the residuals of the nonlinear model, compute the *GIRF* for each of them and then average the responses. In

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[9] 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:

$$IRF\left(h,\delta_j,w_{t-1}\right)=E\left(Y_{i,t+h}/\varepsilon_{jt}=\delta_j,\varepsilon_{jt+1}=0,\ldots,\varepsilon_{jt+h}=0,w_{t-1}\right)-E\left(Y_{i,t+h}/\varepsilon_{jt}=0,\ldots,\varepsilon_{jt+h}=0,w_{t-1}\right)$$

where δ 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.

addition, *GIRFs* are history dependent. To account for this dependency, we compute the *GIRFs* 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.[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 Figures 4 and 5 respectively for 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 five 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 five weeks. The impulse response of SS2 to the term structure shock

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[10] Imposing starting points of F exactly equal to either 1 or 0 is not empirically plausible since we need enough observations in the right and left hand sides of the distribution.

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 US 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 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 6, 7, 8, and 9 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. We use the impulse response results for SS5 in the high volatility regime to illustrate these differences. First of all, 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, while 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 and Milas, 2004). This result stems from the fact that the exposure to the possibility of default (from the floating-rate payer in the swap deal) for the fixed rate payer is higher during the later stage of the contract, hence higher embedded risks for the longer-term contracts.

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 seven 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 during this period. Our result may be consistent with their finding if the correlation between BBB-bond yields and JGB yields is positive.[11]

5.3. Comparison of non-linear and liner impulse response functions

In this subsection, we show that results can differ substantially between linear and nonlinear models. To save space, Figures 10 and 11 only exhibit the impulse responses of swap spreads to default shocks and spreads' own shocks. In Panel A of Figure 10, the response of SS2 to default shock in the high volatility regime from the non-linear 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 non-linear model is completely absent in the linear

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[11] We 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.

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 11, we present the responses of SS5 to its own shock based upon non-linear and linear models. In Panel A, the high volatility regime witnesses a rather short-lived, diminutive reaction of SS5 to its own shock in the non-linear 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.

6. Conclusions

In this paper we model the nonlinear relationship of Japanese yen interest rate swap spreads and a number of risk factors within a smooth transition VAR framework. 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. Our nonlinear model enables us to capture a time-varying component of swap spreads across different maturities. The non-linear dynamics are corroborated by the fact that swap spreads of all maturities are very volatile and large in magnitude during the period of 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 non-linear 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 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. Last, and most importantly, fallacious conclusions of a liner VAR are avoided under the STVAR framework.

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Table 1. Descriptive Statistics

This table displays the descriptive statistics of swap spreads and their economic determinants. SS2, SS5, and SS10 are swap spreads of 2-year, 5-year, and 10-year maturities, respectively. 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.

Panel A: Whole Sample

	DEFAULT	JPPREM	LIQUIDITY	SLOPE	SS10	SS5	SS2	VOLATILITY
Mean	1.524	0.051	0.169	1.197	0.154	0.117	0.081	0.129
Median	1.473	0.028	0.098	1.241	0.093	0.101	0.081	0.027
Maximum	4.995	0.417	0.876	1.683	0.596	0.496	0.316	0.705
Minimum	0.467	-0.098	0.039	0.400	-0.086	-0.077	-0.220	0.000
Std. Dev.	0.739	0.071	0.152	0.245	0.161	0.091	0.074	0.158

Panel B: 1997-2000

	DEFAULT	JPPREM	LIQUIDITY	SLOPE	SS10	SS5	SS2	VOLATILITY
Mean	1.946	0.085	0.267	1.225	0.312	0.172	0.079	0.272
Median	1.944	0.041	0.204	1.236	0.323	0.201	0.075	0.251
Maximum	4.995	0.417	0.876	1.683	0.596	0.496	0.316	0.705
Minimum	0.755	-0.098	0.039	0.407	-0.027	-0.077	-0.220	0.049
Std. Dev.	0.794	0.096	0.188	0.248	0.097	0.099	0.109	0.137

Panel C: 2001-2005

	DEFAULT	JPPREM	LIQUIDITY	SLOPE	SS10	SS5	SS2	VOLATILITY
Mean	1.189	0.023	0.095	1.174	0.029	0.073	0.083	0.015
Median	1.151	0.022	0.091	1.247	0.021	0.063	0.082	0.007
Maximum	2.102	0.086	0.236	1.624	0.214	0.242	0.168	0.185
Minimum	0.467	-0.011	0.066	0.400	-0.086	-0.053	0.029	0.000
Std. Dev.	0.476	0.015	0.022	0.242	0.059	0.051	0.021	0.026

Table 2. Linearity Tests and Identification of Transition Variable

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.

Transition Variable Candidates (in t-1)

		SS	DEFAULT	JPPREM	LIQUIDITY	SLOPE	VOLATILITY
SS2 model	Test statistics	136.58	161.36	206.48	345.18	357.71	385.11
	(*p*-value)	(0.032)	(0.007)	(0.000)	(0.000)	(0.000)	(0.000)
	Test statistics ratio	0.355	0.419	0.536	0.896	0.929	1.000
SS5 model	Test statistics	125.89	158.48	186.38	390.91	400.38	415.20
	(*p*-value)	(0.115)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)
	Test statistics ratio	0.303	0.382	0.449	0.941	0.964	1.000
SS10 model	Test statistics	147.91	155.88	159.86	468.13	480.09	498.02
	(*p*-value)	(0.006)	(0.002)	(0.001)	(0.000)	(0.000)	(0.000)
	Test statistics ratio	0.297	0.313	0.321	0.940	0.964	1.000

Table 3. Functional Form of the Transition Function

This table reports test results of selecting the transition function using lagged volatility as the transition variable. The decisions on the choice between a logistic and an exponential model are indicated in the last column. Using lagged volatility as the transition variable, the *p*-values of Test 1, Test 2 and Test 3 are all about 0.000. Therefore, we conclude that the appropriate transition function is logistic.

Test 1	Test 2	Test 3	
$H_{01}: G_3 = 0$	$H_{02}: G_2 = 0 / G_3 = 0$	$H_{03}: G_1 = 0 / G_3 = G_2 = 0$	
	Results		**Decision**
Reject	N/A	N/A	Logistic
Accept	Reject	Accept	Exponential
Accept	Accept	Reject	Logistic
Accept	Reject	Reject	No decision

Figure 1. Plots of Swap Spreads and Economic Determinants

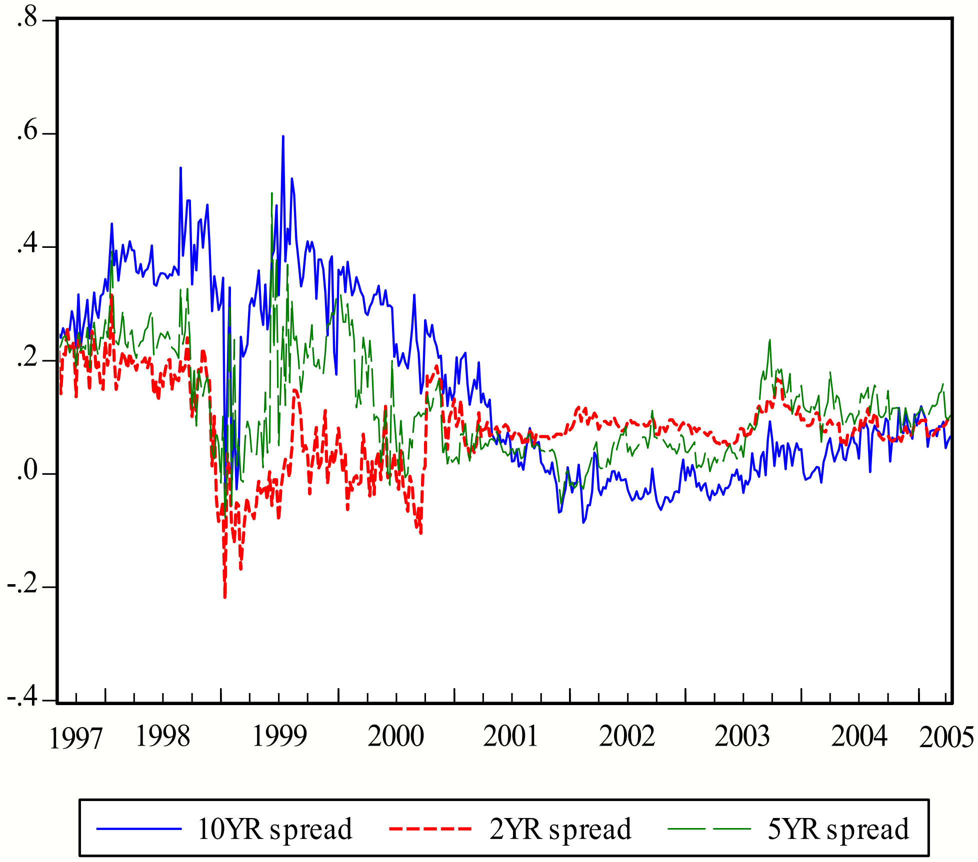
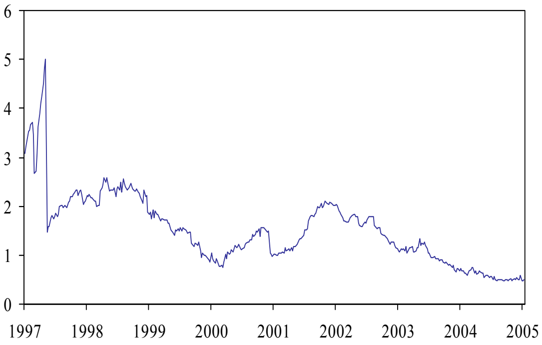
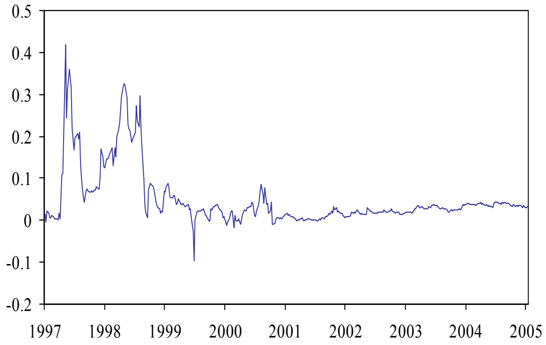


Figure 1. (Continued)

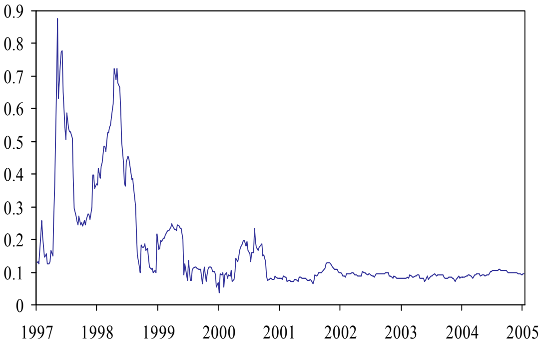
DEFAULT



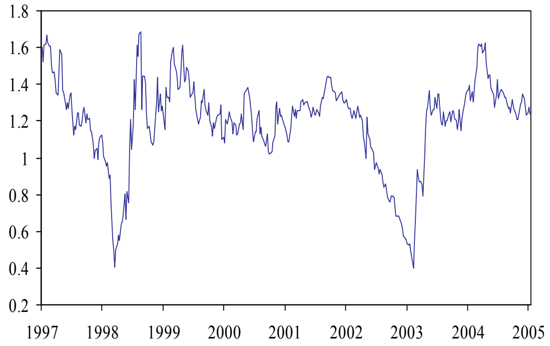
JAPAN PREMIUM



LIQUIDITY



SLOPE



VOLATILITY

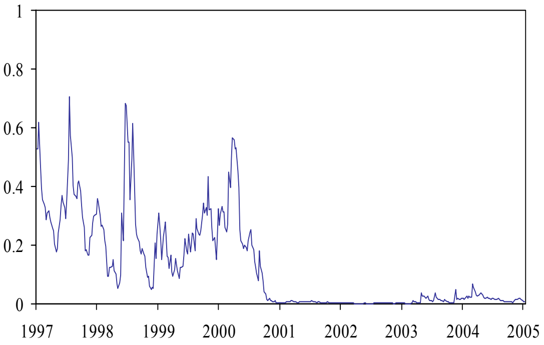
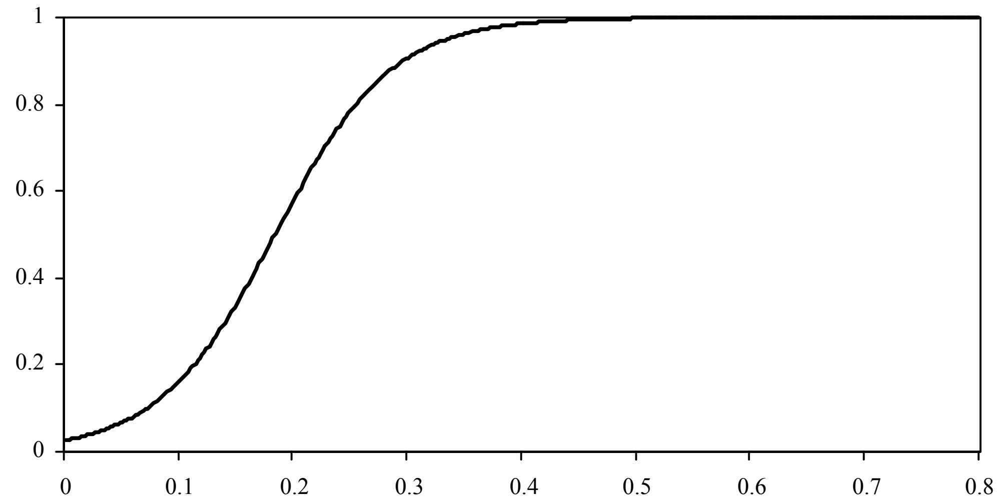


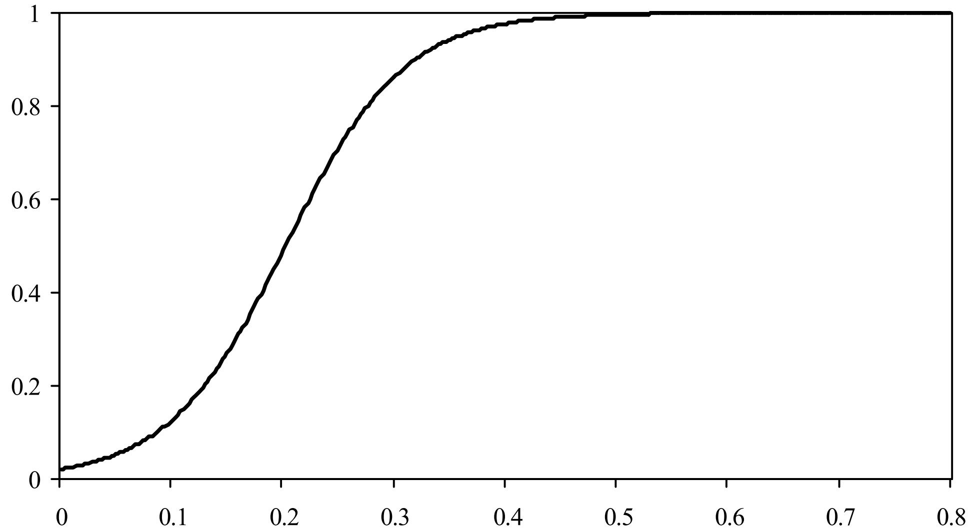
Figure 2. Estimated Transition Function (Vertical Axis) against VOLATILITY (Horizontal Axis) at t-1

Panel A: SS2



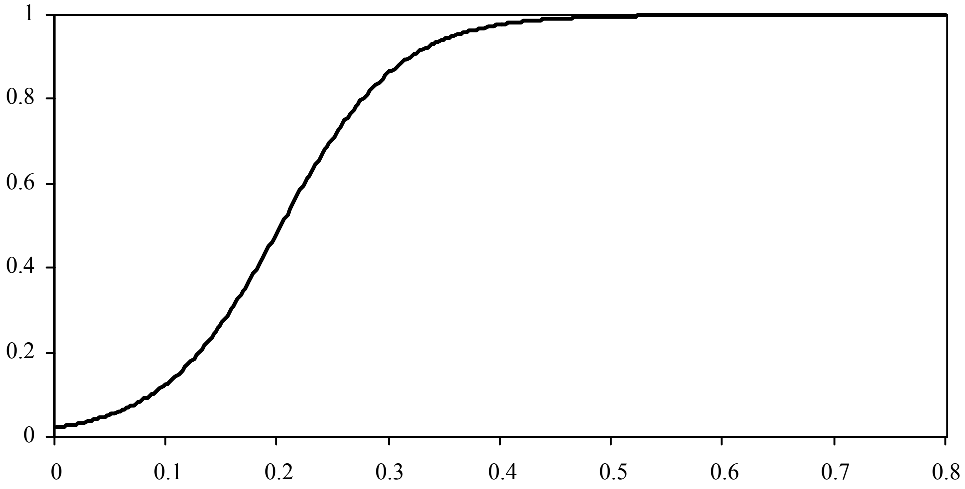
Notes: The first regime (*F* close to one) is interpreted as periods where volatility is high whereas the second regime (*F* close to zero) can be seen as periods associated with relatively low volatility. The estimated transition function is $F(V_{t-1})=\{1+\exp[-3.92(V_{t-1}-0.08)/\sigma]\}^{-1}$,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

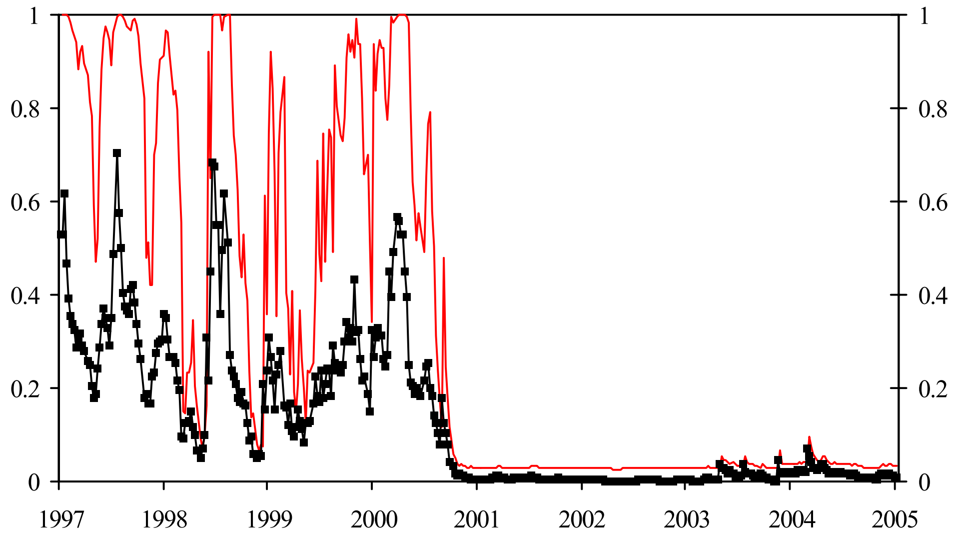
Panel C: SS10



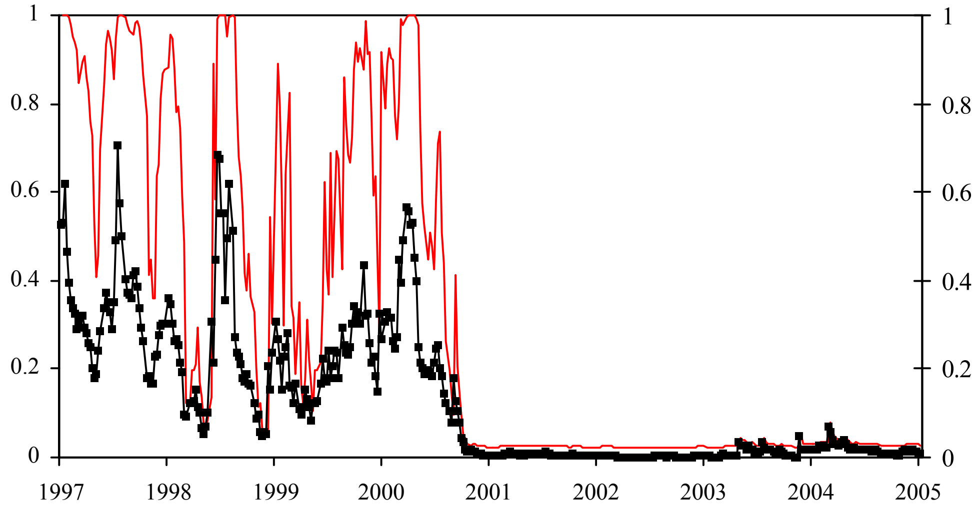
Notes: The first regime (F close to one) is interpreted as periods where volatility is high whereas the second regime (F close to zero) can be seen as periods associated with relatively low volatility. The estimated transition function is $F(V_{t-1})= \{1+ exp[-4.01(V_{t-1}-0.12)/\sigma]\}^{-1}$, where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

Figure 3. Transition Function and VOLATILITY

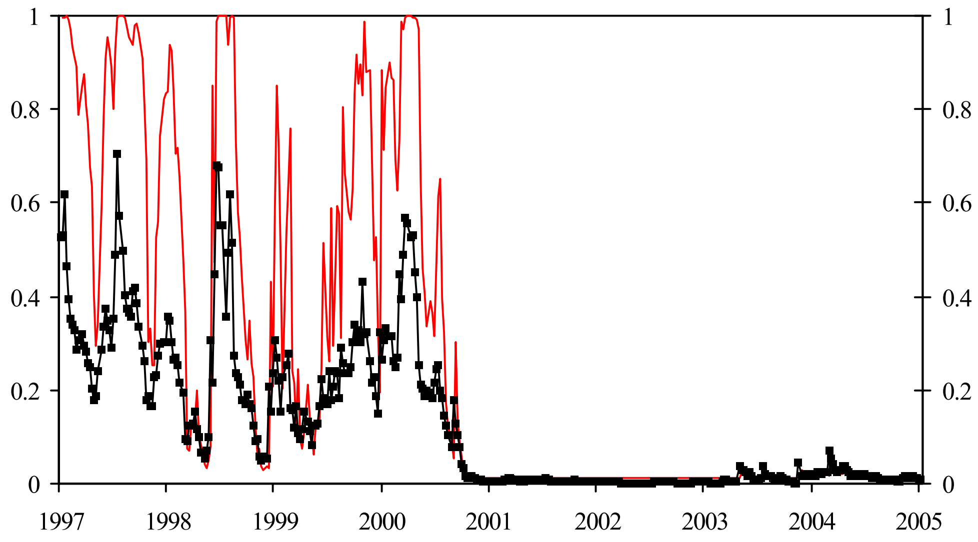
Panel A: SS2



Panel B: SS5

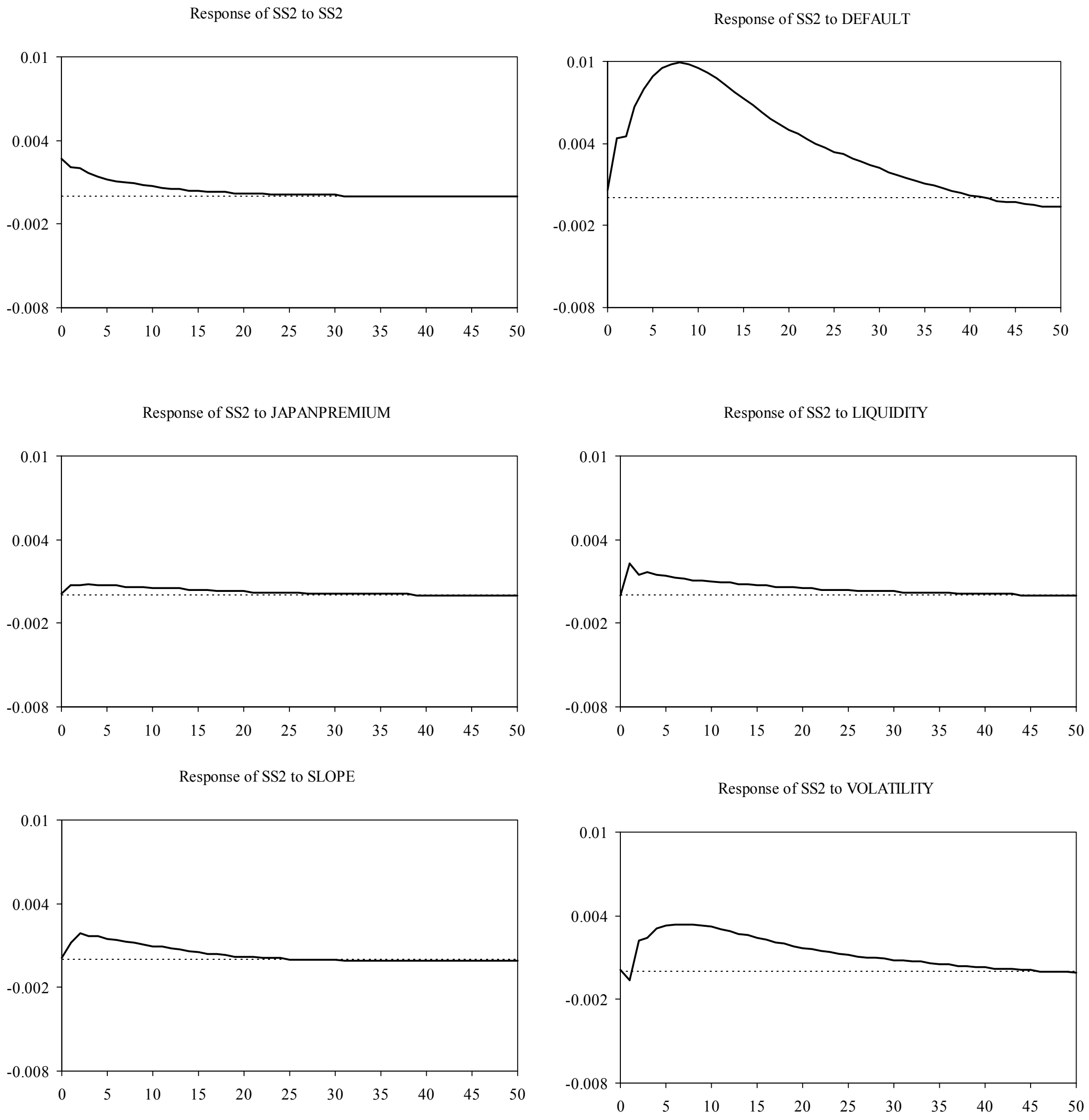


Panel C: SS10



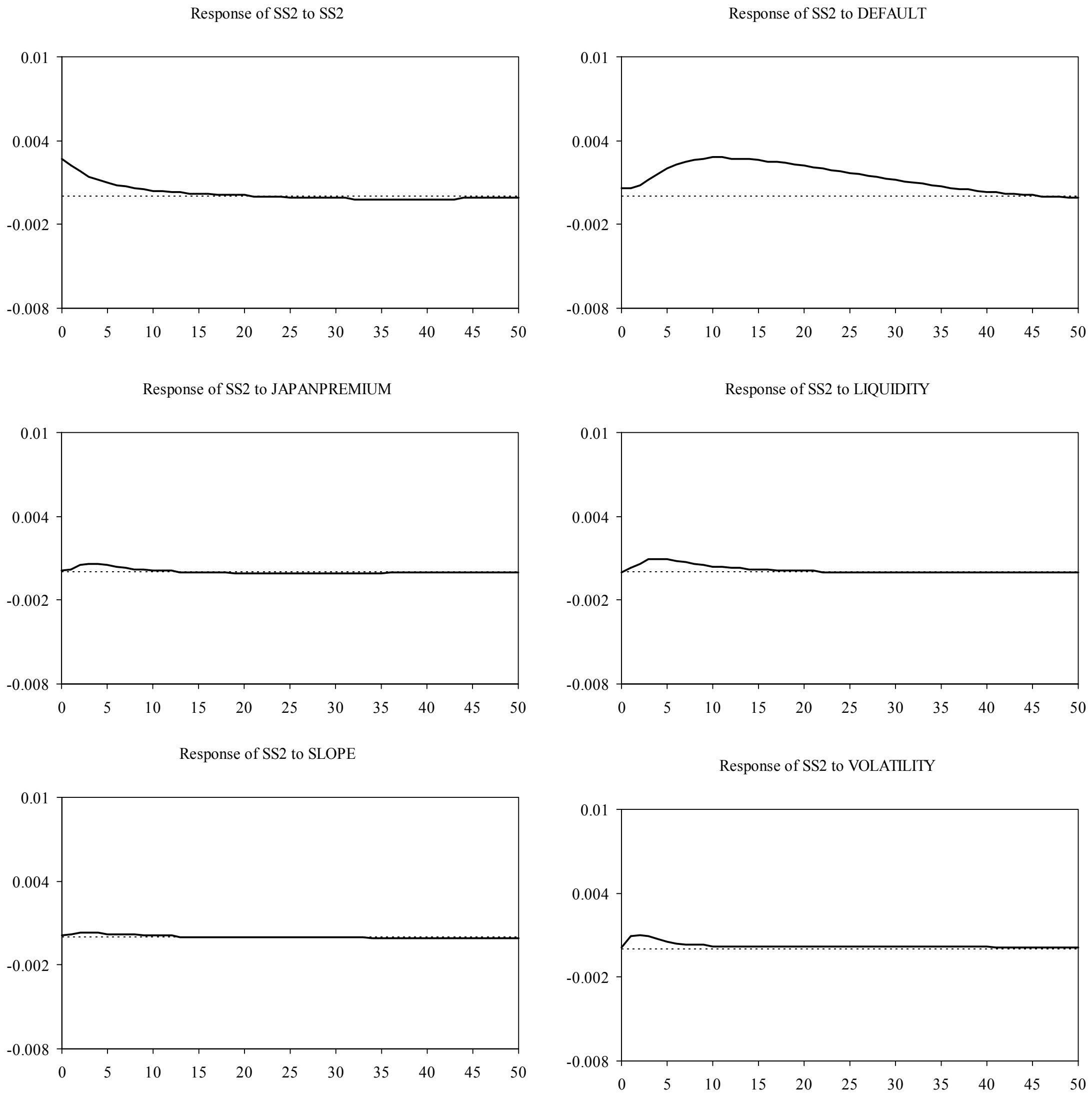
Notes: The transition function is the solid line (left-hand axis) and volatility is the line with blocks (right-hand axis). Values of the transition function close to one refer to the first regime and correspond to periods of high volatility. Note that the break point is at about the end of the banking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

Figure 4. Generalized Impulse Responses of SS2 in the First Regime



Notes: These figures represent the effect on SS2 of one standard deviation shock to all the variables included in the system. The shocks hit the economy when the transition function is 0.85, that is, when volatility is high (first regime).

Figure 5. Generalized Impulse Responses of SS2 in the Second Regime


Response of SS2 to SS2

Response of SS2 to DEFAULT

Response of SS2 to JAPANPREMIUM

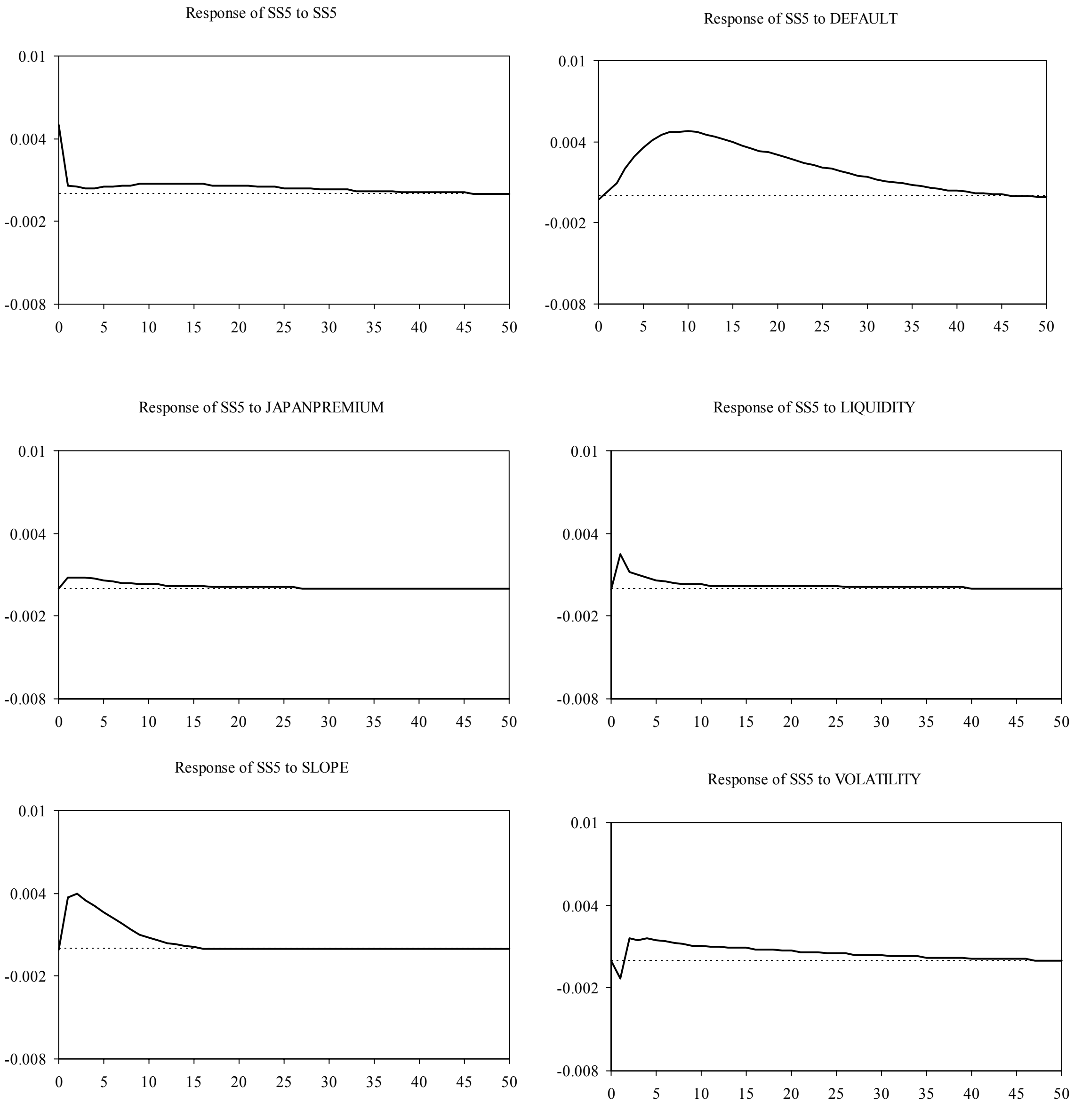
Response of SS2 to LIQUIDITY

Response of SS2 to SLOPE

Response of SS2 to VOLATILITY

Notes: These figures represent the effect on SS2 of one standard deviation shock to all the variables included in the system. The shocks hit the economy when the transition function is 0.15, that is, when volatility is low (second regime).

Figure 6. Generalized Impulse Responses of SS5 in the First Regime


Response of SS5 to SS5

Response of SS5 to DEFAULT

Response of SS5 to JAPANPREMIUM

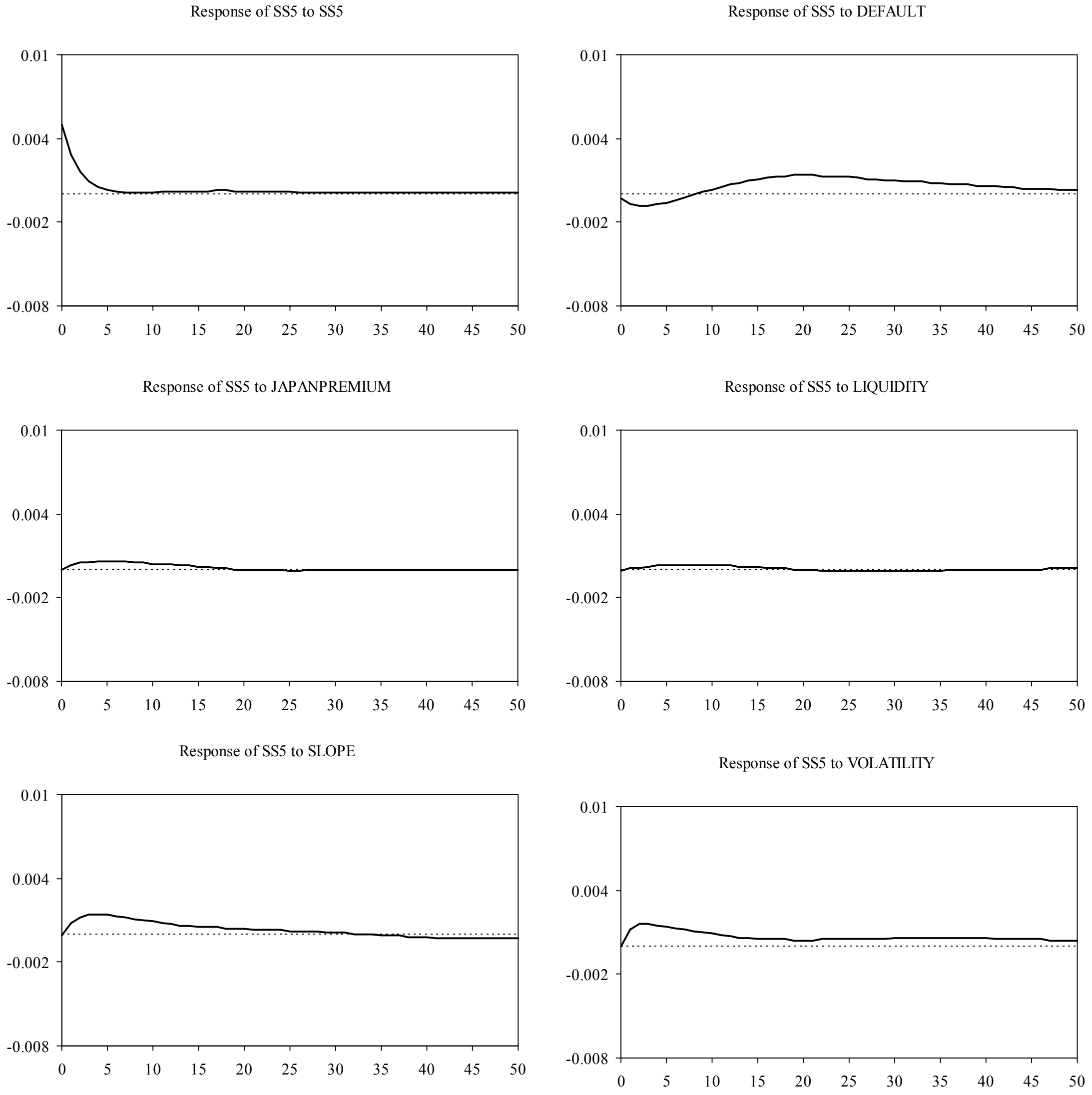
Response of SS5 to LIQUIDITY

Response of SS5 to SLOPE

Response of SS5 to VOLATILITY

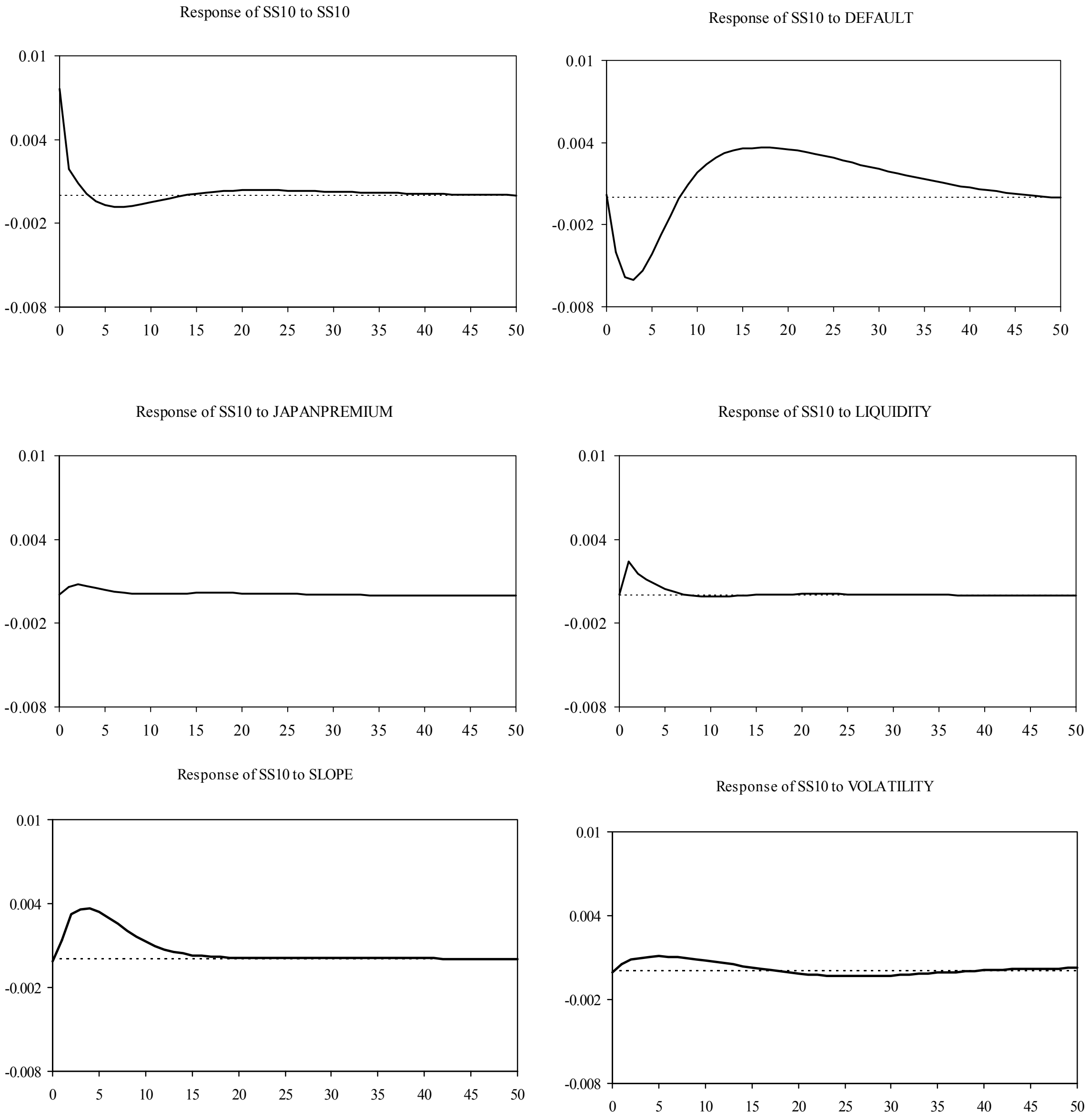
Notes: These figures represent the effect on SS5 of one standard deviation shock to all the variables included in the system. The shocks hit the economy when the transition function is 0.85, that is, when volatility is high (first regime).

Figure 7. Generalized Impulse Responses of SS5 in the Second Regime



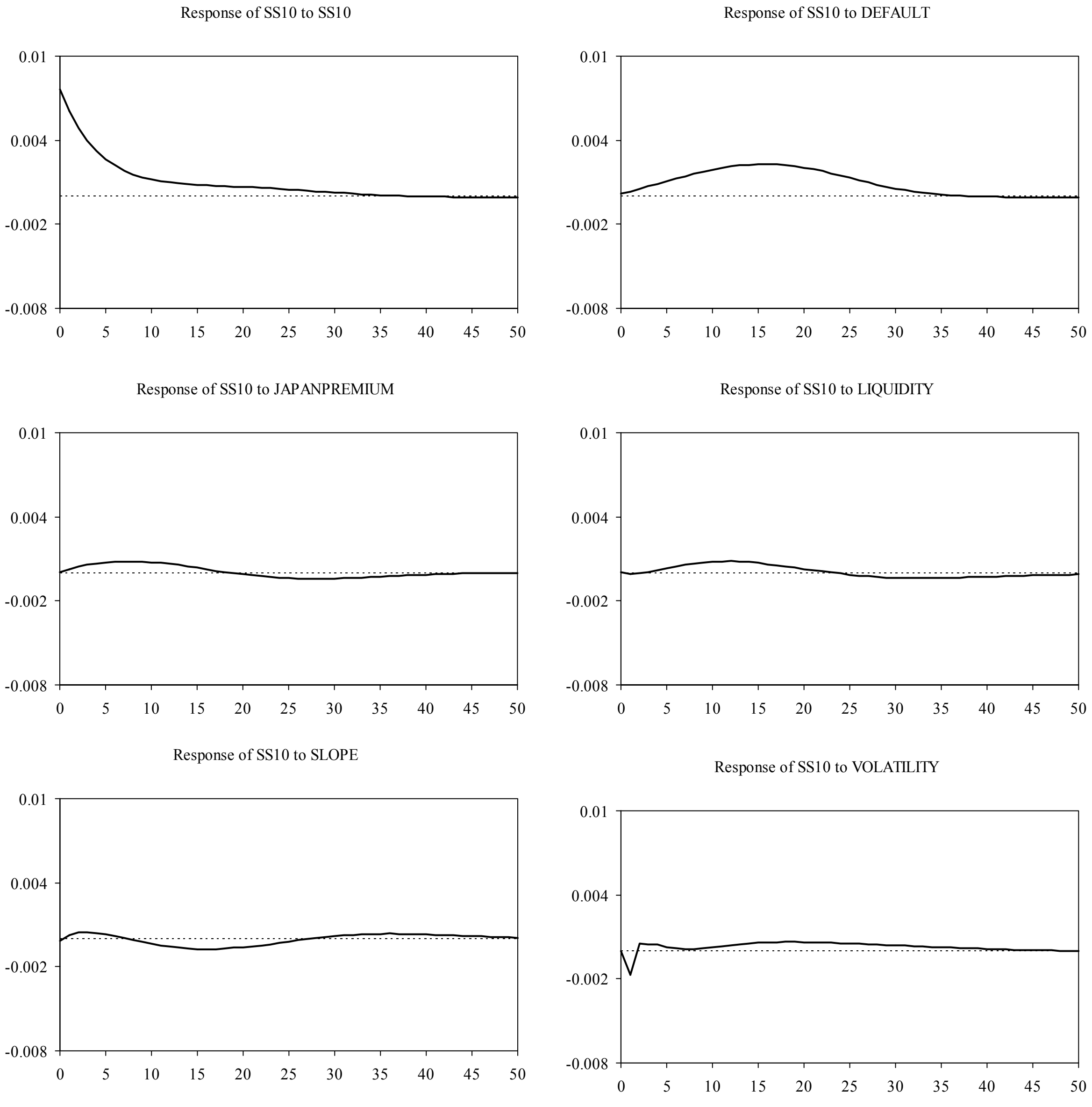
Notes: These figures represent the effect on SS5 of one standard deviation shock to all the variables included in the system. The shocks hit the economy when the transition function is 0.15, that is, when volatility is low (second regime).

Figure 8. Generalized Impulse Responses of SS10 in the First Regime



Notes: These figures represent the effect on SS10 of one standard deviation shock to all the variables included in the system. The shocks hit the economy when the transition function is 0.85, that is, when volatility is high (first regime).

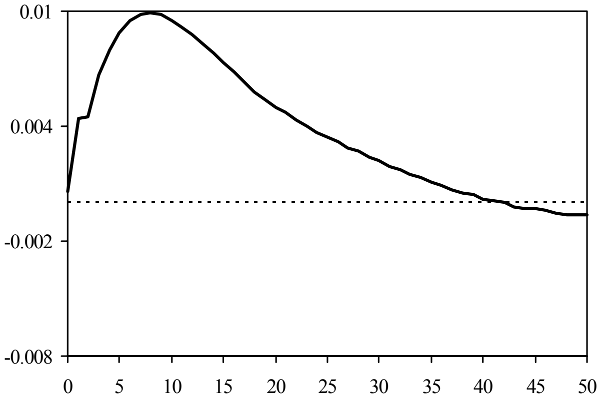
Figure 9. Generalized Impulse Responses of SS10 in the Second Regime



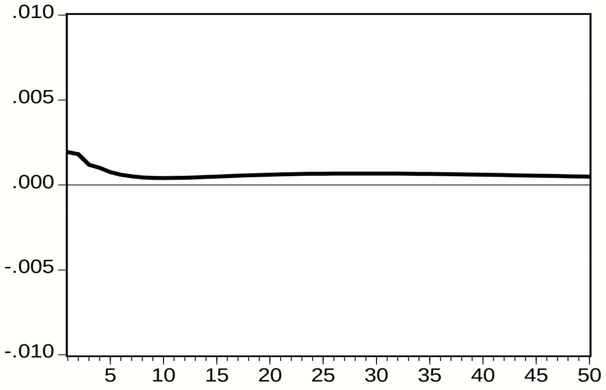
Notes: These figures represent the effect on SS10 of one standard deviation shock to all the variables included in the system. The shocks hit the economy when the transition function is 0.15, that is, when volatility is low (second regime).

Figure 10. Comparison of Liner and Non-linear Impulse Responses of SS2 to Default Shock

Panel A. Non-linear model; first regime



Panel B. Linear model; whole sample



Panel C. Linear model; first regime

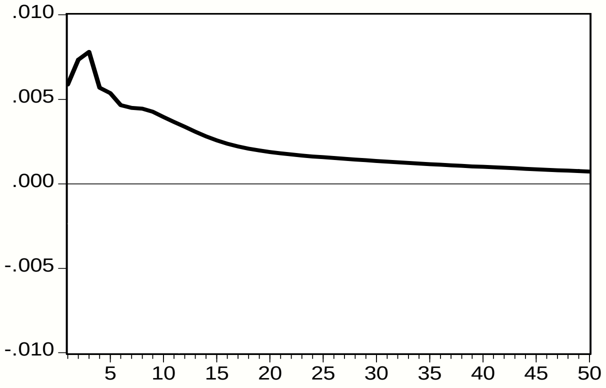
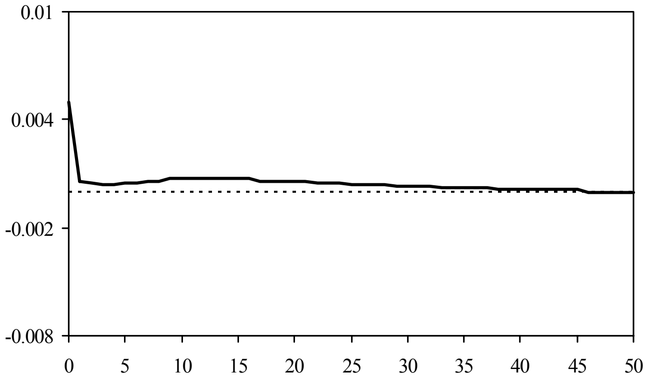
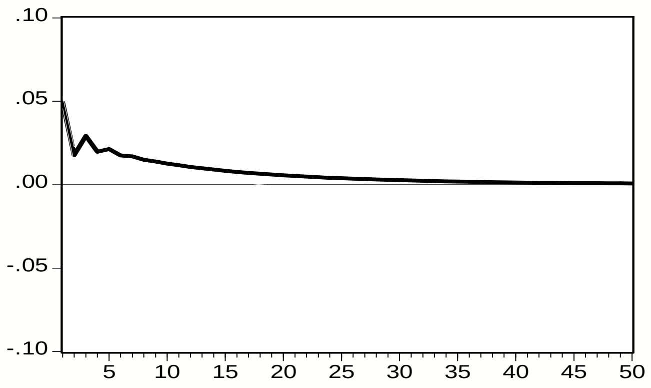


Figure 11: Comparison of Liner and Non-linear Impulse Responses of SS5 to Own Shock

Panel A. Non-linear model; first regime



Panel B. Linear model; whole sample



Panel C. Linear model; first regime