No-arbitrage determinants of Japanese government bond yield and credit spread curves*

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Abstract

We introduce the affine term structure model with observed macroeconomic factors for the government yield and credit spread curves. Empirical results based on the model selection using Japanese data demonstrate that the government bond yield and credit spread curves are dominated by the monetary policy and suggest that the flight-to-quality behavior affects the government bond yield considerably. In addition, our results indicate that the global economic forces such as the U.S. Treasury yield and the U.S. Baa-Aaa credit spread play a major role in the joint dynamics of government yield and credit spread curves, complementing a growing body of literature explaining what drives the yield and credit spread curves. Our impulse response analysis finds that the monetary policy and global economic forces have the persistent and large impacts at all curves.

JEL classification numbers: E32, E43, E44, G12

Keywords: Affine term structure, Credit spreads, Flight-to-quality, JGB yields, Monetary policy

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1 Introduction

Government bonds with different maturities and corporate bonds with different maturities and different risks are traded in the market. The behavior of each yield curve reflects the risk which that bond has, such as default risk and inflation risk. Understanding what moves bond yields is important for at least four reasons: forecasting, monetary policy, debt policy, and derivative pricing and hedging (see, Piazzesi (2009)). Recent works, for example, Gilchrist et al. (2009), Gilchrist and Zakrajšek (2012), and Bleaney et al. (2016), suggest understanding corporate bond spreads is useful for forecasting not only the future short spreads but also the real activity. This paper explores what moves each yield curve using no-arbitrage term structure models, and specifies the key drivers of these yield curves among a wide range of global and local economic measures.

Determinants of sovereign bond yields are examined mostly from liquidity and fiscal perspectives using a term structure model for individual sovereign credit spreads, such as in Dai and Philippon (2005) and Bikbov and Chernov (2010), or suggesting the link with the borrowing costs based on a country-level panel data, including Longstaff et al. (2011) and Costantini et al. (2014), among others. In addition, Pan and Singleton (2008) and Longstaff et al. (2011) use sovereign credit default swap (CDS) data on various countries, and find that sovereign credit spreads are more related to the U.S. stock and high-yield markets than they are to local economic measures. Specifically, Pan and Singleton (2008) suggest that premiums for credit risk in sovereign markets are influenced by spillovers of real economic growth in the United States to economic growth in other regions of the world. Incorporating these lines of research, this paper explores determinants of Japanese government bond yield curve to identify the effects of local economy measures such as monetary policy, inflation, real activity, stock market volatility, and global macroeconomic forces external to the country such as U.S. Treasury yields and U.S. credit spreads. Consistent with the findings in Pan and Singleton (2008) and Longstaff et al. (2011) which indicate the strong relation between sovereign credit risk and global economic forces such as U.S. financial markets (stock and credit risk), the findings in this paper suggest the global economic factor external to the country is an important driver of Japanese government bond yields.

A joint analysis of government bond yields and corporate bond spreads can allow the accurate comprehension of the market prices of risk for the various shocks. A large literature that studies the determinants of credit spreads discusses how default risk is priced. Default risk is an important component of credit spreads, and its usefulness to predict the output growth is confirmed in the theoretical and empirical works. Although the credit spread, which is the difference in the yields between defaultable debt instruments and risk-free government securities of comparable maturity, is considered to indicate the ability of issuers to service their debts, there is an agreement that the credit spread represents not only the default risk but also the other factors including its duration, embedded call option, and expected inflation.

The extent to which the default risk explains the credit spread differs among the studies. For example, Longstaff et al. (2005) find it accounts for the majority of credit spreads across all credit ratings, while Jones et al. (1984) and Elton et al. (2001) show default component accounts for the small fraction of spreads. In addition, the existence of a nondefault component is well recognized in the corporate bond pricing papers. Various economic and financial data are tested to identify the determinants of credit spreads or credit spread changes in the literature, for example, see Collin-Dufresne and Goldstein (2001) for leverage ratios, Collin-Dufresne et al. (2001) for local supply/demand shocks, Campbell and Taksler (2003) for equity volatility, and Longstaff et al. (2005) for bond-specific illiquidity. In addition to the useful insights provided by these studies using regressions, Duffie and Singleton (1999) provide a notable application of the term structure of interest rates to corporate bonds. As discussed comprehensively in Dai and Singleton (2000) and Duffie and Singleton (2003), the term structure models can capture bond yield movements with different maturities, imposing the cross-equation restrictions implied by no-arbitrage. Among papers analyzing the linkage between the term structure of interest rate or corporate bond spreads and the macroeconomic risks, Wu and Zhang (2008) find that inflation, real output growth, and financial market volatility are main factors to influence the credit spread based on the no-arbitrage affine term structure models.

We apply the affine term structure model to arbitrage-free pricing of Japanese government bonds (JGB) and corporate credit spreads so as to identify which kinds of risks have impacts and how these risks are priced on government bond yields and credit spreads. Four important results are obtained from the analysis. First, the monetary base, a proxy for the monetary policy, has the huge negative impacts on the JGB yield at all maturities. What's more, the monetary policy is also a main driver of credit spread curves, especially for A and BBB rating categories. Second, our results indicate that not only the local economic variables but also the global economic factors, namely U.S. Treasury bill rate and U.S. Baa-Aaa corporate credit spreads, significantly influence

JGB yields and credit spreads across all credit-rating classes. Third, the result obtained by the impulse response analysis shows that the responses of JGB yields to the financial market volatility are negative, but those of credit spreads are positive, implying the flight-to-quality behavior. Last, but not the least, the inflation measure including global and domestic measures is not a driving force of JGB yield and credit spread curves.

Empirical results in this paper provide evidences that the monetary policy remarkably affects the JGB yields and credit spreads at all maturities. Meanwhile, under different economic conditions, the interaction between U.S. money and the returns on four classes of financial asset (stocks, commodities, currency index, and government bonds) since 2000 is examined by Cronin (2014), who finds the high spillovers between financial variables and M2, but not the monetary base. Most studies do not provide the evidence supporting the use of the monetary base as an intermediate target for monetary policy, concerning the theoretical and practical problems. As a practical matter, Anderson (2006) documents the central bank is afraid of sharply increasing volatility of market interest rates by controlling the size of its monetary base. Additionally, Shirakawa (2008), who is a former Governor of the BOJ, explains that the monetary base targeting makes the authorization too wide, ranging from the monetary policy committee to the departments implementing market operations. Nonetheless, this paper provides the interesting evidence that the monetary base has been influential and the main driver of government bond yields and credit spread curves in Japan.

The remainder of the paper is organized as follows. The next section of the paper explains the data used to estimate the government yield and credit spread curves. Section 3 explains the variables that we analyze in the model selection. Section 4 discusses the affine term structure models and the estimation strategy for the government yield and credit spread curves. Section 5 presents the empirical results of government yield curve using the JGB data. Empirical results of the joint model of JGB yields and credit spread curves are shown in Section 6. Section 7 concludes.

2 Data

As for the bond market size in terms of amounts outstanding on the global bond market, Japan is the second largest market with about 11.2 trillion U.S. dollars as of the end of 2015 behind the United States (BIS Debt securities statistics). Bonds are issued with a wide range of maturities, especially JGB is one of most popular markets for government debt trading in the world. This means that prices of bonds fluctuate according to changes emanating from Japanese and world economy. In contrast to the JGB market where the purchase by the foreign investor is more than 20% since the latter half of 2015,[1] the trading of Japanese corporate bonds is mostly made by Japanese institutional investors. A number of regulated institutional investors are supposed to invest in bonds rated BBB or higher on major rating agencies' scale such as Standard and Poor's (Baa or higher on Moody's scale). Although there is not a market for junk bonds (high-yield bonds) as of in U.S., corporate bonds rated below investment grade are traded in the Japanese secondary market, which were once issued with ratings in the investment-grade category but their issuers experience a decline in ratings below investment grade (so-called fallen angels). As the number of such corporate bonds is not large enough to calculate the credit spread curve, we use the pricing information for corporate bonds in each of the three rating classes (AA, A, and BBB).[2]

The data for JGB yields with maturities between 1 month and 30 years are monthly continuously compounded spot rates, and obtained from Thomson Reuters Eikon which collects market data from Tradeweb. The sample covers the period from June 2000 to July 2016. We use the same sample period as for the credit spreads. We use these data to calculate the credit spreads as risk-free rates according to the traditional practice (see, for example Wu and Zhang (2008)) because the other benchmarks such as TIBOR, LIBOR, and other swap rates are based on interbank lending rates reflecting the credit risk of banks involved. It means that these rates are not actually default risk fee. An advantage of over-the-counter contracts is not suffering the liquidity squeezes as much as the government bonds. This paper use nonetheless the JGB rate due to the data availability of various maturities.

We compute credit spreads from two pricing sources. First, we use data on yields/rating matrix of corporate bonds traded over-the-counter that is calculated by the JSDA to take into account the differences in the default risk of the issuer (AA, A, and BBB ratings). The number of observations for the yields of corporate bonds with AAA, BB and B ratings is too small to allow us to use in this paper. In terms of the rating information, we use the rating by Rating and Investment Information (hereafter R&I) due to its wide coverage of ratings for Japanese firms. The JSDA publishes the arithmetic average value daily for each rating class and maturity of 1 to 20 years, which covers

[1]The ratio is calculated from the Government Bond Trading Volume by Category of Investors (Japan Securities Dealers Association).

[2]We do not include AAA-rated corporate bonds because of data availability. AAA-rated corporate bonds were sometimes not traded in the market over the sample period.

yen-denominated corporate bonds publicly issued in the Japanese corporate market and excludes corporate bonds with share options, such as convertible bonds and bonds with warrants. For the calculation of the yield, the sample is limited to corporate bonds with a fixed coupon schedule and bullet bonds. As Gilchrist and Zakrajšek (2012) limit their sample to issues with a fixed coupon schedule, these selection criteria ensure the yields of the corporate bonds in this data set are comparable. Data on month-end yields of corporate bonds published by the JSDA for each rating class are drawn from Thomson Reuters Eikon.

To calculate the credit spreads of corporate bonds for each rating class and term to maturity, we match the yields of the corporate bond y_{kt}, where k is the individual rating from AA through BBB, and t is the number of years to maturity from 1 through 20 years, and that of a JGB with the same maturity, y_t^f. Then the credit spread, $cs_{kt} = y_{kt} - y_t^f$, is the excess bond premium. We calculated month-end credit spreads from June 2000 through July 2016. The starting point of June 2000 was determined by the availability of JSDA data on yields for the corporate bonds issued by Japanese firms listed in Thomson Reuter Eikon.

During sample period, the events that followed the nuclear disaster occurred at Tokyo Electric Power Co.'s (TEPCO's) Fukushima Daiichi Nuclear Power Plant on March 11, 2011, had a severe impact on TEPCO, which was Japan's largest corporate bond issuer, and the value of the outstanding TEPCO corporate bonds totaled about 5 trillion yen ($ 60.9 billion) when the disaster occurred (The Nikkei, April 21, 2011). Since the JSDA data for each rating class are the arithmetic average, outstanding TEPCO corporate bonds influenced them decisively, in particular the yield for the rating class to which TEPCO belongs. For example, TEPCO's corporate bonds were rated AA+ by R&I when the Great East Japan earthquake occurred on March 11, 2011. At that time, the JSDA's weekly AA-rated yield for 1 year to maturity closed at 0.286 (%). The great uncertainty of their future costs regarding the nuclear disaster led to a series of downgrades of TEPCO's long-term credit rating. R&I lowered TEPCO's corporate bonds rating from AA+ to AA$^-$ on March 25, 2011, and then the weekly AA-rated closing yield for 1 year to maturity was up to 0.518 by the time TEPCO's corporate bonds were downgraded to A on April 7, 2011. Although the weekly A-rated closing yield for 1 year to maturity was 0.436 before TEPCO's credit rating was downgraded to A, the closing yield rose to 0.698 when TEPCO's corporate bonds were downgraded to A. When R&I lowered TEPCO's credit rating from A to BBB on October 7, 2011, the weekly BBB-rated closing yield for 1 year rose to 2.889 from 1.247 in the following week of the downgrade. The yield for the rating class to which TEPCO's corporate bonds belong was affected significantly.

Then, to mitigate this effect the data on credit spreads after January 2011 were drawn from Thomson Reuters Bond Credit Curve (hereafter TRBCC) where smoothing basis splines are used to derive the curves for Japanese corporate bonds that start August 2010. The sample is also limited to corporate bonds with a fixed coupon schedule and bullet bonds with a remaining term to maturity of more than 1 year, and the credit spread is calculated using comparable-maturity government bonds. Callable bonds are not included in the data drawn from the JSDA and TRBCC.[3] The credit spread from the JSDA tends to be higher in comparison with that of TRBCC across ratings, especially for bonds with a BBB rating. We calculated the differences between these two datasets and adjusted the data after January 2011 by using the average of these differences.[4] More specifically, the following modified credit spreads are used after January 2011

$$cs_{kt}^{modified} = cs_{kt}^{TRBCC} + cs_{kt}^{JSDA} \times \frac{1}{n} \sum \frac{cs_{kt}^{JSDA} - cs_{kt}^{TRBCC}}{cs_{kt}^{JSDA}}$$

where cs_{kt}^{TRBCC} is the credit spread for the corporate bond y_{kt} drawn from TRBCC, cs_{kt}^{JSDA} is the one drawn from JSDA, and n is the number of time-series observations.

3 Variables

Previous papers using macro-finance models already demonstrate that not only the financial variables, but also the macroeconomic factor are related to the yield curves. From a wide array of financial and macroeconomic variables, we use the following variables based on previous works, and look into the both local and global economic forces, then select a set of variables which best fits the data. Definitions and source of the data for the local and global variables are provided in the Appendix A.

3.1 Local variables

There are many local financial and macroeconomic variables which may influence the yield curve of government bonds and corporate bonds, but many of them are highly correlated and con-

[3]Duffee (1998) points out that spreads based on indexes constructed using callable and noncallable bonds are inversely related to Treasury yields, and Gilchrist and Zakrajšek (2012) also imply that the shape of the Treasury term structure and interest rate volatility have economically significant effects on the credit spreads of callable bonds.

[4]Estimation results of same equations using three different data from (i) only JSDA (ii) JSDA and unadjusted TRBCC, and (iii) JSDA and adjusted TRBCC are qualitatively similar with no substantial difference.

tain a lot of noise if used at a time. We focus on variables relating to fundamental risk dimensions underlying an economy as suggested in Wu and Zhang (2008); inflation, real output growth, and financial market volatility.[5] Furthermore, we also include the monetary policy variable, taking into account the innegligible impact of BOJ's monetary policy on the financial markets.

For country-specific inflation indicators, we use the CPI excluding fresh food prices and CGPI （Corporate Goods Price Index). CPI contains the information about the price for the buyer, and CGPI contains one for the seller. Not only the relationship between the interest rate and the inflation has been discussed in an enormous literature (see, for example, Fama (1990), Beaudry and Portier (2006), Piazzesi (2009), and Chernov and Mueller (2012)), but also the corporate bond spreads and inflation is discussed through the possibility of debt deflation (Fisher (1933)). Kang and Pflueger (2015) find that credit spreads rise significantly if inflation risk increases using credit spread indexes from six developed countries. Therefore, the inflation variables are expected to exert influence on both the government bond yields and credit spreads.

GDP is not available on a monthly frequency for Japanese economy, hence we use the growth rates of the Coincident index (CI), the Indices of Industrial Production (IIP), and the Indices of All Industry Activity (IAA) as the economic growth measures instead. The relation between the output growth and Treasury yields curve has been examined in the research on the term structure such as Evans and Marshall (2006), Ang and Piazzesi (2003), and Wu and Zhang (2008). Wu and Zhang (2008) find that positive real output growth shocks increase Treasury yields, but suppress the credit spreads at low credit-rating classes. Thus, the output growth may have different effects on the government bond yields and credit spreads depending on their rating classes. The statistics for Machinery Orders known as a leading indicator for private capital expenditure in Japan is also included to reflect the private investment. Its predictive content for the business cycle is expected to be a determinant of yield curve and credit curves. Gilchrist and Zakrajšek (2012) imply the negative relation between their original credit spread index and the business fixed investment, especially in high-tech equipment.

As a financial market volatility, we use the Nikkei Stock Average Volatility Index (NVIX). Details about the definition and source of the data is provided in the Appendix. According to the research on the financial contagion as in Allen and Gale (2000), Brunnermeier and Pedersen

[5]They use the dynamic factor model to summarize the information in U.S. macroeconomic and financial series (seven inflation-related series, four output-related series, and two financial market volatility indexes).

(2009), and many others, the market liquidity is related to the volatility, and a shock in one market may spill over into other markets. We examine the effect of the stock market volatility on both the government bond yields and credit spreads.

As a proxy for the monetary policy, the value of monetary base is used to capture the plan of the central bank. The level of a short-term nominal interest rate has been used to conduct the monetary policy, but the very low level of interest rates in Japan resulted in the change in its operating procedures. Japan provides an interesting case in which the monetary base is used to affect the yields of financial assets, see Bernanke and Reinhart (2004). Quantitative easing was first implemented in Japan on March 19, 2001 against its persistent deflation and to stimulate its stagnant economy. Within two years, the BOJ increased the monetary base by about 50%. It lasted five years with a significant increase in the quantity of long-term Japanese government bond purchases. Although it was once abandoned in March 2006, the BOJ announced its asset purchasing program, including long-term government bonds, in October 2010. Finally, the BOJ initiated a qualitative and quantitative easing policy in April 2013, accelerating the purchase of long-term government bonds. At this monetary policy meeting, the main operating target for money market operations was changed from the uncollateralized overnight call rate to the monetary base. It is expected that the monetary policy affects the JGB yield curve according to its JGBs purchases. A close link between the JGB and the corporate bond markets suggests that the credit spread curve is also affected by the monetary policy.

3.2 Global variables

The state of the global economy is as important as the local economy in the increasing interdependence of world economies. We use global variables relating to the global financial markets and macroeconomic conditions to identify whether the factors external to the issuing country are driving forces of government bonds yields and credit spreads. Furthermore, it is natural to explore the relation with the global factors due to its second largest size of Japanese bond markets in the world.

As global economic factors, we select the variables among possible global economic forces which are regarded as international indexes and considered to be influential in the global economy through the extensive economic and trading relationships with other countries. Risk dimensions underlying an economy are identified as with the local variables; inflation, real output growth, and financial market risk.

To capture the change in the global inflation, we include the Thomson Reuters/CoreCommodity CRB Index (CRB Index) which is a representative indicator of global commodity markets comprising a basket of 19 commodities, with 39% allocated to energy contracts, 41% to agriculture, 7% to precious metals, and 13% to industrial metals. In general, the international commodity futures price index reflects overall price movements of commodities traded around the world, because it contains a lot of commodities to be used as product raw materials. Hence, it is viewed as a leading indicator of price inflation rate.

U.S. Treasury 10 Year yield which is an indicator of the condition of the U.S. economy is included to capture the condition of global economy. Although this may not be a perfect indicator of the global real output growth, its largest economy in the world can betoken the global business cycle. Moreover, Longstaff et al. (2011) point out that the change in U.S. Treasury yield may also incorporate a flight-to-liquidity element due to the variation in the perceived safety of U.S. Treasury. Thus, U.S. Treasury yield can signal not only the condition of U.S. economy but also the investor's expectation for the global economic growth due to its benchmark status in the world financial market.

The U.S. corporate credit spread of the Moody's Seasoned Baa Corporate Bond Yield minus Moody's Seasoned Aaa Corporate Bond Yield (Baa-Aaa credit spread) is included as a global risk indicator. When the economic condition is worse, the Baa-rated bond is more likely to default than the Aaa-rated bond. Therefore, the small (large) Moody's Baa-Aaa credit spread indicates that the good (poor) economic conditions are expected assuming both Baa and Aaa-rated bonds do not default (Baa-rated bonds are more likely to default). Gilchrist and Zakrajšek (2012) confirm that the Baa-Aaa credit spread contains some marginal information for near-term economic developments. Then U.S. Baa-Aaa credit spreads also indicate the investor's attitude toward the economic growth, which spreads in all markets.

4 Model and Estimation Strategy

Our model for the Japanese government bond yield and credit spread curves is based on a affine term structure model (ATSM) with observed macroeconomic factors. In this section we will introduce our model and its estimation strategy.

4.1 ATSM for the government bond yield curve

Our model for the yield curve is essentially the same as that of Ang et al. (2006), except that our factors solely consist of macroeconomic variables without any yield-curve factors and our data are monthly, so that we interpret one period to be 1 month. Alternatively, our model can be considered as a discrete version of term structure model of Wu and Zhang (2008) with some generalization.

In this framework, the vector of state variable is assumed to follow a Gaussian vector autoregression (VAR) with one lag as

$$X_t = \mu + \Phi X_{t-1} + \Sigma \varepsilon_t,\ \varepsilon_t \sim \text{iid } N(0, I). \tag{1}$$

Here μ is a $K \times 1$ vector, Φ is a $K \times K$ matrix, Σ is a $K \times K$ lower-triangular matrix, and K is the number of factors. In addition, the one-period short-rate r_t is assumed to be an affine function of all state variables

$$r_t = \alpha_r + \beta_r' X_t.$$

Affine term structure models are derived from the particular pricing kernel m_{t+1} following the log-normal process：

$$m_{t+1} = \exp\left(r_t - \frac{1}{2}\lambda_t' \lambda_t - \lambda_t' \varepsilon_{t+1}\right),$$

where λ_t is a $K \times 1$ vector characterizing the time-varying market price of risk associated with the source of uncertainty ε_t. We further assumes that this market price of risk λ_t is an affine process of X_t:

$$\lambda_t = \lambda + \Lambda X_t$$

for a $K \times 1$ vector λ and a $K \times K$ matrix Λ.[6]

Under these specifications, it can be shown that the factors follow a Gaussian VAR(1) model under the risk neutral Q-measure:

$$X_t = \mu^Q + \Phi^Q X_{t-1} + \Sigma \varepsilon_t^Q,\ \varepsilon_t^Q \sim \text{iid } N(0, I)$$

for

$$\begin{cases} \mu^Q = \mu - \Sigma\lambda \\ \Phi^Q = \Phi - \Sigma\Lambda. \end{cases}$$

[6] Wu and Zhang (2008) assumes that Λ is a lower-triangular matrix. In this sense, our model is a generalization of term structure model of Wu and Zhang (2008).

Furthermore, with these specifications, no-arbitrage assumption implies that the price p_{t+1}^{n} of an n-period nominal bond at time t can be written as

$$p_t^{n+1} = E_t\left[m_{t+1} p_{t+1}^{n}\right].$$

The resulting bond prices are exponential functions of the state vector

$$p_t^n = \exp(A_n + B_n' X_t)$$

for a scalar A_n and $(K+1) \times 1$ vector B_n of coefficients that are functions of time-to-maturity n. These coefficients can be computed from the following difference equations

$$\begin{aligned} A_{n+1} &= A_n + B_n'(\mu - \Sigma\lambda) + \frac{1}{2} B_n' \Sigma \Sigma' B_n - \alpha_r, \\ B_{n+1}' &= B_n'(\Phi - \Sigma\Lambda) - \beta_r' \end{aligned} \quad (2)$$

The initial conditions given by $A_0 = 0$, $B_0 = 0$. As a consequence, bond yields are affine functions of the state vector as

$$y_t^n = -\frac{\log p_t^n}{n} \quad (3)$$

$$= -\frac{A_n}{n} - \frac{B_n' X_t}{n} \quad (4)$$

4.2 ATSM of corporate bond spreads in discrete time

To derive a ATSM of credit spreads, the one-period credit spread (or risk-neutral mean loss rate) for the credit-rating class i, s_t^i is assumed to be an affine function of all state variables

$$s_t^i = \alpha_i + \beta_i' X_t.$$

Duffie and Singleton (1999) show that under some conditions no-arbitrage assumption implies that the credit spread $d_t^{i,n}$ of an n-period corporate bond for the credit-rating class i at time t can be written as

$$d_t^{i,n+1} = E_t\left[m_{t+1}(1 - s_t^i) d_{t+1}^{i,n}\right] \approx E_t\left[m_{t+1} \exp(-s_t^i) d_{t+1}^{i,n}\right]$$

As can be shown in Appendix B, absence of arbitrage implies that $d_t^{i,n}$ is also exponential affine in the economic factors:

$$d_t^{i,n} = \exp(A_n^i + B_n^{i\prime} X_t).$$

In addition, these coefficients can be computed from the following difference equations

$$\begin{aligned} A^i_{n+1} &= A^i_n + B^{i\prime}_n(\mu - \Sigma\lambda) + \frac{1}{2}B^{i\prime}_n\Sigma\Sigma' B^i_n - \alpha_r - \alpha_i, \\ B^{i\prime}_{n+1} &= B^{i\prime}_n(\Phi - \Sigma\Lambda) - \beta'_r - \beta'_i. \end{aligned} \tag{5}$$

We define the credit spread on the corporate bond as the difference between the spot rate on the corporate bond and the corresponding spot rate on the government bond. With this definition, credit spreads are affine functions of the state vector as

$$cs^{i,n}_t = -\frac{A^i_n - A_n}{n} - \frac{B^{i\prime}_n - B'_n}{n} X_t. \tag{6}$$

4.3 Estimation

To estimate the government yield curve model, we use the JGB yield data with maturities 1 month, 3 months, 6 months, and every year from 1 to 10 years.[7] Let Y^1_t denote the 13×1 vector consisting of these yields, namely

$$Y^1_t = (y^1_t, y^3_t, y^6_t, y^{12}_t, y^{24}_t, y^{36}_t, y^{48}_t, y^{60}_t, y^{72}_t, y^{84}_t, y^{96}_t, y^{108}_t, y^{120}_t)'$$

One common approach to estimation, employed for example Ang et al. (2006) is to suppose that these yields are observed with measurement error. In other words, Y^1_t can be expressed as

$$Y^1_t = A^1 + B^1 X_t + \Sigma^1_e u^1_t,\ u^1_t \sim \text{iid } N(0, I) \tag{7}$$

where Σ^1_e is a 13×13 diagonal matrix capturing the variance of the measurement error, A^1 and B^1 are calculated by stacking $-A_n/n$ and $-B'_n/n$, respectively for the appropriate n.

From (1) and (7), we can calculate the conditional density for the tth observation as follows:

$$\begin{aligned} f(X_t, Y^1_t | X_{t-1}, Y^1_{t-1}) &= f(X_t | X_{t-1}, Y^1_{t-1}) f(Y^1_t | X_t, X_{t-1}, Y^1_{t-1}) \\ &= \phi(X_t, \mu + \Phi X_{t-1}, \Sigma\Sigma')\phi(Y^1_t, A^1 + B^1 X_t, \Sigma^1_e \Sigma^{1\prime}_e), \end{aligned}$$

where $\phi(\cdot, c, \Omega)$ is the multivariate normal density with mean c, and variance-covariance matrix Ω. Let θ be a vector consisting of all parameters, then the log likelihood is

$$\begin{aligned} L(\theta) &= \sum_{t=1}^{T} \log \phi(X_t, \mu + \Phi X_{t-1}, \Sigma\Sigma') + \sum_{t=1}^{T} \phi(Y^1_t, A^1 + B^1 X_t, \Sigma^1_e \Sigma^{1\prime}_e) \\ &= L(\theta_1) + L_2(\theta_1, \theta_2), \end{aligned}$$

[7] Spot rates for JGB with 1 month maturity are available only from September, 2012. We linearly extrapolated those missing data from the spot rates with maturities 3 and 6 months and replaced them with 0 if they are below 0.

where $\theta_1 = (vec(\Phi)', vech(\Sigma))'$ and $\theta_2 = (\lambda', vec(\Lambda)', \alpha_r, \beta_r')'$ and

$$
\begin{aligned}
L_1(\theta_1) &= \sum_{t=1}^{T} \log \phi(X_t, \mu + \Phi X_{t-1}, \Sigma\Sigma') \\
L_2(\theta_1, \theta_2) &= \sum_{t=1}^{T} \phi(Y_t^1, A^1 + B^1 X_t, \Sigma_e^1 \Sigma_e^{1\prime})
\end{aligned}
$$

Following, for example, Ang and Piazzesi (2003) and Ang et al. (2006), we use a two-step consistent estimation procedure as follows. In the first step, we estimate θ_1 by maximizing the marginal likelihood $L_1(\theta_1)$. In the second step, taking these estimates of θ_1 as given, we estimate θ_2 by maximizing the marginal likelihood $L_2(\theta_2)$.

To estimate the joint model of government bond yield and credit spread curves, in addition to government yields data of Y^1, we use the credit spread data with maturities 1 month and every year from 1 to 5 years for each credit-rating class .[8] Let Y_t^2 denote the 19×1 vector consisting of Y^1 and these credit spreads for the credit-rating class i, namely

$$
Y_t^{2,i} = (Y^{1\prime}, cs_t^{i,1}, cs_t^{i,12}, cs_t^{i,24}, cs_t^{i,36}, cs_t^{i,48}, cs_t^{i,60})'
$$

Assuming that these data are observed with measurement error, Y_t^1 can be expressed as

$$
Y_t^{2,i} = A^{2,i} + B^{2,i} X_t + \Sigma_e^{2,i} u_t^{2,i}, \; u_t^{2,i} \sim \text{iid } N(0, I) \tag{8}
$$

where $\Sigma_e^{2,i}$ is a 19×19 diagonal matrix capturing the variance of the measurement error, $A^{2,i}$ is calculated by stacking $-A_n/n$ and $-(A_m^i - A_m)/m$ for the appropriate n and m. Similarly, $B^{2,i}$ is calculated by stacking $-B_n'/n$ and $-(B_n^{i\prime} - B_n')/m$ for the same n and m.

We also employ the two step approach to estimate the joint model, by estimating θ_1 in the first step and estimating the rest of parameters denoted θ_2^i holding estimates of θ_1 fixed in the second step.

5 JGB Yield Curve Model

In this section, we document the empirical results of the JGB yield curve model (4). Specifically, we start with the model selection results to identify the important factors to explain the dynamics of JGB yield curve. Then, we analyze the effects of each factor by calculating the impulse responses of each yield to shocks on each factor.

[8] We linearly extrapolated those missing data from the credit spreads with maturities 1 and 2 years and replaced them with 0 if they are below 0, since credit spreads with 1 month maturity are not available.

5.1 Model Selection

In this subsection, we discuss the model selection results for JGB yield curve model (4). We adopt the forward selection procedure using the Schwarz information criterion (SIC) to choose the important factors to determine the dynamics of JGB yield curve.[9] In this approach, we start with a model including the variable that gives the best fit of the model with the lowest value of SIC. Then, we add variables to the model one at a time. At each step, we examine the addition of each variable based on SIC, adding the variable, if any, whose inclusion gives the lowest value of SIC. We repeat this process until no variable improves the model or lowers the SIC value.

The second column of Table 1 contains the SIC when we estimate the models including only each variable. As can be seen, the model with the monetary base, which is a proxy for the monetary policy, is preferred with the lowest SIC among a set of possible determinants in the first selection. The BOJ established a quantitative easing policy in March 2001 with a significant increase in the quantity of Japanese government bond purchases by targeting the current account balances, which is a major component of monetary base, as new policy target. Although the policy was terminated in March 2006, the BOJ introduced the comprehensive monetary easing with the Asset Purchase Program in October 2010, including long-term government bonds. Finally, the BOJ initiated a quantitative and qualitative easing policy in April 2013, accelerating the purchase of long-term government bonds. Therefore, it is not surprising that the monetary base has the most explanatory power on the JGB yield curve under an aggressive monetary easing policy.

[Table 1 around here]

Next, the models with monetary base and another variable is estimated to examine whether additional variable inclusion improves the model.[10] The results of SIC are summarized in the third column of Table 1. In this second selection, the model with the monetary base and 10-year U.S. Treasury yield is preferred. In other words, the result suggests that the U.S. bond market

[9]Backward selection is another widely used procedure in practice. In this backward selection, we start with estimating a model with all possible determinants and eliminate the least significant variable one by one. However, our model is rather complicated and it is not realistic to estimate a model with all possible determinants. Therefore, we adopt the forward selection.

[10]Precisely speaking, the estimation results depend on the order of macro economic variables, since Σ in (1) is assumed to be a lower-triangular matrix. In other words, the recursive structure proposed by Sims (1980) is imposed in (1). To make this assumption plausible, we order the global variables first followed by the local variables. Within each global or local variable, we always order new variable after already chosen variable(s).

has a significant impact on the JGB market, indicating the international financial integration in bond markets as reported by Kumar and Okimoto (2011). In addition, this result may reflect the interdependence of world economies captured by the U.S. bond market.

The fourth column of Table 1 report the SIC for the models consisting of the monetary base, 10-year U.S. Treasury yield, and another variable. As can be seen, the model with the monetary base, 10-year U.S. Treasury yield, and the Nikkei Stock Average Volatility Index (NVIX) shows the best fit with the lowest SIC among a set of possible determinants. The result suggests that the flight-to-quality behavior affects the JGB markets considerably, which is fairly consistent with the results of Ohmi and Okimoto (2016).

Finally, no additional variable improves the model with higher SIC in the fourth selection, as can be confirmed from the last column of Table 1. In other words, our results indicate that the monetary policy, the global economic state, and the financial market volatility are three of the most important factors to explain the dynamics of the JGB yield curve and no other variables can improve the model. Compared with studies using U.S. data e.g. Ang and Piazzesi (2003), Wu and Zhang (2008), and international data e.g. Pan and Singleton (2008), Bikbov and Chernov (2010), Longstaff et al. (2011), the inflation and real activity are not found to be important to explain the JGB yield curve, but as in these studies, the financial market volatility is an important determinant. What is more, JGB yield is linked to the global economic factor captured by the 10-year U.S. government bond yield.

5.2 Impulse response analysis

In the last subsection, we have identified the monetary base, 10-year U.S. Treasury yield, and NVIX as important determinants of the JGB yield curve. To investigate the effects of each variable on the JGB yield curve in detail, we calculate the contemporaneous impulse response of each yield to a one-standard deviation shock on each factor as Wu and Zhang (2008) in this subsection.

The left-upper panel in Figure 1 plots the contemporaneous response of JGB yield curve to a one-standard deviation shock on each determinant. The x-axis is in months, and the impulse responses are given in the annualized percentages. As can be seen from Figure 1, the monetary base has the large negative effects on the JGB yields at all maturities with downward-sloping, meaning that the magnitude of negative response is larger at longer maturities. More specifically, one-standard deviation shock to monetary base decreases 1-year JGB yield by 6 basis points, but 5-

year yield by more than 15 basis points. This result indicates that the BOJ's monetary easing after the introduction of quantitative easing policy in 2001 have been effective to substantially lower the long-term interest rates. At the same time, this result suggests that there is a possibility for the JGB yield curve to shift up once the BOJ start monetary easing tapering, implying the difficulty of exit strategy.

[Figure 1 around here]

The responses to NVIX, a proxy of the financial market volatility, are also negative with almost horizontal line. This implies that the financial market volatility affects JGB yields of all maturities relatively uniformly. Although the magnitude of declines is not that big with about 2 basis points, these declines are not negligible, given the extremely low interest rate circumstances in Japan over the last 15 years. In other words, the flight-to-quality behavior has sizable effects on the JGB yield curve.

In contrast to above two variables, the responses to the 10-year U.S. Treasury yield shock are positive with slightly upward-sloping. Specifically, one-standard deviation shock to the 10-year U.S. Treasury yield increases 1-year JGB yield by 5 basis points, but 5-year yield by about 8 basis points. Again these responses are substantial, given the situation of JGB markets. The result is particularly important, since the recent uncertainty associated with the U.S. monetary policy as well as fiscal policy have fluctuated the U.S. long-term interest rate considerably, affecting the JGB market significantly.

In sum, the results of our impulse response analysis demonstrate that a main driver of the JGB yield curve is the monetary base, a proxy for the monetary policy, with huge negative impacts, especially for longer maturities. The global economic state, measured by the 10-year U.S. Treasury yield affects positively on the JGB yields with sizable magnitude. Finally the domestic financial market volatility has relatively small, but still important negative effects on the JGB yield curve, reflecting the flight-to-quality behavior.

6 Joint Model of JGB Yield and Credit Spread Curves

In this section, we extend the JGB curve model to the joint model of the JGB yield and credit spread curves expressed by (4) and (6). Our benchmark model is the model with three important determinants of the JGB yield curve, namely the monetary base, 10-year U.S. Treasury yield, and NVIX. Then, we examine additional factors for the joint dynamics of the JGB yield and credit spread curves to identify the important determinants of the two curves. We also investigate the contemporaneous impulse response of each credit spread to shocks on each factor.

6.1 Model Selection

This subsection discusses the model selection results for the joint model of the JGB yield and credit spread curves (4) and (6). The results of the previous section identified the monetary base, 10-year U.S. Treasury yield, and NVIX as important determinants of the JGB yield curve. Therefore, we start with the model with these three variables as a benchmark model and examine possible additional factors to capture the joint dynamics of the JGB yield and credit spread curves for each rating class. Otherwise, our model selection is the same as that of the previous section using the forward selection based on the SIC.

To explore the additional determinants, first we estimate the benchmark model, confirming that the SIC of the benchmark model for each rating is -243.06, -224.88, and -210.54 for AA-, A-, and BBB-rated category, respectively. Next, we estimate the models with four variables by adding one extra variable to the benchmark model. Then, we examine the addition of each variable based on the SIC, adding the variable, if any, whose inclusion gives the lowest value of SIC. We repeat this process until no variable improves the model or lowers the SIC value.

The results of forward variable selection are summarized in Table 2. The results indicate that for the AA-rated credit spreads, the U.S. Baa-Aaa corporate bond credit spread, which is an indicator for the global credit risk appetite, is the most influential variable in addition to the three determinants of the JGB yield curve. The results also suggest that machinery orders and CI monthly growth rates are next two additional important determinants, while no other variable is essential to explain the joint dynamics of the JGB yield and AA-rated credit curves, once we include these six variables into the model. For A-rated credit spreads, the results display that the same set of variables is selected as can be seen from Table 2. However, this does not necessarily mean that these variables have the same effects on the credit spreads for these two rating categories, which will be investigated with the impulse response analysis in the next subsection.

[Table 2 around here]

In contrast, for BBB-rated credit spreads the machinery orders is picked in the first selection, and followed by the U.S. corporate credit spread and CI monthly growth rates. Although BBB-rated bonds are considered investment grade, the results indicate that the issuer in this lower medium credit quality face more exposure to the adverse domestic economic condition, meaning that BBB-rated credit spreads are more sensitive to the domestic private capital expenditure than the global risk indicator. Thus, although determinants of credit spread curves at different ratings are found to be same, the variables might affect each curve in a slightly different fashion. The impulse response analysis in the next subsection will clarify this point more formally.

In sum, additional determinants of the credit spreads, which explain the defaultable bond pricing, turn out to be the same across rating categories (AA-, A-, and BBB-ratings). These are the U.S. Baa-Aaa corporate bond credit spread, machinery orders, and CI monthly growth rates. Thus, our results demonstrate that the global credit risk appetite measured by the U.S. corporate credit spreads not surprisingly play a significant role in the Japanese corporate bond markets. In addition, in contrast to the JGB yield curve, the business condition is turned out to be critical to explain the dynamics of credit spread curve. Another interesting feature of the results is that the inflation measures including global and domestic measures are not a driving force of the joint dynamics of JGB yield and credit spread curves. Assuming that the asset prices are more affected by uncertainty about the permanent component of inflation, our results suggest the lack of a run-up in the volatility of permanent component of inflation in Japan since the early 1990s, as demonstrated in Wright (2011) based on the international panel dataset of government bond yields.

6.2 Impulse response analysis

In the last subsection, we have shown that the U.S. Baa-Aaa corporate bond credit spread, machinery orders, and CI monthly growth rates are three additional determinants for the joint dynamics of the JGB yield and credit spread curves for all rating categories. However, this does not necessarily mean that these variables have the same effects on the credit spreads for all rating categories. To shed light on this point, we calculate the contemporaneous impulse response of each credit spread curve to a one-standard deviation shock on each factor, following Wu and Zhang (2008) in this subsection.

As can be seen from Figure 1, for the AA-rated credit spread curve, the response to the monetary base is negative at all maturities with slightly downward-sloping at the short maturities but almost flat after 1-year maturity. As a result, the monetary base has the almost same effects on both 1- to 5-year AA-rated credit spread, which is about -5 basis point. The responses of A-rated credit spread curve have a very similar pattern, but is about twice as large as those of AA-rated category. The BBB-rated credit curve responses more prominently negatively with the upward-sloping, meaning that the magnitude of negative response is smaller at longer maturities. More specifically, one-standard deviation shock to the monetary base decreases 1-year BBB-rated credit spread by 36 basis points, but 5-year credit spread by about 20 basis points. Thus, monetary easing policies by BOJ seem to have huge effects on credit spread curves, particularly for the lower rating curves.

Responses to the 10-year U.S. Treasury yield are generally negative, meaning that if the U.S. long-term interest rate goes up unexpectedly, the Japanese credit spreads decrease. This is most likely because a rise in the U.S. long-term interest rates increases the JGB yields as suggested in the previous section with almost no effect on the Japanese corporate bond yields.

In contrast to the JGB yield responses to NVIX, the financial market volatility has the positive impact on the credit spread curves with larger impacts on lower rating curves. This is not unreasonable, since the flight-to-quality behavior induce the inflow to the JGB market, but the outflow from the corporate bond markets. Somewhat similar responses are observed for the shock to the U.S. corporate credit spread, although they are generally larger than those of NVIX. Again this is not surprising, since the global credit risk appetite is closely related to the flight-to-quality behavior. Roughly speaking, both variables affect AA-rated credit spreads by 1 to 4 basis points, while BBB-rated spreads to 15 to 30 basis points.

Although both machinery orders and CI growth rates are selected as significant determinants for the joint dynamics of the JGB yield and credit spread curves, their effects are relatively small compared to other variables with generally less than 5 basis point effects after 1-year maturities. Notable exception is the effects of machinery orders on the BBB-credit spread at the short-term maturities with 14 basis point decrease at 1-year maturity.

In sum, our results show that those three determinants of the JGB yield curve, namely the monetary base, 10-year U.S. Treasury yield, and NVIX have large effects on the credit spread curves as well. Although the U.S. corporate credit spread affects the credit spread curves comparably with NVIX, the economic variables have only marginal effects. More specifically, our results demonstrate that the JGB yield and credit spread curves in Japan are dominated by the monetary policy.

In addition to the monetary policy, the domestic and global financial market factors such as NVIX and the U.S. credit spread play a major role in the Japanese credit spreads.

7 Conclusion

We determine empirically what moves government bond yield and credit spread curves using Japanese data since 2000. Given the extremely low interest rate circumstances in Japan over the last 15 years, this paper provides interesting evidence. The model selection results identify three important determinants to explain the dynamics of the JGB yield curve: the monetary policy; the global economic state; and the financial market volatility. Our joint model of JGB yields and credit spread curves show that the global credit risk appetite, the domestic private capital expenditure, and the domestic economic growth are the additional determinants of the credit spreads, which turn out to be the same across rating categories. However, these variables affect each curve in a slightly different fashion. BBB-rated credit spreads are more sensitive to the domestic private capital expenditure than the global risk indicator.

The extremely low levels of interest rates in Japan have led the central bank to make changes in its operating procedures and communication strategies with markets. Our results indicate that the monetary base has been influential, and affects the financial asset pricing remarkably, at least JGB yields and credit spreads across all credit-rating classes. What is more, the impulse response results show that their responses to the monetary policy are quite uniform at all maturities up to 5 years. Therefore, our impulse response analysis shows that the JGB yield and credit spread curves in Japan are dominated by the monetary policy. In sharp contrast to the monetary policy, the inflation measures including global and domestic measures are not found to be a driving force of the dynamics of JGB yield and credit spread curves.

This paper explores the important drivers of JGB yield and credit spread curves among a wide range of global and local economic measures, which allows us to complement a growing body of literature explaining determinants of yield and credit spreads curves. Our findings demonstrate that the global economic factors external to the country play a significant role in government bond yields as well as in Japanese credit spreads. Results indicate the importance of taking the international financial integration in bond markets into consideration, when analyzing the yields of financial assets, especially bond yields.

Appendix A. Definition and sources of Data

This appendix describes the details about the definition and sources of data used as local and global economic factors in this paper.

1. Baa-Aaa Credit Spreads. The Baa-Aaa corporate bond credit spread is calculated as the basis-point spread between yields on Moody's Seasoned Baa- and Aaa-rated corporate bonds. The monthly data on Moody's Seasoned Aaa Corporate Bond Yield and Moody's Seasoned Baa Corporate Bond Yield are retrieved from FRED, Federal Reserve Bank of St. Louis.

2. CI. The Coincident index (CI) monthly growth rate is based on an index of Business Conditions published monthly by the Cabinet Office, the government of Japan. The value is obtained directly from its website. CI is constructed from a set of following coincident indicators: production index, shipments index for mining and manufacturing, shipments index for durable consumer goods, index for non-scheduled hours worked, shipments index for investment goods (excluding transportation equipments), retail sales, wholesale sales, operating profit (all industries), shipments index for SMEs (manufacturing), and the ratio of active job openings.

3. CGPI. The Corporate Goods Price Index (CGPI) measuring the price developments of goods traded in the corporate sector is released monthly by the Bank of Japan. The value is obtained from its website. CGPI covers commodities classified into Producer Price Index, Export Price Index, and Import Price Index. The base year for the indexes and weight calculation is the calendar year 2010.

4. CPI. The Consumer Price Index (CPI) is reported monthly by Ministry of Internal Affairs and Communications. The data are obtained from the website of Statistic Bureau, Ministry of Internal Affairs and Communications. This paper uses the CPI excluding fresh food prices, whose prices often fluctuate considerably depending on the weather to figure the basic trend in the prices of goods and services, which is often called Core index.

5. CRB. The Thomson Reuters/CoreCommodity CRB Index comprising a basket of 19 commodities, with 39% allocated to energy contracts, 41% to agriculture, 7% to precious metals, and 13% to industrial metals is published in real time. This paper uses the month-end value of Thomson Reuters/Corecommodity Commodity Research Bureau Index Excess Return which is obtained from the Thomson Reuters Eikon.

6. IAA. The Indices of All Industry Activity (IAA) monthly growth rate is based on indices created by weight-averaging the Indices of Construction Industry Activity, Indices of Industrial Production, and Indices of Tertiary Industry Activity, with the added value weight of the base year, which are published monthly by METI. The data on IAA is obtained from its website (2010 Average=100).

7. IIP. The Indices of Industrial Production (IIP) monthly growth rate is based on the Production Index of mining and manufacturing industries published monthly by the Ministry of Economy, Trade and Industry (METI). METI conducts monthly The Current Production Statistics Survey, and their coverage is mining and manufacturing industries. The number of the selected items for the Production Index is 487 items for the entire mining and manufacturing industries. The data on IIP is obtained from its website (Index,2010=100).

8. Machinery Orders. The JPY values of machinery orders by private sectors (manufacturing and non-manufacturing) excluding ships are reported monthly by the Cabinet Office, the government of Japan. They select 280 manufacturers in the major machinery sectors to examine more than 80% coverage of the total sector. The value is obtained directly from its website (unit: billion JPY).

9. Monetary Base. The Monetary Base refers to Currency Supplied by the Bank of Japan defined as a sum of Banknotes in Circulation, Coins in Circulation, and Current Account Balances (Current Account Deposits in the Bank of Japan). The value is published monthly by Bank of Japan and obtained directly from its website.

10. NVIX. The Nikkei Stock Average Volatility Index are published in real time, and calculated by using prices of Nikkei 225 futures and Nikkei 225 options on the Osaka Exchange (OSE). We use the month-end value of this volatility index which is obtained from the Thomson Reuters Eikon.

11. Treasury Yields (10Y). The U.S. government bond 10Y is represented by the Thomson Reuters US 10 Year Government Benchmark Index. This paper uses the month-end value obtained from Thomson Reuters Datastream.

Appendix B. Derivation of recursive bond prices

To derive the recursions in (2), suppose that the price of an n-period bond is given by $p_t^n = \exp(A_n + B_n' X_t)$. Then,

$$\begin{aligned}
p_t^{n+1} &= E_t\left[\exp\left(r_t - \frac{1}{2}\lambda_t'\lambda_t - \lambda_t'\varepsilon_{t+1}\right)p_{t+1}^n\right] \\
&= E_t\left[\exp\left(-\alpha_r - \beta' X_t - \frac{1}{2}\lambda_t'\lambda_t - \lambda_t'\varepsilon_{t+1} + A_n + B_n' X_{t+1}\right)\right] \\
&= \exp\left(-\alpha_r - \beta' X_t - \frac{1}{2}\lambda_t'\lambda_t + A_n\right) E_t[\exp\{-\lambda_t'\varepsilon_{t+1} + B_n' X_{t+1}\}] \\
&= \exp\left(-\alpha - \beta' X_t - \frac{1}{2}\lambda_t'\lambda_t + A_n\right) E_t[\exp\{-\lambda_t'\varepsilon_{t+1} + B_n'(\mu + \Phi X_t + \Sigma\varepsilon_{t+1})\}] \\
&= \exp\left[-\alpha + A_n + B_n'\mu + (B_n'\Phi - \beta')X_t - \frac{1}{2}\lambda_t'\lambda_t\right] E_t[\exp\{-(\lambda_t' - B_n'\Sigma)\varepsilon_{t+1})\}] \\
&= \exp\left[-\alpha + A_n + B_n'\mu + (B_n'\Phi - \beta')X_t - B_n'\Sigma\lambda_t + \frac{1}{2}B_n'\Sigma\Sigma' B_n\right] \\
&= \exp\left[A_n + B_n'(\mu - \Sigma\lambda) + \frac{1}{2}B_n'\Sigma\Sigma' B_n - \alpha + \{B_n'(\Phi - \Sigma\Lambda) - \beta'\}X_t\right]
\end{aligned}$$

To derive the recursions in (5), suppose that the price of an n-period corporate bond for the credit-rating class i is given by $d_t^{i,n} = \exp(A_n' + B_n^{i\prime} X_t)$.

$$\begin{aligned}
d_t^{i,n+1} &= E_t[m_{t+1}\exp(-s_t^i)d_{t+1}^{i,n}] \\
&= E_t\left[\exp\left(-r_t - \frac{1}{2}\lambda_t'\lambda_t - \lambda_t'\varepsilon_{t+1} - s_t^i + A_n^i + B_n^{i\prime} X_{t+1}\right)\right] \\
&= \exp\left(-r_t - s_t^i - \frac{1}{2}\lambda_t'\lambda_t + A_n^i\right) E_t[\exp\{-\lambda_t'\varepsilon_{t+1} + B_n^{i\prime} X_{t+1}\}] \\
&= \exp\left(-\alpha_r - \beta_r' X_t - \alpha_i - \beta_i' X_t - \frac{1}{2}\lambda_t'\lambda_t + A_n^i\right) E_t[\exp\{-\lambda_t'\varepsilon_{t+1} + B_n^{i\prime}(\mu + \Phi X_t + \Sigma\varepsilon_{t+1})\}] \\
&= \exp\left[-\alpha_r - \alpha_i + A_n^i + B_n^{i\prime}\mu + (B_n^{i\prime}\Phi - \beta_r' - \beta_i')X_t - \frac{1}{2}\lambda_t'\lambda_t\right] E_t[\exp\{-(\lambda_t' - B_n^{i\prime}\Sigma)\varepsilon_{t+1})\}] \\
&= \exp\left[-\alpha_r - \alpha_i + A_n^i + B_n^{i\prime}\mu + (B_n^{i\prime}\Phi - \beta_r' - \beta_i')X_t - B_n^{i\prime}\Sigma\lambda_t + \frac{1}{2}B_n^{i\prime}\Sigma\Sigma' B_n^i\right] \\
&= \exp\left[A_n^i + B_n^{i\prime}(\mu - \Sigma\lambda) + \frac{1}{2}B_n^{i\prime}\Sigma\Sigma' B_n^i - \alpha_r - \alpha_i + \{B_n^{i\prime}(\Phi - \Sigma\Lambda) - \beta_r' - \beta_i'\}X_t\right]
\end{aligned}$$

References

Allen, F. and D. Gale (2000). Financial contagion. *Journal of Political Economy 108*(1), 1–33.

Anderson, R. G. (2006). Monetary base. Working Paper 2006-049A, Federal Reserve Bank of St. Louis.

Ang, A. and M. Piazzesi (2003). A no-arbitrage vector autoregression of term structure dynamics with macroeconomic and latent variables. *Journal of Monetary Economics 50*(4), 745—787.

Ang, A., M. Piazzesi, and M. Wei (2006). What does the yield curve tell us about GDP growth? *Journal of Econometrics 131*, 359–403.

Beaudry, P. and F. Portier (2006). Stock prices, news, and economic fluctuations. *American Economic Review 96*(4), 1293–1307.

Bernanke, B. S. and V. R. Reinhart (2004). Conducting monetary policy at very low short-term interest rates. *American Economic Review 94*(2), 85–90.

Bikbov, R. and M. Chernov (2010). No-arbitrage macroeconomic determinants of the yield curve. *Journal of Econometrics 159*(1), 166–182.

Bleaney, M., P. Mizen, and V. Veleanu (2016). Bond spreads and economic activity in eight European economies. *Economic Journal*, *forthcoming*.

Brunnermeier, M. K. and L. H. Pedersen (2009). Market liquidity and funding liquidity. *Review of Financial Studies 22*(6), 2201–2238.

Campbell, J. Y. and G. B. Taksler (2003). Equity volatility and corporate bond yields. *Journal of Finance 58*(6), 2321–2349.

Chernov, M. and P. Mueller (2012). The term structure of inflation expectations. *Journal of Financial Economics 106*(2), 367–394.

Collin-Dufresne, P. and R. S. Goldstein (2001). Do credit spreads reflect stationary leverage ratios? *Journal of Finance 56*(5), 1929–1957.

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

Costantini, M., M. Fragetta, and G. Melina (2014). Determinants of sovereign bond yield spreads in the EMU: An optimal currency area perspective. *European Economic Review 70*, 337—349.

Cronin, D. (2014). The interaction between money and asset markets: A spillover index approach. *Journal of Macroeconomics 39*, 185–202.

Dai, Q. and T. Philippon (2005). Fiscal policy and the term structure of interest rates. NBER Working Paper 11574.

Dai, Q. and K. J. Singleton (2000). Specification analysis of affine term structure models. *Journal of Finance 55*(5), 1943–1978.

Duffee, G. R. (1998). The relation between Treasury yields and corporate bond yield spreads. *Journal of Finance 53*(6), 2225–2241.

Duffie, D. and K. J. Singleton (1999). Modeling term structures of defaultable bonds. *Review of Financial Studies 12*(4), 687–720.

Duffie, D. and K. J. Singleton (2003). *Credit Risk*. Princeton, NJ: Princeton University Press.

Elton, E. J., M. J. Gruber, D. Agrawal, and C. Mann (2001). Explaining the rate spread on corporate bonds. *Journal of Finance 56*(1), 247–277.

Evans, C. L. and D. A. Marshall (2006). Economic determinants of the nominal treasury yield curve. Working paper WP 2001-16, Federal Reserve Bank of Chicago.

Fama, E. F. (1990). Term-structure forecasts of interest rates, inflation and real returns. *Journal of Monetary Economics 25*, 59–76.

Fisher, I. (1933). The debt-deflation theory of Great Depressions. *Econometrica 1*(4), 337–357.

Gilchrist, S., V. Yankov, and E. Zakrajšek (2009). Credit market shocks and economic fluctuations: Evidence from corporate bond and stock markets. *Journal of Monetary Economics 56*(4), 471—493.

Gilchrist, S. and E. Zakrajšek (2012). Credit spreads and business cycle fluctuations. *American Economic Review 102*(4), 1692—1720.

Jones, E. P., S. P. Mason, and E. Rosenfeld (1984). Contingent claims analysis of corporate capital structures: An empirical investigation. *Journal of Finance 39*(3), 611–625.

Kang, J. and C. E. Pflueger (2015). Inflation risk in corporate bonds. *Journal of Finance 70*(1), 115—162.

Kumar, M. S. and T. Okimoto (2011). Dynamics of international integration of government securities' markets. *Journal of Banking and Finance 35*(1), 142–154.

Longstaff, F. A., S. Mithal, and E. Neis (2005). Corporate yield spreads: Default risk or liquidity? New evidence from the credit default swap market. *Journal of Finance 60*(5), 2213—2253.

Longstaff, F. A., J. Pan, L. H. Pedersen, and K. J. Singleton (2011). How sovereign is sovereign credit risk? *American Economic Journal: Macroeconomics 3*, 75—103.

Ohmi, H. and T. Okimoto (2016). Trends in stock-bond correlations. *Applied Economics 48*(6), 536–552.

Pan, J. and K. J. Singleton (2008). Default and recovery implicit in the term structure of sovereign CDS spreads. *Journal of Finance 63*(5), 2345–2384.

Piazzesi, M. (2009). Affine term structure models. In Y. Aït-Sahalia and L. P. Hansen (Eds.), *Handbook of Financial Econometrics*, Volume 1, Chapter 12, pp. 691–1324. Amsterdam: Elsevier Science, North-Holland.

Shirakawa, M. (2008). *Gendai no Kinyu Seisaku (Modern monetary policy in theory and practice)*. Tokyo: Nikkei Publishing.

Sims, C. A. (1980). Macroeconomics and reality. *Econometrica 48*(1), 1–48.

Wright, J. H. (2011). Term premia and inflation uncertainty: Empirical evidence from an international panel dataset. *American Economic Review 101*(4), 1514–1534.

Wu, L. and F. X. Zhang (2008). A no-arbitrage analysis of macroeconomic determinants of the credit spread term structure. *Management Science 54*(6), 1160—1175.

Table 1: Variable selection for the JGB model

	1st Selection	2nd Selection	3rd Selection	4th Selection
CPIINF	-136.328	-152.634	-154.620	-153.777
CGINF	-140.604	-153.036	-154.541	-153.995
CBRINF	-136.328	-153.352	-154.804	-154.040
ECG1	-140.243	-152.749	-155.044	-154.149
ECG2	-138.435	-152.621	-154.857	-153.761
ECG3	-140.721	-152.942	-154.788	-154.166
MACHINE	-142.431	-154.374	-154.858	-155.028
NVIX	-147.148	-153.633	**-155.527**	NA
MBASE	**-152.656**	NA	NA	NA
USGB10Y	-147.298	**-154.942**	NA	NA
BAA-AAA	-145.024	-152.876	-155.092	-154.171

Notes: The table reports the Schwarz information criterion (SBIC) as shown in (4) when different sets of variables are estimated. The inflation measures CPIINF, CGINF,and CBRINF refer to CPI inflation, CGPI inflation, and CRB inflation respectively. The economic growth measures ECG1, ECG2, ECG3, and MACHINE refer to the growth rates of the Coincident index, the Indices of Industrial Production, the Indices of All Industry Activity, and the machinery orders by private sectors respectively. The financial volatility measure NVIX refers to the Nikkei Stock Average Volatility Index. The monetary policy measure MBASE refers to the monetary base. The global economic state measure USGB10Y refers to the U.S. government bond 10Y. The global default risk measure BAA-AAA refers to the U.S. Baa-Aaa corporate bond credit spread. The number in boldface is the lowest SBIC at each selection stage. A variable selected in the earlier stage is represented by NA at a subsequent stage. The sample period is 2000:06 to 2016:07.

Table 2: Variable selection for the JGB and credit spread model

	1st Selection	2nd Selection	3rd Selection	4th Selection
AA-rated category				
CPIINF	-241.516	-243.037	-244.106	-244.114
CGINF	-241.963	-243.145	-244.437	-244.500
CBRINF	-242.292	-243.083	-244.272	-244.256
ECG1	-241.243	-243.253	-244.545	-244.341
ECG2	-240.947	-242.786	-244.463	-244.142
ECG3	-241.642	-243.460	**-244.855**	NA
MACHINE	-242.871	**-244.428**	NA	NA
BAA-AAA	**-243.489**	NA	NA	NA
A-rated category				
CPIINF	-224.317	-226.651	-227.711	-227.525
CGINF	-224.169	-226.503	-228.034	-228.003
CBRINF	-224.207	-226.667	-227.753	-227.871
ECG1	-224.258	-226.289	-228.014	-228.107
ECG2	-224.254	-226.102	-228.088	-227.740
ECG3	-224.215	-226.532	**-228.261**	NA
MACHINE	-225.117	**-228.065**	NA	NA
BAA-AAA	**-227.058**	NA	NA	NA
BBB-rated category				
CPIINF	-210.024	-211.616	-212.079	-212.643
CGINF	-209.936	-211.437	-212.466	-213.333
CBRINF	-210.552	-211.917	-212.566	-212.938
ECG1	-210.103	-211.508	-212.742	-212.727
ECG2	-209.924	-211.930	-212.552	-212.631
ECG3	-210.161	-212.110	**-213.388**	NA
MACHINE	**-211.862**	NA	NA	NA
BAA-AAA	-210.526	**-212.707**	NA	NA

$Notes$: The table reports the Schwarz information criterion (SBIC) for the joint model (4) and (6) when different sets of variables are estimated. The inflation measures CPIINF, CGINF,and CBRINF refer to CPI inflation, CGPI inflation, and CRB inflation respectively. The economic growth measures ECG1, ECG2, ECG3, and MACHINE refer to the growth rates of the Coincident index, the Indices of Industrial Production, the Indices of All Industry Activity, and the machinery orders by private sectors respectively. The global default risk measure BAA-AAA refers to the Baa-Aaa corporate bond credit spread. The number in boldface is the lowest SBIC at each selection stage. A variable selected in the earlier stage is represented by NA at a subsequent stage. The sample period is 2000:06 to 2016:07.

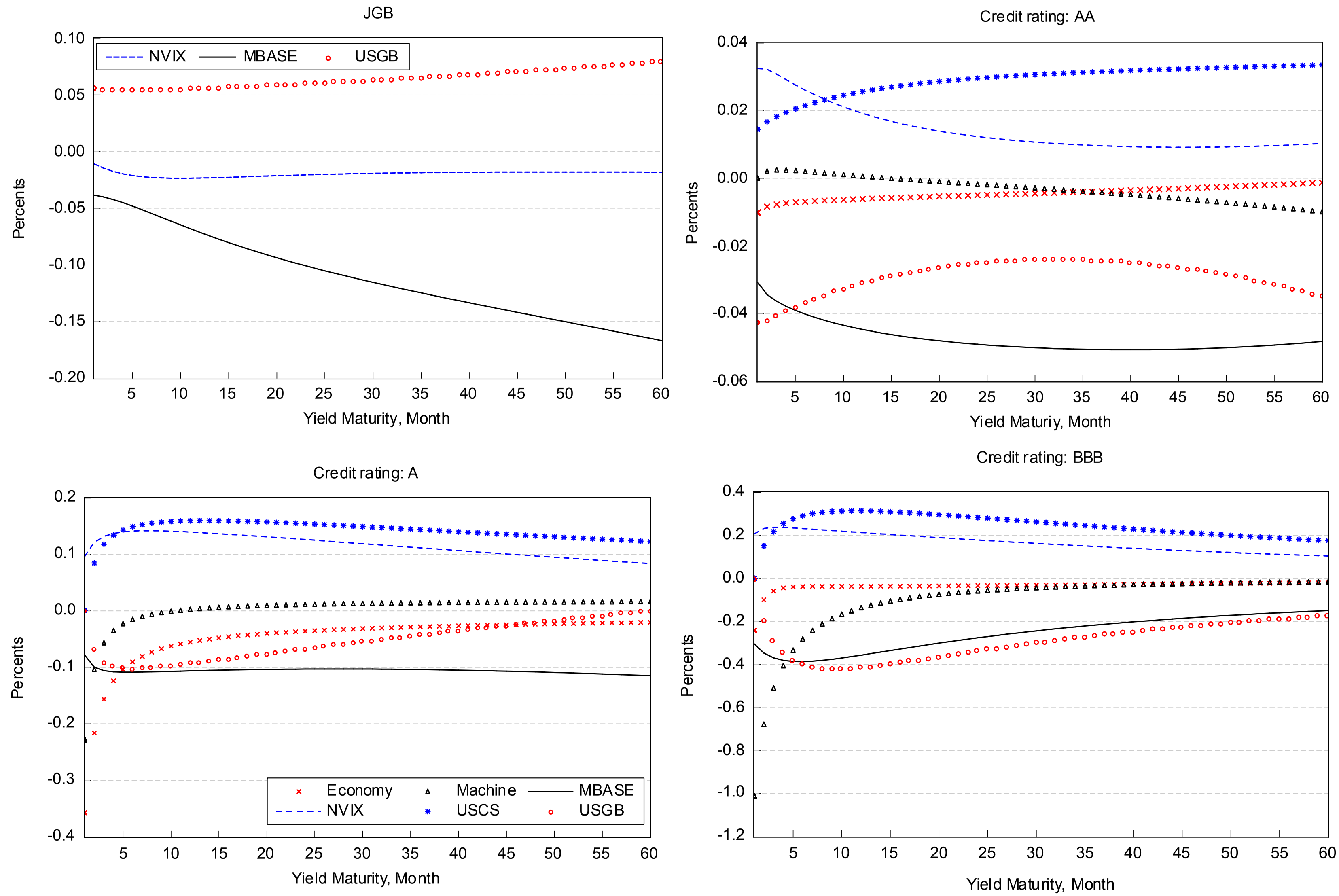

Figure 1: Contemporaneous response of the yield curve and credit spread curves to unit shocks

Notes: Impulse Responses (IR's) for JGB yields and credit spreads for three rating classes (AA, A, and BBB). The IR's from NVIX are drawn as dashed lines; the monetary base, solid lines; the Treasury yields, circles; the U.S. Baa-Aaa credit spread, stars; the IAA, the x's; the machinery orders, triangles.