RIETI Discussion Paper Series 17-E-104

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The Research Institute of Economy, Trade and Industry
http://www.rieti.go.jp/en/

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July 2017

No-arbitrage Determinants of Japanese Government Bond Yield and Credit Spread Curves[1]

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Abstract

We introduce an affine term structure model with observed macroeconomic factors for the government bond 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 monetary policy and suggest that the flight-to-quality behavior considerably affects the government bond yield. In addition, our results indicate that global economic forces, such as the U.S. Treasury yield and 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 contemporaneous response and historical decomposition analyses find that monetary policy and global economic and financial forces have large impacts on all maturities and curves.

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

JEL classification: E32, E43, E44, G12

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[1]A part of this study is a result of the research project at the Research Institute of Economy, Trade and Industry (RIETI) by the first author. The authors would like to thank Junko Koeda and participants at the 2017 Nippon Finance Association Meeting, the 2017 Asian Meeting of the Econometric Society, and IAAE 2017, and seminar participants at Bank of Japan, Mizuho securities, and RIETI for valuable comments and discussions. The second author gratefully acknowledges the financial assistance provided by the Japan Society for the Promotion of Science (JSPS) KAKENHI grant number JP25705010. This research was funded in part by Nomura Foundation grant number N17-3-E30-005.

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1 Introduction

Government bonds with different maturities and corporate bonds with different maturities and risks are traded in the market. The behavior of each yield curve reflects the risk associated with the bonds, such as that of default and inflation. Piazzesi (2009) discusses that understanding what moves bond yields is important for at least four reasons: forecasting, monetary policy, debt policy, and derivative pricing and hedging. For example, among others, Gilchrist et al. (2009), Gilchrist and Zakrajšek (2012), and Bleaney et al. (2016) suggest that understanding corporate bond spreads is useful for forecasting not only the future short spreads, but also real activity. This study 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 a link with the borrowing costs based on country-level panel data, such as in Longstaff et al. (2011) and Costantini et al. (2014). In addition, Pan and Singleton (2008) and Longstaff et al. (2011) use sovereign credit default swap (CDS) data for various countries and find that sovereign credit spreads are more related to the U.S. stock and high-yield markets than 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 U.S. to economic growth in other regions of the world. Incorporating these lines of research, this study explores the determinants of the Japanese government bond (JGB) 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, like U.S. Treasury yields and credit spreads. Consistent with the findings in Pan and Singleton (2008) and Longstaff et al. (2011), which indicate the strong relationship between sovereign credit risk and global economic forces, such as U.S. financial markets (stock and credit risk), the findings in this study suggest that the global economic factors external to the country are important drivers of the JGB 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 body of literature that studies the determinants of credit spread, which is the difference in the yields between defaultable debt instruments and risk-free government securities of comparable maturity, 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 theoretical and empirical works. Although the credit spread 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 other factors, including its duration, embedded call option, and expected inflation.

However, the extent to which the default risk explains the credit spread differs among the studies. For example, Longstaff et al. (2005) find that it accounts for the majority of credit spreads across all credit ratings, while Jones et al. (1984) and Elton et al. (2001) show that the default component accounts for a small fraction of spreads. In addition, the existence of a non-default component is well recognized in corporate bond-pricing studies. 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 studies analyzing the linkage between the term structure of interest rates or corporate bond spreads and macroeconomic risks, Wu and Zhang (2008) suggest that inflation, real output growth, and financial market volatility are the main factors that influence the credit spread based on the no-arbitrage affine term structure models (ATSMs).

We apply the ATSM to the arbitrage-free pricing of JGBs and 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, is a main driver of the JGB yield curve. Moreover, the monetary policy has significant negative impacts on the JGB yield curve and credit spread curve for all rating classes. Second, our results indicate that not only the local economic variables, but also the global economic and market factors, namely the U.S. Treasury bill rate and Baa-Aaa credit spreads, significantly influence JGB yields and credit spreads across all credit-rating classes. Third, the result obtained by the contemporaneous response analysis shows that the responses of JGB yields to financial market volatility are negative, but those of credit spreads are positive, implying flight-to-quality behavior. Last, but not the least, the inflation measures, including global and domestic measures, are not a driving force of JGB yield and credit spread curves. This result documents an interesting feature of Japanese bond markets, making a great contrast to the theoretical and empirical studies that suggest the close relationship between the interest rate and inflation, such as Fama (1990), Piazzesi (2009), Chernov and Mueller (2012), and Kang and Pflueger (2015).

The empirical results in this study provide evidence that 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 theoretical and practical problems. As a practical matter, Anderson (2006) documents that the central bank is afraid of the 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 Bank of Japan (BOJ), explains that monetary-base targeting makes the authorization too wide, ranging from the monetary policy committee to the departments implementing market operations. Nonetheless, this study provides the interesting evidence that the monetary base has been influential and the main driver of government bond yield and credit spread curves in Japan.

The remainder of the paper is organized as follows. Section 2 explains the data used to estimate the government yield and credit spread curves, while Section 3 explains the variables that we analyze in the model selection. Section 4 discusses the ATSMs and estimation strategy for the government yield and credit spread curves, while Section 5 presents the empirical results of the government yield curve using the JGB data. The empirical results of the joint model of JGB yield and credit spread curves are shown in Section 6, and Section 7 concludes the paper.

2 Data

As for the bond market size, measured by the 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 U.S. (according to the Bank for International Settlements' debt securities statistics). JGBs are issued with a wide range of maturities and one of the most popular securities for government debt trading in the world. This means that JGB prices fluctuate according to changes emanating from the Japanese and world economies. In contrast to the JGB market, where the purchases by foreign investors account for 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 the major rating agencies' scales, such as that of 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 now in U.S., corporate bonds rated below investment grade are traded in the Japanese secondary market, and were once issued with ratings in the investment-grade category, but their issuers experienced 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 one month and 10 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 December 2015. We use the same sample period for the credit spreads. We use these data to calculate the credit spreads as risk-free rates according to the traditional practice (see, e.g., 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 the involved banks. This means that these rates are not actually default risk free. An advantage of over-the-counter contracts is not suffering the liquidity squeezes as much as the government bonds. Nonetheless, this study uses the JGB rate due to the data availability of various maturities.

We compute the credit spreads from two pricing sources. First, we use data on yields/rating

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

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

matrix of corporate bonds traded over-the-counter, which 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 study. In terms of the rating information, we use that of 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 one to 20 years, which covers yen-denominated corporate bonds publicly issued in the Japanese corporate market, and excludes corporate bonds with share options, such as convertible bonds and those with warrants. We, however, focus on corporate yields with maturity less than five years due to the data availability for our analysis. For the calculation of the yield, the sample is also 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, making the yields of the corporate bonds in this dataset comparable. Data on the 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 corporate bond at time t, $y_t^{i,n}$, where i is the individual rating from AA through BBB and n is the time to maturity, to that of a JGB with the same maturity, y_t^n. Then, the credit spread, $cs_t^{i,n} = y_t^{i,n} - y_t^n$, is the excess bond premium. We calculate month-end credit spreads from June 2000 through December 2015; 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 the sample period, the events that followed the nuclear disaster that 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; 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 averages, 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 one year to maturity closed at 0.286 (%). The great uncertainty of the future costs regarding the nuclear disaster led to a series of downgrades in 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 one 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 one 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. Further, when R&I lowered TEPCO's credit rating from A to BBB on October 7, 2011, the weekly BBB-rated closing yield for one year rose to 2.889 from 1.247 in the week following the downgrade. The yield for the rating class to which TEPCO's corporate bonds belong was significantly affected.

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 beginning in 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 one year; 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 compared to 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. More specifically, the following modified credit spreads are used after January 2011:

$$cs_t^{i,n,modified} = cs_t^{i,n,TRBCC} + cs_t^{i,n,JSDA} \times \frac{1}{N}\sum \frac{cs_t^{i,n,JSDA} - cs_t^{i,n,TRBCC}}{cs_t^{i,n,JSDA}},$$

where $cs_t^{i,n,TRBCC}$ is the credit spread for the corporate bond $y_t^{i,n}$ drawn from TRBCC, $cs_t^{i,n,JSDA}$ is that drawn from JSDA, and N is the number of overlapped time-series observations.

3 Variables

Previous studies using macro-finance models already demonstrate that not only the financial variables, but also the macroeconomic factors, are related to the yield curves. From a wide array of financial and macroeconomic variables, we use the following variables based on previous works,

[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.

and look into both the local and global economic forces; then, we select a set of variables that best fits the data. The definitions and sources of the data for the local and global variables are provided in Appendix A.

3.1 Local variables

There are many local financial and macroeconomic variables that may influence the yield curves of government and corporate bonds, but many of them are highly correlated and may cause a multicollinearity problem if used simultaneously. Thus, we focus on variables relating to the fundamental risk dimensions underlying an economy, as suggested in Wu and Zhang (2008): inflation, real output growth, and financial market volatility.[4] Furthermore, we also include the monetary policy variable, taking into account the considerable impact of the BOJ's monetary policy on the financial markets.

For country-specific inflation indicators, we use the Consumer Price Index (CPI), excluding fresh food prices, and Corporate Goods Price Index (CGPI). The CPI contains information about the price for the buyer, and CGPI contains that for the seller. Not only has the relationship between the interest rate and inflation been discussed in a large amount of the extant literature (see, e.g., Fama (1990), Beaudry and Portier (2006), Piazzesi (2009), and Chernov and Mueller (2012)), but also the corporate bond spreads and inflation through the possibility of debt deflation (Fisher (1933)). Moreover, 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.

We use the growth rates of the Indices of Industrial Production (IIP), Indices of All Industry Activity (IAA), and Coincident Index (CI) as the economic growth measures. The relationship between the output growth and Treasury yield curve has been examined in the research on term structure, such as Evans and Marshall (2007), 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 in 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

[4]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).

Japan, are also included to reflect private investment. Their predictive content for the business cycle is expected to be a determinant of yield and credit curves. Further, Gilchrist and Zakrajšek (2012) document the negative relationship between their original credit spread index and the business fixed investment, especially in high-tech equipment.

For financial market volatility, we use the Nikkei Stock Average Volatility Index (NVIX); details about the definitions and sources of the data is provided in Appendix A. According to research on the financial contagion, as in Allen and Gale (2000), Brunnermeier and Pedersen (2009), and many others, market liquidity is related to volatility, and a shock in one market may spill over into other markets. Thus, we examine the effect of stock market volatility on both government bond yields and credit spreads.

As a proxy for monetary policy, the 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 a change in its operating procedures, providing an interesting case in which the monetary base is used to affect the yields of financial assets, as discussed in Bernanke and Reinhart (2004). Quantitative easing was first implemented in Japan on March 19, 2001 to combat its persistent deflation and stimulate its stagnant economy. 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. 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 JGB 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 quantitative and qualitative easing policy in April 2013, accelerating the purchase of long-term government bonds. It is expected that monetary policy affects the JGB yield curve according to JGB purchases. A close link between the JGB and corporate bond markets suggests that the credit spread curve is also affected by monetary policy.

3.2 Global variables

The state of the global economy is as important as that of the local economy with 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 bond yields and credit spreads. Furthermore, it is natural to explore the relationship with global factors, due to Japan having the second largest bond market in the world.

For global economic factors, we select the variables among possible global economic forces, which are regarded as international indexes and considered influential in the global economy through extensive economic and trading relationships with other countries. The risk dimensions underlying an economy are identified the same as in the case of the local variables: inflation, real output growth, and financial market risk.

To capture the change in 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 the 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 the price inflation rate.

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

The U.S. 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 is the Aaa-rated bond. Therefore, the small (large) Moody's Baa-Aaa credit spread indicates that good (poor) economic conditions are expected. Moreover, Gilchrist and Zakrajšek (2012) confirm that the Baa-Aaa credit spread contains some marginal information for near-term economic developments. Further, U.S. Baa-Aaa credit spreads also indicate the investor's attitude toward economic growth, which spreads in all markets.

4 Model and Estimation Strategy

Our model for the JGB yield and credit spread curves is based on an ATSM with observed macroeconomic factors. In this section, we will introduce our model and its estimation strategy.

4.1 Affine term structure model for 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; thus, we interpret one period to be one month. Alternatively, our model can be considered a discrete version of the term structure model of Wu and Zhang (2008) with some generalization.

In this framework, the vector of the 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:

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

where α_r is a scalar and β_r is a $K \times 1$ vector of coefficients.

ATSMs 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 assume 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.[5]

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

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

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

Furthermore, with these specifications, the no-arbitrage assumption implies that the price p_t^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 $K \times 1$ vector B_n of coefficients that are functions of time to maturity n. As shown by Ang and Piazzesi (2003), these coefficients can be computed from the following difference equations:

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

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

$$y_t^n = -\frac{\log p_t^n}{n} \tag{3}$$

$$= -\frac{A_n}{n} - \frac{B_n' X_t}{n}. \tag{4}$$

4.2 Affine term structure model of corporate bond spreads in discrete time

To derive an 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:

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

where α_i is a scalar and β_i is a $K \times 1$ vector of coefficients.

Duffie and Singleton (1999) show that, under some conditions, the no-arbitrage assumption implies that the price $d_t^{i,n}$ 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, the absence of arbitrage implies that $d_t^{i,n}$ is also an 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:

$$\begin{aligned} A_{n+1}^i &= A_n^i + B_n^{i\prime}(\mu - \Sigma\lambda) + \frac{1}{2}B_n^{i\prime}\Sigma\Sigma' B_n^i - \alpha_r - \alpha_i, \\ B_{n+1}^{i\prime} &= B_n^{i\prime}(\Phi - \Sigma\Lambda) - \beta_r' - \beta_i'. \end{aligned} \tag{5}$$

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

$$cs_t^{i,n} = -\frac{A_n^i - A_n}{n} - \frac{B_n^{i\prime} - B_n'}{n}X_t. \tag{6}$$

4.3 Estimation

To estimate the government yield curve model, we use the JGB yield data with maturities of one, three, and six months, as well as every year from one to 10.[6] Let Y_t^1 denote the 13×1 vector consisting of these yields, namely

$$Y_t^1 = (y_t^1, y_t^3, y_t^6, y_t^{12}, y_t^{24}, y_t^{36}, y_t^{48}, y_t^{60}, y_t^{72}, y_t^{84}, y_t^{96}, y_t^{108}, y_t^{120})'.$$

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

$$Y_t^1 = A^1 + B^1 X_t + \Sigma_e^1 u_t^1,\ u_t^1 \sim \text{iid } N(0, I), \tag{7}$$

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

[6] Spot rates for JGBs with one-month maturity are available only from September 2012. We linearly extrapolated the missing data from the spot rates with maturities of three and six months, and replaced them with 0 if below 0.

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

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

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

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

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 the government yields data of Y^1, we use the credit spread data with maturities of one month and every year from one to five for each credit-rating class.[7] 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, respectively.

[7] Since credit spreads with one-month maturity are not available, we linearly extrapolated them from the credit spreads with maturities of one and two years, and replaced them with 0 if below 0.

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, respectively.

We also employ the two-step approach to estimate the joint model, by estimating parameters θ_1 for VAR model (1) in the first step and the rest of the parameters denoted by θ_2^i, holding estimates of θ_1 fixed, in the second step.

5 Japanese Government Bond 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, in order to explain the dynamics of the JGB yield curve. Then, we analyze the effects of each factor by calculating the contemporaneous response of each yield to shocks on each factor, and investigating the historical contribution of each factor to the variation in JGB yields.

5.1 Model selection

In this subsection, we discuss the model selection results for the 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 the JGB yield curve.[8] In this approach, we start with a model that includes the variable that provides the best fit of the model with the lowest SIC value. 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 provides the lowest SIC value. 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 JGB purchases, by targeting the current account balances, which is a major component of the monetary base, as a new policy target. Although the policy was terminated in March 2006, the BOJ introduced comprehensive monetary easing with the Asset Purchase Program, includ-

[8] Backward selection is another widely used procedure in practice, which begins with estimating a model with all possible determinants and eliminates the least significant variable, one by one. However, our model is rather complicated and not realistic to estimate a model with all possible determinants. Therefore, we adopt forward selection.

ing long-term government bonds, in October 2010. 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 are estimated to examine whether additional variable inclusion improves the model.[9] The SIC results 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 has a significant impact on the JGB market, indicating the international financial integration in bond markets, as reported by Kumar and Okimoto (2011) and Dahlquist and Hasseltoft (2013). In addition, this result may reflect the interdependence of world economies captured by the U.S. bond market.

The fourth column of Table 1 reports 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 NVIX shows the best fit with the lowest SIC among a set of possible determinants. This result suggests that the flight-to-quality behavior affects the JGB markets considerably, which is fairly consistent with the results of Bansal et al. (2014) and 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, global economic and bond market state, and 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, such as Ang and Piazzesi (2003), Wu and Zhang (2008), and international data, such as Pan and Singleton (2008), Bikbov and Chernov (2010), Longstaff et al. (2011), inflation and real activity are not found to be important to explain the JGB yield curve; however, as in these studies, financial market volatility is an

[9]Precisely speaking, the estimation results depend on the order of the macroeconomic 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 a new variable after one that is already chosen.

important determinant. Further, JGB yield is linked to the global economic and bond market factor captured by the 10-year U.S. government bond yield.

To see the performance of our selected model, the dashed line in the upper panel of Figure 1 displays the estimated 10-year JGB yields across time from 2000:08 through 2015:12, along with the actual 10-year JGB yields, as displayed as the solid line. The estimated 10-year JGB yields show quite similar dynamics to the actual 10-year JGB yields. The only occasion when two lines differ significantly is the period before the so-called Value at Risk (VaR) shock in June 2003, more than tripling the 10-year JGB yields over three months. This is a rather peculiar period and, thus, it is not unreasonable that the model cannot capture the movement. The lower panel of Figure 1 plots the average JGB yields as a function of maturity, computed using the historical average of each factor (dashed line) along with the historical average of actual JGB yields (solid line). As can be seen, these curves closely match, meaning that the average JGB yield curve is estimated with high precision. In other words, this close correspondence suggests that our JGB yield model can describe the JGB yield curve quite well on average. In sum, our selected model demonstrates reasonable fit in both time series and cross-sections.

[Figure 1 around here]

5.2 Contributions of each determinant

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. We will investigate the contributions of each factor through contemporaneous response analysis and historical decomposition in this subsection.

To investigate the effects of each variable on the JGB yield curve in detail, we calculate the contemporaneous response of each yield to a one-standard-deviation shock on each factor, as in Wu and Zhang (2008). Figure 2 plots the contemporaneous response of the JGB yield curve to these shocks. The x-axis is in months, and the responses are given in annualized percentages. As can be seen from this figure, the monetary base has significant negative effects on the JGB yields at all maturities that are downward-sloping, meaning that the magnitude of negative responses is larger at longer maturities. More specifically, a one-standard-deviation shock to the monetary base decreases the one-year JGB yield by six basis points, and the five-year yield by more than 15 basis points. This result indicates that the BOJ's monetary easing, after the introduction of its quantitative easing policy in 2001, has been effective in substantially lowering long-term interest rates.

[Figure 2 around here]

The response of each yield to NVIX, a proxy of financial market volatility, is also negative with an almost horizontal line. This implies that financial market volatility relatively uniformly affects JGB yields of all maturities. Although the magnitude of the declines is not particularly large, with about two basis points, these declines are not negligible, given the relatively high fluctuation of NVIX and 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 the above two variables, the response of each yield to the 10-year U.S. Treasury yield shock is positive and slightly upward-sloping. Specifically, a one-standard-deviation shock to the 10-year U.S. Treasury yield increases the one-year JGB yield by five basis points, but the five-year yield by about eight basis points. Again, these responses are substantial, given the situation of JGB markets. This result is particularly important, since the recent uncertainty associated with U.S. monetary and fiscal policy has caused the U.S. long-term interest rate to fluctuate considerably, significantly affecting the JGB market.

In sum, the results of the contemporaneous response analysis demonstrate that a main driver of the JGB yield curve is the monetary base, a proxy for monetary policy, with very significant negative impacts, especially for longer maturities. The global economic and bond market state, measured by the 10-year U.S. Treasury yield, positively affects 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.

To investigate the historical contribution of each factor on the variation in JGB yields, Figure 3 illustrates the decomposition of the variation in 10-year JGB yields from the sample mean into each of the factor variation components, namely the monetary base, 10-year U.S. Treasury yield, and NVIX, along with the variation.[10] Each variation is computed using the deviation of each variable from its historical average. Higher yields than those of the sample mean are observed until the middle of 2010, just before the BOJ announced its Asset Purchase Program, which included long-term government bonds. The only exception is the period before the VaR shock when the JGB

[10]For this figure, we have taken the three-month moving average to filter out the short-run fluctuation.

market experienced the historic low level caused by the onset of the war in Iraq and solid monetary easing by Governor Fukui after his inauguration in March 2003. The monetary base accounts for the positive and a large percentage in the variation until 2011; on the other hand, it tends to present negatively and considerably more in the variation after 2011. This is because the value of the monetary base in the former part of the sample period is smaller than the average value. In the period after 2011, the value of the monetary base is larger than the average value induced by the BOJ's aggressive monetary easing, keeping the monetary base at a record high. Thus, the negative variation after 2011 is due primarily to differences in the monetary base.

[Figure 3 around here]

The 10-year U.S. Treasury yield presents the negative component mostly after the introduction of the quantitative easing program by the Federal Reserve Board (FRB) in November 2008. This is because the aggressive monetary easing by the FRB and worldwide demand for the relatively high-yielding safe assets during and after the Great Recession (December 2007 to June 2009) make the 10-year U.S. Treasury yield lower than its historical average over the last nearly seven years. In addition, the 10-year U.S. Treasury yield explains the comparable variation to the monetary base, both in direction and size, most of the time. A notable difference is observed between 2009 and 2012 when the 10-year U.S. Treasury yield presents the negative component in the variation. Even after the recession ended in June 2009, the historically low 10-year U.S. Treasury yield, reflecting the situation of global economies, continues to negatively contribute to the variation during this period, while the monetary base contributes little or positively.

In comparison to the monetary base and 10-year U.S. Treasury yield, the NVIX explains less variation in JGB yields. However, it incorporates aspects of the market sentiment and accounts for more variation when financial events and geopolitical issues occur. For example, after the rise in the NVIX due to the September 11, 2001 attacks, the relatively high market uncertainty continued into the mid-2000s. Thus, the NVIX serves as a negative component of the variation in yields during this period. In addition, the NVIX is also the negative component between March 2008 and December 2010, which corresponds to the period of global financial crisis.

In sum, these results reveal the role of the monetary base in explaining a greater portion of the variation in JGB yields, in particular, their recent decline. Further, the 10-year U.S. Treasury yield also explains a sizable fraction of variation in JGB yields, while the NVIX contributes generally little and negatively in only a few occasions, such as the global financial crisis.

6 Joint Model of Japanese Government Bond 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 response of each credit spread to shocks on each factor as well as the historical contribution of each factor to the variation in credit spreads.

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, 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 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 the AA-, A-, and BBB-rated categories, 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 SIC value of. We repeat this process until no variable improves the model or lowers the SIC value.

The results of the forward variable selection are summarized in Table 2, and indicate that, for the AA-rated credit spreads, the U.S. Baa-Aaa corporate bond credit spread, which is an indicator of 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 additional two 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 with the same order, as can be seen from Table 2.

[Table 2 around here]

In contrast, for BBB-rated credit spreads, machinery orders are chosen in the first selection, followed by the U.S. 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 domestic private capital expenditure than to the global risk indicator. Thus, although the determinants of credit spread curves at different ratings are found to be the same, the variables might affect each curve in a slightly different manner. The contemporaneous response analysis and historical decomposition in the next subsection will more formally clarify this point.

To see how our selected joint model of the JGB yield and credit spread curves describes the credit spread curves, Figures 4 and 5 compare the estimated time-series and average credit spreads with the corresponding actual credit spreads, respectively. Specifically, Figure 4 plots the five-year-maturity actual credit spreads as solid lines and estimated credit spreads as dashed lines for the AA, A, and BBB rating classes, over the period 2000:08 to 2015:12. Each panel shows the estimated five-year-maturity credit spread curve for each rating class with actual credit spreads for a corresponding rating class. The estimated credit spreads in each rating class have the same pattern as the actual credit spreads for most of the sample period, and the large gap between the estimated and actual credit spreads occurs in during the period of global financial crisis between 2008 and 2010, particularly for the A and BBB rating classes. During the period of global financial crisis, the actual credit spreads for the A and BBB rating classes are more volatile than are the estimated credit spreads. The historical evolution of the credit spread curve for each rating class has notable differences in both actual and estimated credit spreads. We discuss these differences across credit-rating classes by computing the contemporaneous response of each credit spread curve, as well as the historical contribution of each factor, in next subsection.

[Figures 4 and 5 around here]

Figure 5 displays the average credit spread curves computed using the historical average of each factor, along with the actual credit spreads for the AA, A, and BBB rating classes. The solid line in each panel denotes the actual credit spreads for each credit-rating class and maturity, while the dashed line in each panel represents the estimated average credit spread curve computed using the historical average of each factor for each credit-rating class and maturity. The estimated average AA-rated credit spread curve and actual credit spread curve have upward-sloping patterns, suggesting that the shortest AA-rated credit spread is lower than the longest on average. As for the A rating class, the estimated and actual credit spread curves are also upward-sloping. Moreover, for the actual BBB-rated credit spreads, the hump occurs at four years (48 months) of maturity. No significant difference between the actual and estimated credit spread curves is observed, but the actual credit spreads are not as smooth as the estimated ones for the BBB rating class. Overall, the movements of the estimated average credit spread curve and actual credit spreads have almost the same pattern for all rating classes; however, detailed differences across credit-rating classes are observed, as mentioned above. We will more carefully examine the effects of the determinants on the credit spread curves for different rating classes in the next subsection.

In sum, the additional determinants of the credit spreads, which explain the defaultable bond pricing, turn out to be the same across rating classes (AA, A, and BBB), and include 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. credit spreads, not surprisingly plays a significant role in the Japanese corporate bond markets. In addition, in contrast to the JGB yield curve, the business condition is found to be critical to explaining the dynamics of the credit spread curve. Another interesting feature of the results is that the inflation measures, including both global and domestic, are not a driving force of the joint dynamics of the JGB yield and credit spread curves, making a great contrast to the previous studies that suggest the close relationship between the corporate bond yields and inflation, such as Kang and Pflueger (2015). Assuming that the asset prices are more affected by the uncertainty of the permanent component of inflation, our results suggest the lack of an increase in the volatility of the 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 Contributions of each determinant

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 classes. However, this does not necessarily mean that these variables have the same effects on the credit spreads for all rating classes. To shed light on this point, we calculate the contemporaneous response of each credit spread to a one-standard-deviation shock on each factor, following Wu and Zhang (2008).

As can be seen from Figure 6, for the AA-rated credit spread curve, the response to the monetary base is negative at all maturities, and slightly downward-sloping at the short maturities, but almost flat after one-year of maturity. As a result, the monetary base has almost the same effects on both the one- and five-year AA-rated credit spreads, or about -5 basis points. The responses of the A-rated credit spread curve have a very similar pattern, but are about twice as large as those of the AA-rated category. The BBB-rated credit curve responses are more prominent, negative, and upward-sloping, meaning that the magnitude of negative responses is smaller at longer maturities. More specifically, a one-standard-deviation shock to the monetary base decreases the one-year BBB-rated credit spread by 36 basis points, but the five-year credit spread by about 20 basis points. Thus, monetary easing policies by the BOJ seem to have huge effects on the credit spread curves, particularly for the lower rating curves.

The responses to the 10-year U.S. Treasury yield are generally negative, indicating that if the U.S. long-term interest rate goes up unexpectedly, the Japanese credit spreads will decrease. This is most likely because a rise in the U.S. long-term interest rate 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 the NVIX, financial market volatility has a positive impact on the credit spread curves, with larger impacts on the lower rating curves. This is not unreasonable, since the flight-to-quality behavior induces inflow to the JGB market, but outflow from the corporate bond markets. Somewhat similar responses are observed for the shock to the U.S. credit spread, although they are generally larger than those of the 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 one to four basis points, while they affect BBB-rated spreads by 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 the other variables, with effects generally less than five basis points. A notable exception is the effects of machinery orders on the BBB-credit spread of the short-term maturities, with a 14-basis-point decrease at one-year maturity.

Therefore, our results show that these 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. credit spread affects the credit spread curves comparably with the 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 monetary policy. In addition to monetary policy, the domestic and global financial market factors, such as the NVIX and U.S. credit spread, play a major role in Japanese credit spreads.

Figure 7 illustrates the decomposition of the variation in five-year credit spreads for each rating class from the sample mean into different factor variation components.[11] Each variation is computed using the deviation of each variable from its historical average. To make the images plain and clear, components of U.S. Baa-Aaa corporate bond credit spread and the NVIX are united as a risk component (Risk), and those of machinery orders and CI monthly growth rates are united as an economic component (Economy) in Figure 7. Each panel corresponds to each rating class. For all rating classes, the spike in credit spreads is observed in the period of global financial crisis between 2008 and 2010. Another spike is observed after the Great East Japan earthquake that occurred on March 11, 2011. This disaster had a significant impact not only on TEPCO, but also on other electric companies that possess nuclear power plants, by increasing the uncertainty about future profitability. The spike in the AA rating class seems to be caused by such uncertainty of AA-rated electric companies, and TEPCO bonds seem to cause the spike in the BBB rating class.

[Figure 7 around here]

Under an aggressive monetary easing policy, the recent variation for all rating classes is below the sample mean. Considering the results in Figures 3 and 7, the recent monetary policy has substantially lowered both the JGB yields and credit spreads in recent years. Moreover, the monetary base component explains the variations across rating classes in the same way. It serves mostly as a positive component in the variation until March 2011, after which it turns out to be a negative component. The global economic and bond market state indicator, the 10-year U.S. Treasury yield, presents the negative component until approximately November 2008, and the positive component for all rating classes since then. These two components indicate that each credit spread incorporates the monetary policy and global economic state components in a similar fashion.

[11] For this figure, we have taken the three-month moving average to filter out the short-run fluctuation.

The distinctive components in the high- and upper-medium grades (AA and A ratings) are a risk factor (U.S. Baa-Aaa corporate bond credit spread and NVIX), which accounts for the positive and large percentage of the variation during the period of global financial crisis. In contrast, the Economy factor (machinery orders and CI monthly growth rates) accounts for a larger portion in the variation in the lower-medium grade (BBB). It is interesting and important to note that the domestic economic factor is not one of the key components in the JGB yield and credit spreads for high- and upper-medium grades, but it is for the lower-medium grade, which implies that the credit spread for the lower-medium grade is more sensitive to the domestic economic forces than is that for higher credit quality.

7 Conclusion

We empirically determine what causes the movement of the 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 study provides interesting evidence. The model selection results identify three important determinants to explain the dynamics of the JGB yield curve: monetary policy, global economic and bond market state, and financial market volatility. Our joint model of JGB yields and credit spread curves shows that the global credit risk appetite, domestic private capital expenditure, and domestic economic growth are the additional determinants of the credit spreads, which turn out to be the same across rating classes. However, these variables affect each curve in a slightly different manner. While the market risk indicators play a significant role in the dynamics of the AA- and A-rated credit spreads, the BBB-rated credit spreads are more sensitive to the domestic economic factors than the market risk indicators.

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 remarkably affects financial asset pricing, at least the JGB yields and credit spreads, across all credit-rating classes. Moreover, the contemporaneous response results show that the responses to monetary policy are quite uniform at all maturities up to five years, suggesting that the JGB yield and credit spread curves in Japan are dominated by monetary policy. This finding is also confirmed in the historical decomposition analysis. In sharp contrast to monetary policy, inflation measures, including global and domestic, are not found to be a driving force of the dynamics of the JGB yield and credit spread curves.

This study explores the important drivers of the 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 the 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. Further, the results emphasize the importance of considering international financial integration in bond markets when analyzing the yields of financial assets, especially those of bonds.

One might be concerned about the validity of applying the standard ATSM to the arbitrage-free pricing of JGBs and credit spreads for some reasons, such as the relatively lower liquidity of corporate bonds compared to JGBs and the association with ZLB/ELB in the interest rate policy. However, our selected models describe the actual curves quite well on average, and demonstrate reasonable fit in both time series and cross-sections. The focus of this paper is to provide the fundamental model to explain JGB yield and credit spread curves in the extremely low interest rate world. The model incorporating specific characteristics of Japanese interest rate policy could be an interesting future research line, which allows the detailed analysis of the interaction between the unconventional monetary policy and the pricing of JGBs and corporate bonds.

Appendix A. Definition and sources of Data

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

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 and Baa Corporate Bond Yields are retrieved from the Federal Reserve Bank of St. Louis.

2. CI. The CI monthly growth rate is based on an index of business conditions published monthly by the Cabinet Office of the Japanese government. The value is obtained directly from its website. CI is constructed from a set of the 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 equipment), retail sales, wholesale sales, operating profit (all industries), shipments index for small and medium-sized enterprises (manufacturing), and ratio of active job openings.

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

4. CPI. The CPI is reported monthly by the Ministry of Internal Affairs and Communications. The data are obtained from the website of the Statistics Bureau. This study uses the CPI excluding fresh food prices, which often fluctuate considerably depending on the weather, to figure out the basic trend in the prices of goods and services; it is often referred to as the Core Index in Japan.

5. CRB. The Thomson Reuters/CoreCommodity CRB Index, comprised of 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 study uses the month-end value of Thomson Reuters/Corecommodity CRB Index's Excess Return, which is obtained from the Thomson Reuters Eikon.

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

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

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

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

10. NVIX. The NVIX is published in real time, and calculated using the prices of Nikkei 225 futures and Nikkei 225 options on the Osaka Exchange. 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 U.S. 10 Year Government Benchmark Index. This study uses the month-end value obtained from Thomson Reuters Datastream.

Appendix B. Derivation of recursive corporate bond prices

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.

Bansal, N., R. A. Connolly, and C. Stivers (2014). The stock-bond return relation, the term structure's slope, and asset-class risk dynamics. *Journal of Financial and Quantitative Analysis 49*(3), 699–724.

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 126*(598), 2257–2291.

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.

Dahlquist, M. and H. Hasseltoft (2013). International bond risk premia. *Journal of International*

Economics 90(1), 17–32.

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 (2007). Economic determinants of the nominal treasury yield curve. *Journal of Monetary Economics 54*, 1986–2003.

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 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

$Notes$: This table reports the SIC, 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, and ECG3 refer to the growth rates of the IIP, IAA, and CI, respectively. MACHINE refers to the machinery orders by private sectors. 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 numbers in boldface are the lowest SIC 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 2015:12.

Table 2: Variable selection for 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

$Notes$: This table reports the SIC 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, and ECG3 refer to the growth rates of the IIP, IAA, and CI, respectively. MACHINE refers to the machinery orders by private sectors. The global default risk measure BAA-AAA refers to the U.S. Baa-Aaa corporate bond credit spread. The numbers in boldface are the lowest SIC 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 2015:12.

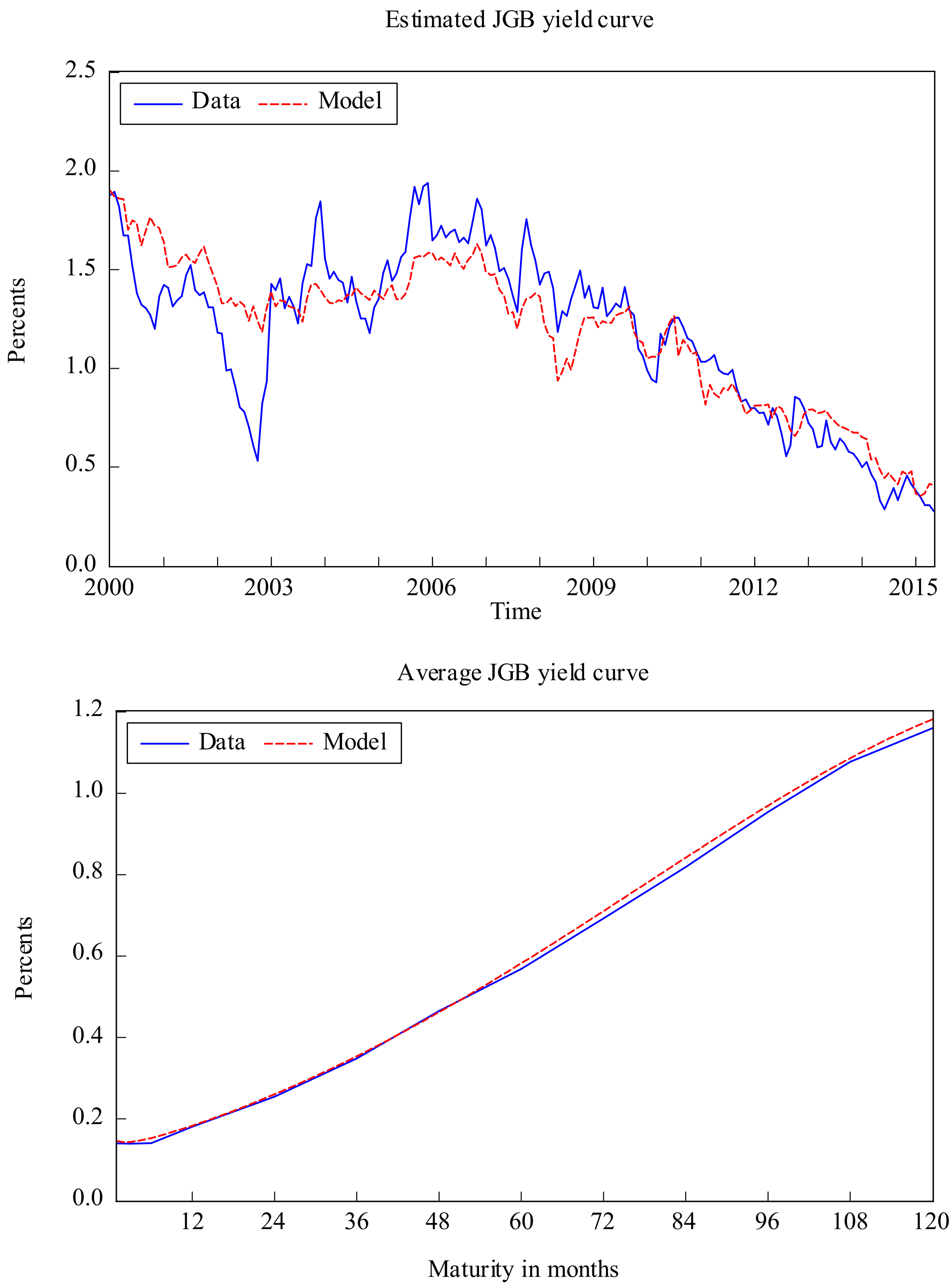

Figure 1: Actual and estimated JGB yield curves

Notes: The upper panel plots the actual JGB yield and estimated JGB yield curves for 10-year maturity across time, from 2000:08 through 2015:12. The lower panel plots the actual JGB yield and average JGB yield curves, computed using the historical average of each factor.

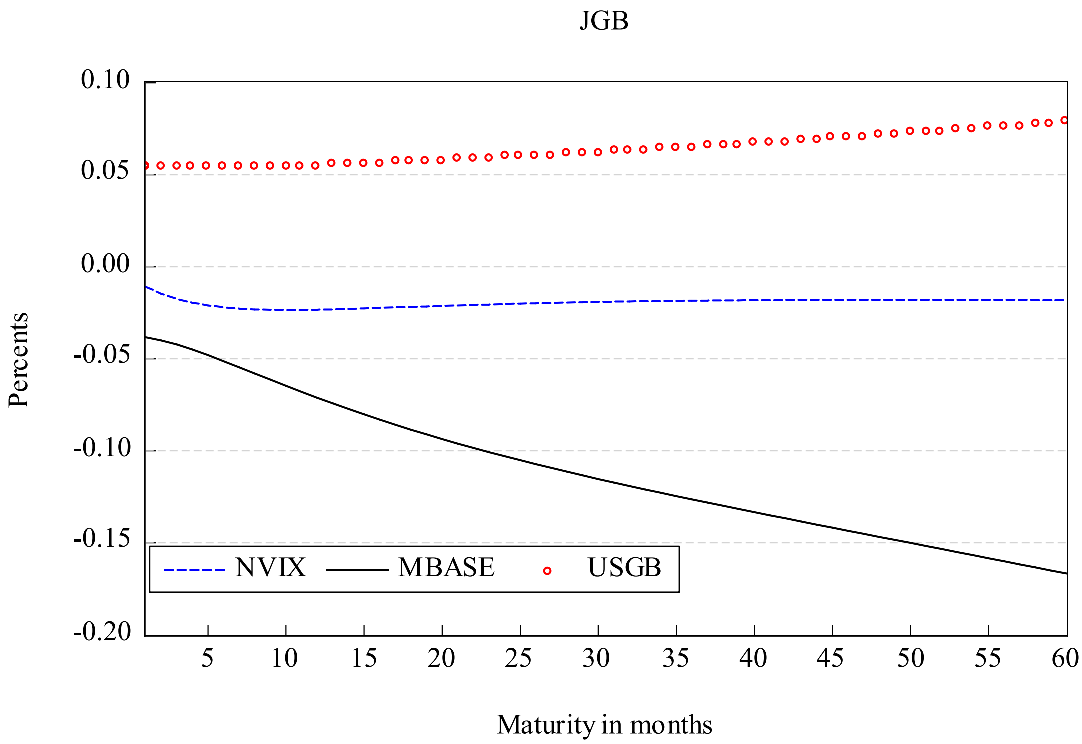

Figure 2: Contemporaneous response of JGB yield curve to a one-standard-deviation shock
$Notes$: The contemporaneous responses from the NVIX are drawn as dashed lines; the monetary base, solid lines; and the Treasury yields (USGB), circles.

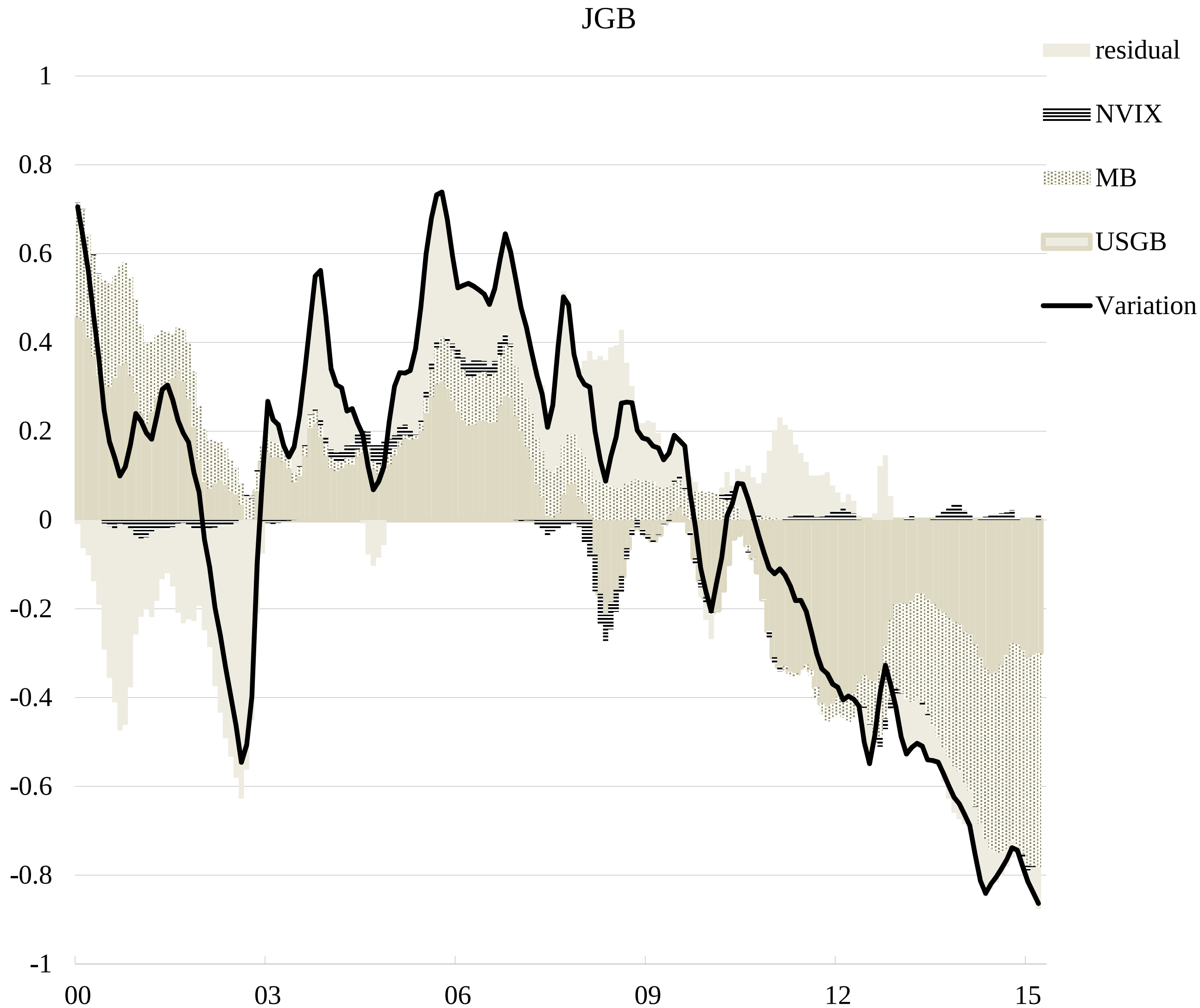

Figure 3: Factor decomposition: JGB yield curves

$Notes$: This figure shows the contributions of factors, namely, the monetary base (MBASE), U.S. government bond 10Y (USGB), and NVIX, to the variation in 10-year JGB yields. The vertical axis shows percentages. Sample period: 2000:10-2015:12.

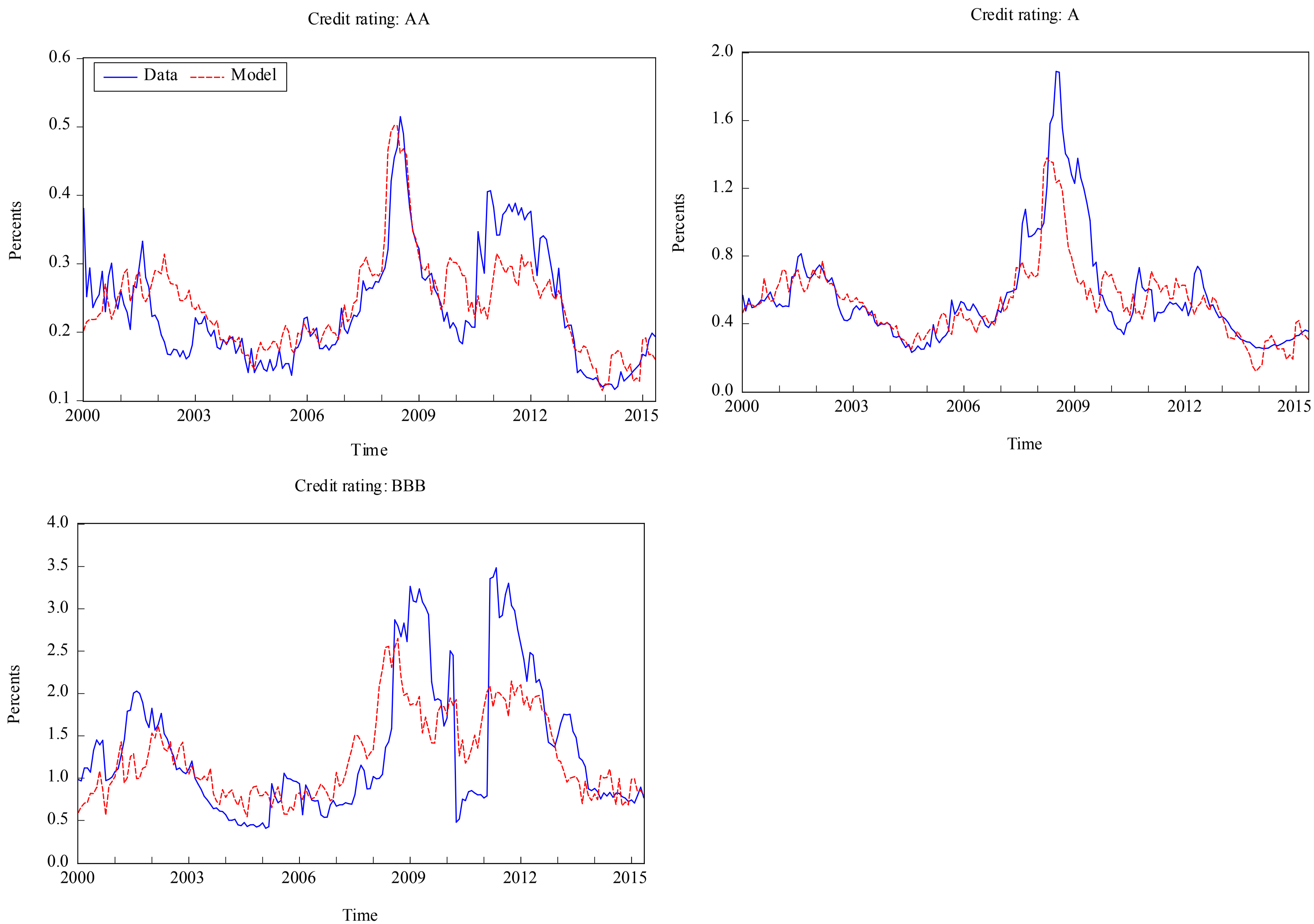

Figure 4: Estimated credit spread curves across time

Notes: This figure plots the actual and estimated credit spreads at five-year maturity for the three rating classes across time, from 2000:08 through 2015:12.

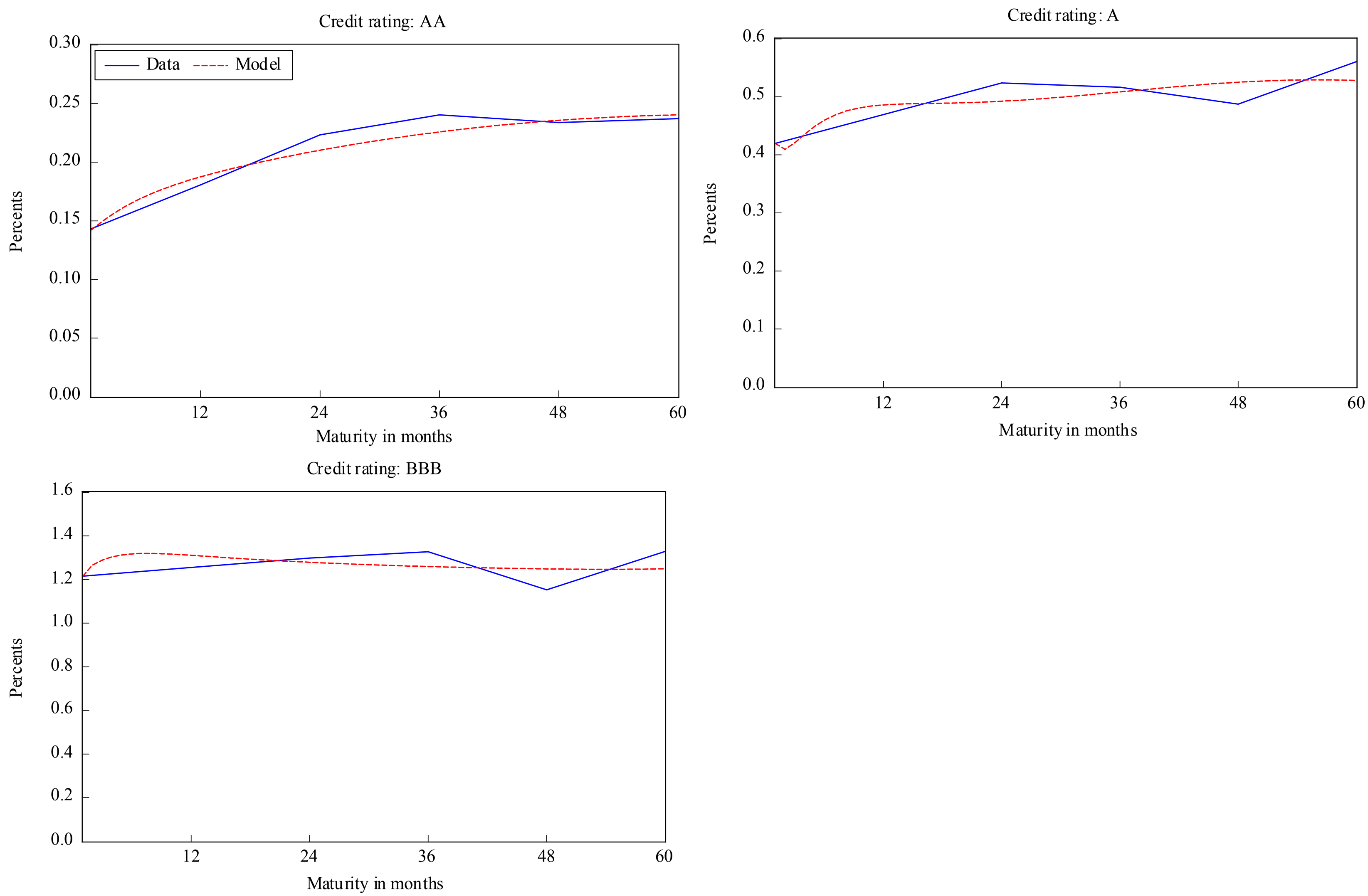

Figure 5: Average credit spread curves

Notes: This figure plots the actual and estimated credit spread curves for the three rating classes, computed using the historical average of each factor.

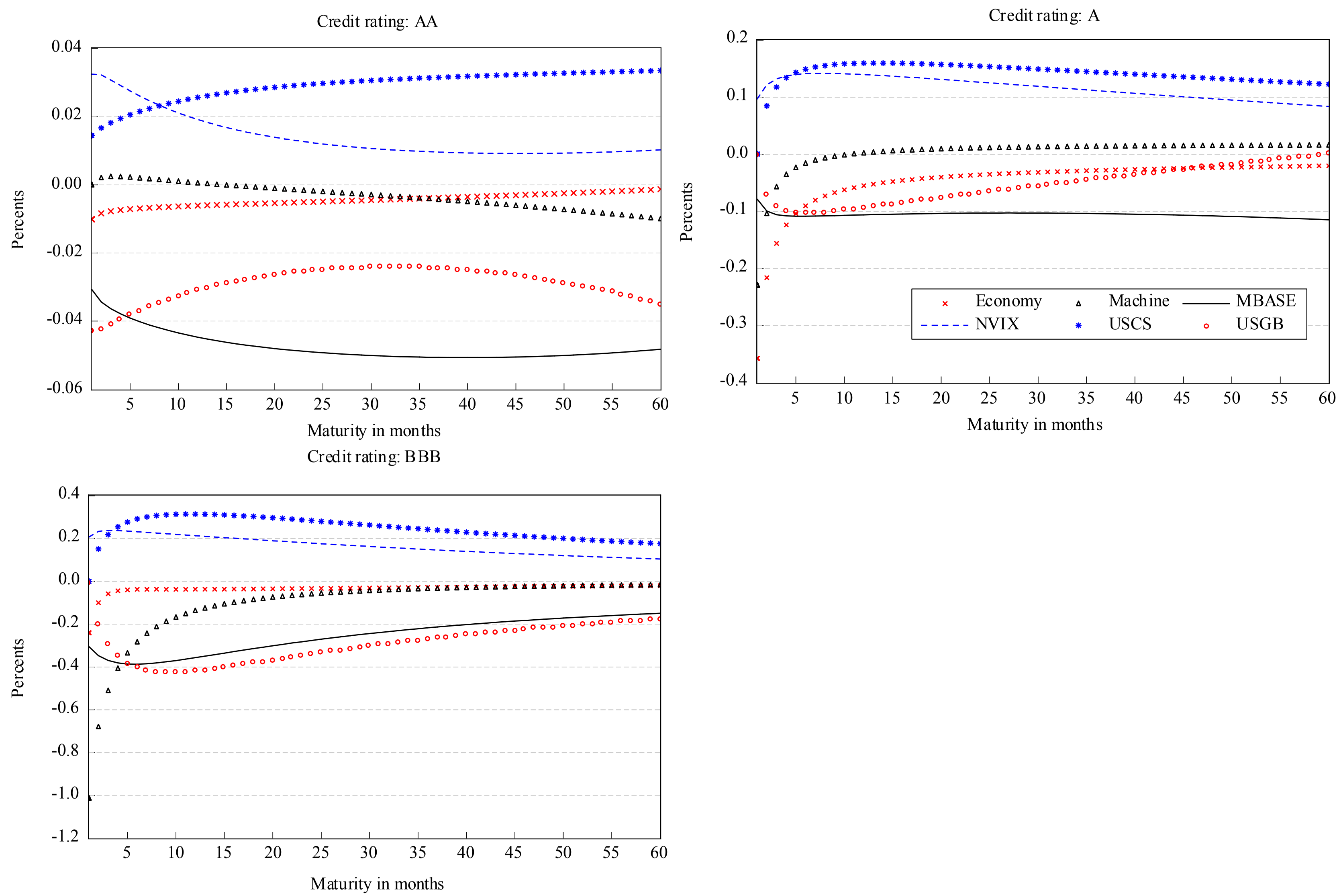

Figure 6: Contemporaneous response of credit spread curves to a one-standard-deviation shock

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

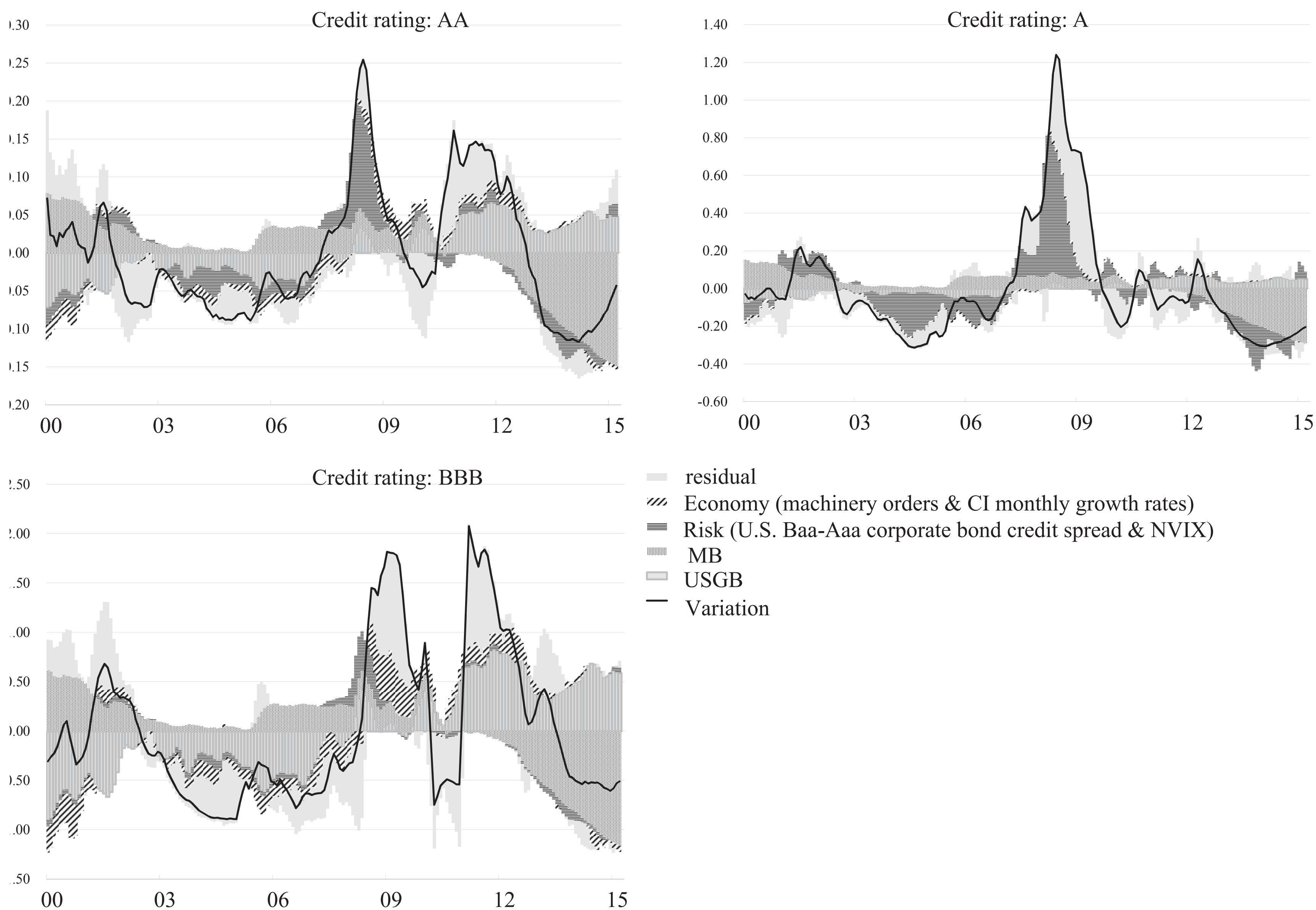

Figure 7: Factor decomposition: credit spreads

Notes: This figure shows the contributions of factors to the variation in five-year credit spreads for each rating class. The factors are the monetary base (MBASE), U.S. government bond 10Y (USGB), U.S. Baa-Aaa credit spread and NVIX (Risk), and growth rates of the IAA and machinery orders (Economy). The vertical axis shows the percentages. Sample period: 2000:10-2015:12.