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Abstract

This paper reviews the financial market functioning under the zero interest rate policy (ZIRP) and the subsequent quantitative monetary easing policy (QMEP) conducted by the Bank of Japan (BOJ). First, the estimation results of the JGB yield curve using the Black-Gorovoi-Linetsky (BGL) model show that (i) the shadow interest rate has been negative since the late 1990s, turned around upward in 2003, and has been on an uptrend since then, and (ii) the first-hitting time until the negative shadow interest rate hits zero again under the risk-neutral probability is estimated to be about 3 months as of the end of February 2006. Second, under the ZIRP and QMEP, the risk premiums for Japanese banks have almost disappeared in the short-term money markets like the market for negotiable certificates of deposits, while they have remained in the credit default swap market and the stock market. This result supports the view that the market participants have positively perceived the BOJ's ample liquidity provisions in containing the near-term defaults of banks caused by the liquidity shortage.

Keywords: Bank of Japan; Term Structure of Interest Rates; Zero Lower Bound; Zero Interest Rates; Quantitative Monetary Easing Policy; Bank Risk Premium
JEL classification: E43, E44, E52, G12

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1. Introduction

This paper aims to review the financial market functioning under the Bank of Japan (BOJ) 's recent monetary policy, the zero interest rate policy (ZIRP) and the subsequent quantitative monetary easing policy (QMEP). In doing so, this paper pays particular attention to quantitatively assessing (i) market perceptions about the BOJ's monetary policy from the Japanese government bond (JGB) yield curve and (ii) the effects of the BOJ's monetary policy on the risk premiums for Japanese banks in the short-term money markets, as well as the long-term credit markets like the credit default swap (CDS) and the stock markets.

Japan has long suffered from an economic slump since the bursting of the bubble economy in the early 1990s. The Tokyo Stock Price Index (TOPIX) fell by about 70 percent from its peak to the low in 2003. Declining asset prices severely hit the financial system, banking sector, in particular. Despite the capital injections of public funds into major banks to address the non-performing loan (NPL) problems, the banking sector did not fully recover until quite recently. Business fixed investment continued to suffer from an excess of the late 1980s and the impaired financial system.

In an attempt to find a breakthrough, the BOJ responded with (i) a lowering of the uncollateralized overnight call rate to 0.5 percent after the end of 1995, (ii) a further lowering to almost zero percent after February 1999 (ZIRP), and (iii) the adoption of "quantitative easing monetary policy (QMEP)" after March 2001. As argued in Baba *et al*. [2005] and Ueda [2005], the ZIRP and QMEP have been an attempt to influence expectations about the future monetary policy, rather than to change today's policy instrument. In this sense, the ZIRP and QMEP are often called an exercise in expectations management or in shaping expectations.

The QMEP had two pillars: (i) provision of ample liquidity with the outstanding balance of current accounts at the BOJ as its operating policy target; and (ii) "a commitment" to maintain the policy until the year-on-year rate of change in the core CPI (core CPI inflation rate) registers zero percent or higher on a sustainable basis.[1] To that end, the BOJ has actively used various types of market operations including a purchasing operation for long-term JGBs. Thus, it seems fair to say that the QMEP augments the ZIRP in terms of both easing effects and expectations management.

Japan's economy finally started recovering in January 2002, and the core CPI inflation rate rose to the surface in October 2005, and turned positive next month. Reacting to these circumstances, the BOJ abandoned the QMEP in March 2006, and returned to the ZIRP.[2]

Given the above nature of the ZIRP and QMEP, some authors tried to estimate the effects of the BOJ's attempt to manage expectations on the JGB yield curve. They share a common framework: a macro-finance approach. Bernanke, Reinhart, and Sack [2004] and Oda and Ueda [2005] are such examples. Under the macro-finance framework, they add a specific macroeconomic structure to the JGB yield curve model. This framework is useful in directly analyzing how some specific macro-factors influence the entire or part of the JGB yield curve. On the other hand, they exclusively rely on the specific macroeconomic structure they choose, which leaves an *ad-hoc* inkling. Also, their models do not seem to closely trace the actual JGB yield curve.[3]

This paper attempts to review the effects of the BOJ's expectations management on the JGB yield curve using a totally different approach from the macro-finance approach: the Black model of interest rates as options. Black [1995] interprets a nominal short-term interest rate as a call option on the "equilibrium" or "shadow" interest rate, where the option is struck at zero percent.

1 The core CPI means the CPI excluding fresh food.
2 The official statement released by the BOJ after the monetary policy meeting on March 9, 2006 is as follows. "The Bank of Japan decided to change the operating target of money market operations from the outstanding balance of current accounts at the Bank to the uncollateralized overnight call rate….The Bank of Japan will encourage the uncollateralized overnight call rate to remain at effectively zero percent."
3 For instance, Bernanke, Reinhart, and Sack [2004] find that the predicted JGB yield curves lie above the actual yield curves after 1999 and the deviation narrows in November 2000 after the end of the ZIRP, and widens again in June 2001 with the adoption of the QMEP. This result implies that their macro-finance model does not closely trace the actual JGB yield curves.

Put differently, Black [1995] argues that the nominal short-term interest rate cannot be negative since currency serves as an option, in that if an instrument should have a negative interest rate, investors choose currency instead. Employing this notion enables us to use an underlying (shadow) spot rate process that can take on negative values and simply replace all the negative values of the shadow interest rate with zeros for the observed short-term nominal interest rate.

The Black model has the following advantages over other types of models such as a macro-finance model. First, we do not need to assume any *ad-hoc* macro-economic structure. Second, we can significantly improve the fitting to the actual JGB yield curve. Third, we can directly incorporate the notion of "a zero lower bound on the short-term nominal interest rate" in a more straightforward manner. Fourth, we can directly assess the time period until the negative shadow interest rate first hits zero as the expected duration time of the ZIRP, as well as the market expectations about the long-run level of the shadow interest rate.[4,5]

While the basic concept of the Black model is quite robust and is appealing particularly to the recent Japanese situation where short-term interest rates have been indeed zero, the model had the disadvantage in that it was analytically intractable.[6] Quite recently, however, Gorovoi and Linetsky [2004] successfully derive the analytical solutions for zero-coupon bonds using eigenfunction expansions under several specifications for the shadow interest rate process. We follow their solutions, and thus we call the model Black-Gorovoi-Linetsky (BGL) model in this paper.

Another important task of the BOJ's monetary policy during the QMEP period was to alleviate concerns over the financial-sector problems. As described in Baba *et al*. [2005], many of the

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4 Further, we do not even need to assume specific distributions for the timing of the policy change.

5 Black [1995] originally recommends applying his model to the U.S. situation in the 1930s, which was also a period of extremely low interest rates. On the other hand, Gorovoi and Linetsky [2004] and Baz, Prieul, and Toscani [1998] strongly recommend applying the Black model to the recent Japanese situation.

6 See Rogers [1995, 96] for this line of criticism.

BOJ's market operations had the dual role of providing ample liquidity and addressing problems in financial sector. In the process, the BOJ assumed a certain amount of credit risk. This paper also assesses the market perceptions about this aspect of the BOJ's policy by observing the price developments in various markets from the short-term money markets to CDS and stock markets. The main objective here is to investigate the time horizons over which the effect of the BOJ's monetary policy extended in calming down the market perceptions about the credit risk for the Japanese banks.

The rest of the paper is organized as follows. Section 2 presents the overview of the price developments in the Japanese financial markets under recent easing monetary policy conducted by the BOJ. Section 3 reviews the effects of the BOJ's monetary policy on the JGB yield curve, paying particular attention to the market perceptions about the BOJ's monetary policy stance. Section 4 investigates the influences of the BOJ's monetary policy on the risk premiums for Japanese banks in the short-term money markets, as well as the CDS and stock markets. Section 5 concludes the paper by discussing the policy implications from the findings in this paper.

2. Recent Price Developments in the Japanese Financial Markets

2.1 BOJ's Monetary Policy and the JGB Yields

First, let me summarize monetary policy actions by the BOJ since the 1990s. The BOJ started to ease in 1991, then lowered the uncollateralized overnight call rate to under 0.5 percent in 1995. This, however, was not enough to counteract deflationary pressures. The BOJ further lowered it to 0.25 percent in 1998, and to effectively zero percent in February 1999, which is the start of the ZIRP. In April 1999, the BOJ promised to maintain the zero interest rates until "the deflationary concerns are dispelled." Then, Japan's economy recovered, growing at 3.3 percent between the third quarter of 1999 and the third quarter of 2000. Consequently, the BOJ abandoned the ZIRP in August 2000.

Japan's economy, however, went into a serious recession again, together with other advanced economies, led by worldwide declines in the demand for high-tech goods as an aftermath of the bursting of the "IT bubbles."

To cope with the deflationary pressures, the BOJ introduced the QMEP in March 2001. The QMEP consisted of (i) supplying ample liquidity using the current account balances (CABs) held by the financial institutions at the BOJ as the operating policy target, and (ii) the commitment to maintain ample liquidity provision until the core CPI inflation rate becomes zero or positive on a sustainable basis. The target for the CABs was raised several times, reaching 30-35 trillion yen in January 2004, which amounts to more than five times of the required reserves. Consequently, the actual CABs rose substantially under the QMEP, as shown in Chart 1. To meet the target, the BOJ conducted various purchasing operations for instruments such as bills and CP, in addition to treasury bills (TBs) and long-term JGBs.[7]

The overnight call rate declined to 0.01 percent under the ZIRP, and declined further to 0.001 percent under the QMEP. Medium- and long-term interest rates also substantially declined, as shown in Chart 2. Interest rates in Japan are also quite low in comparison with other countries like the United States and Germany, as shown in Chart 3.[8] The BOJ abandoned the QMEP on March 9, 2006, and returned to the ZIRP.

2.2 Interest Rates in the Short-Term Money Markets

Next, let me look at the interest rates in the short-term money markets. First, credit risks of Japanese and non-Japanese banks are expected to be priced in TIBOR and LIBOR, since the

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[7] The three building blocks of QMEP, (i) ample liquidity provision, (ii) the commitment to maintain ample liquidity provision, and (iii) the use of various types of market operations, a purchasing of long-term JGBs, in particular, roughly correspond to the three policy prescriptions for stimulating the economy without lowering current interest rates, proposed by Bernanke and Reinhart [2004].

[8] As shown in Baba *et al.* [2005], long-term JGB yields in recent years are also lower than long-term U.S. government bond yields in the 1930s.

majority of referenced banks for TIBOR and LIBOR are Japanese and non-Japanese banks, respectively.[9] Indeed, the so-called "Japan premium," generally defined as the spread between TIBOR and LIBOR (TL spread), rose sharply to nearly 100 bps in U.S. dollars and 40 bps in Japanese yen at the height of the Japanese financial crisis in 1997-98.[10] The Japan premium was also considered to reflect non-Japanese major banks' skepticism on opaque Japanese accounting and banking supervision system beyond a simple relative indicator of credit risk, as suggested by Ito and Harada [2004]. As shown in Chart 4, the TL spread has fluctuated around zero since the adoption of the ZIRP in 1999. Another noteworthy point here is as follows. Around 2001 to 2002, concerns over the instability of Japanese banks became highlighted again mainly due to their low earnings and newly emerging nonperforming loans. This time, however, the TL spread did not widen at all. Ito and Harada [2004] assert that the TL spread lost its role as an indicator of the market perceptions about the vulnerability of Japanese banks.

Another important indicator of credit risks for Japanese banks is the interest rates on the negotiable certificates of deposits (NCDs). NCDs are debt instruments issued by banks including city, regional, trust, and foreign banks in Japan. They were the first-ever product with deregulated interest rates in Japan and since they are uninsured by the deposit insurance, the NCD interest rates are expected to reflect credit risks for issuing banks.[11] Chart 5 plots the spread of NCD interest rate over the BOJ's target level of the uncollateralized overnight call rate, together with the TIBOR spread over the same target call rate. Note here that since the adoption of the QMEP, both NCD and TIBOR spreads have remained stable at a very low level with only one temporary spike toward the end of fiscal year 2001, despite of the reemergence of the financial instability around 2001 and

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[9] TIBOR and LIBOR are Tokyo Interbank Offered Rate and London Interbank Offered Rate, respectively. See Baba and Nishioka [2005] and Ito and Harada [2004] for more details about LIBOR and TIBOR.

[10] The following financial institutions failed in 1997: Sanyo Securities (November 3), Hokkaido Takushoku Bank (November 17), Yamaichi Securities (November 24), and Tokuyo City Bank (November 26). The concern over the financial stability continued until Long-term Credit Bank of Japan (October 23, 1998) and Nippon Credit Bank (December 12, 1998) were nationalized.

[11] See Baba *et al*. [2006] for more details about the NCD market in Japan.

2002.

2.3 Longer-Term Credit Spreads

Third, let me turn to the long-term credit spreads. As shown in Chart 6, credit spreads of corporate bonds over the JGB yields with the same maturity have narrowed since the adoption of the ZIRP. From this chart, we can observe two significant surges in the credit spreads particularly on BBB-rated bonds. The first surge was from the end of 1997 to 1999, as in the TL and NCD spreads (Charts 4 and 5). The second surge occurred around 2002. This period also corresponds to the period of financial instability, as mentioned above.[12] Since around 2003, credit spreads have substantially narrowed and the narrowing has extended even to corporate bonds with a BBB credit rating. Baba *et al*. [2005] show that credit spreads have barely covered *ex post* default risks for such bonds with relatively lower ratings. Despite such favorable conditions for issuers, the issue amounts of corporate bonds have not increased much.

Wrapping up the developments in the short-term money markets, JGB markets, and corporate bond markets, the following observation can be made, as argued by Baba *et al*. [2005]. Declines in short-term interest rates forced Japanese investors to look for higher yields by taking various risks in other markets. They first turned to the duration risk by investing their funds in longer-term JGBs. With the decline in long-term JGB yields, however, they began to expect large potential capital losses in the event of a reversal of interest rates. Facing such circumstances, Japanese investors next turned to credit instruments such as corporate bonds. Their active investments in these instruments have substantially narrowed credit spreads even for bonds with relatively low ratings.[13]

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[12] Also, MYCAL Corporation filed for bankruptcy protection in September 2002, which worsened the sentiments of the overall credit markets.

[13] This investment behavior is sometimes called “reach for yield,” investing in assets with returns too low to be justified by rational economic agents. Nishioka and Baba [2004] support the existence of this type of

2.4 Stock Prices

Fourth, Chart 7 shows stock price indices: TOPIX and the stock price index of the banking sector. Both indices has exhibited a very similar movement since 1995, but the bank index experienced much severer slumps in the financial crisis of the late 1990s and in the period of financial instability around 2001 to 2002. The similar movement is due mainly to the large capitalization share of bank stocks in the TOPIX, but we should not overlook the fact that a large decline in the stock prices itself triggered the financial instability in September 2001, particularly when the TOPIX declined below the 1,000 mark. Not surprisingly, the stock prices of the banks with large stock-holdings substantially fell in this period. Then, as the disposal of NPLs gradually progressed, the stock prices of banks started to recover from the start of 2003. The TOPIX have returned to almost the same level in January 2006 as in January 1995, but the bank index remains at about 60 percent of the value as of January 1995.[14]

3. The BOJ's Monetary Policy and the JGB Yield Curve

3.1 JGB Yield Curve

This section reviews the effects of the BOJ's monetary policy on the JGB yield curve with a particular attention given to quantitatively assessing the JGB market perceptions about the BOJ's monetary policy. First, Chart 8 displays the transition of the JGB yield curve since the start of the ZIRP in February 1999. Evidently, the flattening of the JGB yield curve, together with an overall downward shift, sufficiently progressed under the ZIRP and QMEP until the middle of 2003. As a result, conventional yield curve models such as Vasicek or CIR (Cox, Ingersoll, and Ross) models

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activity by investigating the pricing in the Japanese government and corporate bond markets using the three-factor CAPM, where mean, variance, and skewness of returns are evaluated in determining the optimal portfolio.

[14] Ito and Harada [2006] provide a detailed survey of the developments in the bank stock prices from the late 1990s.

no longer successfully trace the changing shape of the JGB yield curve.[15] Extremely low levels of the short- and medium-term interest rates reflect the market participants' perceptions about the duration of the ZIRP, which has been explicitly committed to be sought after with the core CPI inflation rate as a policy guideline by the BOJ under the QMEP. In fact, the thrust of the ZIRP and QMEP lies in "managing expectations," as argued by Baba *et al.*[2005] and Ueda [2005]. In what follows, let me review the estimation results from applying the Black model of interest rates as options to the JGB yield curve. The model turned to be very useful in fitting to the extremely flattened JGB yield curve and quantitatively assessing the duration time of the ZIRP expected by the JGB market without adding any *ad hoc* macroeconomic structure to the model.

3.2 The Black Model of Interest Rates as Options

Black [1995] assumes that there is a shadow instantaneous interest rate that can become negative, while the observed nominal interest rate is a positive part of the shadow interest rate. The rationale for this assumption is quite straightforward. As long as investors can hold currency with zero interest rates, nominal interest rates on other financial instruments must remain non-negative to rule out arbitrage. Specifically, the observed nominal interest rate r_t can be written as

$$r_t = \max\left[0, r_t^*\right] = r_t^* + \max\left[0, -r_t^*\right], \qquad r_0^* = r \tag{1}$$

where r_t^* is the shadow interest rate. The relationship between r_t and r_t^* is illustrated in Chart 9. In other words, equation (1) shows that the observed nominal interest rate can be viewed as a call option on the shadow interest rate that is struck at zero percent. Also, the second equality in equation (1) tells us that the observed nominal interest rate can be expressed as the sum of the shadow interest rate and an option-like value that provides a lower bound for the nominal interest rate at zero percent when the shadow interest rate is negative. We call this option-like value as the

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15 See Vasicek [1977] for the Vasicek model, and Cox, Ingersoll, and Ross [1985] for the CIR model.

floor value in this paper, following Bomfim [2003]. In other words, the floor has the option to switch investors' bondholdings into currency, if r_t^* falls below zero.

Under normal circumstances, r_t^* is sufficiently above zero so that the floor value in equation (1) can be safely ignored. When the short-term nominal interest rates are at zero or near zero, however, long-term interest rates embed more-than-usual term premiums and thus the expectations about the future movements of the short-term interest rates.

The slope of the term structure for time to maturity T can be written by

$$R(r, T) - r_0 = \frac{1}{T}\int_{s=0}^{T} f(r, s)ds - \max[0, r], \tag{2}$$

where $R(r, T) - r_0$ can thus be interpreted as the value of a portfolio of options since $R(r, T)$, the yield-to-maturity, is an average of instantaneous forward rates, $f(r, s)$ ($s = 0, \ldots T$) and each of the forward rates exhibits option properties. More specifically, $f(r, s)$ can be viewed as

$$f(r, s) = \mathrm{E}_r[r_s] + \text{forward premium} + \text{floor value}, \tag{3}$$

where $\mathrm{E}_r[\bullet] \equiv \mathrm{E}[\bullet | r_0^* = r]$. As discount bond prices are derived from forward rates, the floor value is compounded all over the yield curve, resulting in a steeper yield curve than the curve that could be expected should currency not exist.

How should we interpret the shadow interest rate in the Black model? Let me first present the view of Black [1995] himself.[16] Suppose the situation where the equilibrium nominal interest rate that clears the saving-investment gap is negative. Chart 10 illustrates such a situation for a given rate of expected inflation. This situation is akin to the so-called liquidity trap, where under deflationary pressures, very low nominal interest rates cause people to hoard currency. As a result, it neutralizes monetary policy attempts to restore full employment.[17] In Chart 10, savings and investments, or supply and demand of capital, are equal at a negative value of r^*. The prevailing

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[16] Bomfim [2003] and Baz, Prieul, and Toscani [1998] follow this interpretation.

[17] See Keynes [1936], Hicks [1937], and Robertson [1948] for classical debates about the liquidity trap. For the recent Japan's case, see Krugman [1998] and Baz, Prieul, and Toscani [1998].

interest rate is zero, however, since currency exists. This leaves the saving-investment gap uncleared. The real-life examples of such situations include the United States during the Great Depression in the 1930s (Black [1995], Bernanke [2002]), and Japan since the 1990s (Krugman [1998]).

Second, the shadow interest rate may just give us a clue to finding the time until the short-term interest rate becomes positive again, given that the current shadow interest rate is negative. In this sense, the expected time for the negative shadow interest rate becomes positive again (first-hitting time) is roughly regarded as the duration time of the ZIRP perceived by the JGB market participants. Note here that if the JGB market participants think that the BOJ continues the ZIRP until Japan's economy surely breaks away from the liquidity trap, both interpretations coincides each other. Considering the BOJ's official statement "until deflationary concerns are dispelled," and the BOJ's cautiousness in setting monetary policy, the JGB market participants are likely to think so.

On the other hand, the Black model of interest rates as options had the disadvantage in that it was analytically intractable. In fact, Rogers [1995, 1996] criticizes the Black model for this reason and favors the models with a reflecting boundary at the zero interest rate, despite the criticism to them on economic grounds.[18] Gorovoi and Linetsky [2004], however, show that the Black model is as analytically tractable as the reflecting boundary models, and successfully obtain the analytical solutions for zero-coupon bonds under several specifications for the shadow interest rate process. Also, Linetsky [2004] finds the analytical solution to the first-hitting time until the negative shadow interest rate reaches zero.[19] Thus, let me call the Black model with an analytical solution by Gorovoi and Linetsky [2004] BGL model and review some results obtained for the JGB yield curves using the BGL model in what follows.

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18 Black [1995] argues that when the zero interest rate is a reflecting boundary, the rate "bounces off" zero, and this seems strange in terms of a real economic process.

19 See Appendix 1 for technical details.

3.3 Estimation Results of the BGL Model

3.3.1 Fixed-Parameter BGL Model

First, Ichiue and Ueno [2006] estimate the following model with the fixed parameters throughout the sample period from January 1995 to December 2005, using the end-of-month JGB yields. They assume that under the actual probability P, r_t^* follow a process given by

$$dr_t^* = \kappa^P\left(\theta^P - r_t^*\right)dt + \sigma\, dB_t^P, \tag{4}$$

$$\lambda_t = \delta_0 + \delta_1 r_t^*, \tag{5}$$

where θ^P is the long-run level of the shadow interest rate that is likely to reflect the views of market participants about the future state of the real economy, κ^P is the rate of mean reversion toward the long-run level, and σ is the volatility parameter. Also, λ_t denotes the market price of risk, and δ_0 and δ_1 denote the parameters to be estimated. With this choice of market price of risk, r_t^* follows an Ornstein-Uhlenbeck process under both the actual probability P and the risk-neutral probability Q. Specifically, under Q,

$$dr_t^* = \kappa^Q\left(\theta^Q - r_t^*\right)dt + \sigma\, dB_t^Q, \tag{6}$$

where $\kappa^Q = \kappa^P + \delta_1\sigma$ and $\kappa^Q\theta^Q = \kappa^P\theta^P - \delta_0\sigma$. They estimate the parameters using the Kalman filter after linearizing the model.[20] For estimation, they use the JGB yields with 0.5- 2-, 5-, and 10-year maturities, as well as the collateralized overnight call rate.[21]

Chart 11 (i) reports the parameter estimates. All of the parameters are estimated with expected signs and are significant except for δ_1. Next, Chart 11 (ii) exhibits the estimated shadow interest rate, together with the core CPI inflation rate, and the corresponding first-hitting time. The noteworthy points here are as follows. First, the shadow interest rate declined and reached zero percent for the first time in late 1995, and fluctuated around zero percent until 1997. Since then, it

[20] See Appendix 2 for technical details. Throughout the paper, we use the discount bond yields estimated from the prices of coupon bonds with 5-, 10-, and 20-year maturities at issue using McCulloch [1971] method. The data source is the Japan Securities Dealers Association

[21] The collateralized call rate plays the role of guiding the shadow interest rate when the shadow rate is positive. See Appendix 2 for more details.

had been on a consistent downtrend until the middle of 2003. Then, it turned around and has been on an uptrend. If we follow the interpretation by Black [1995], the depth of the negativity of the shadow interest rates implies the degree to which the economy is perceived to be in a liquidity trap by market participants. Second, the shadow interest rate seems to have closely followed the core CPI inflation rate with several-month lags since early 2001.[22] In March 2001, the BOJ introduced the explicit commitment stating that it would continue the QMEP until the core CPI inflation rate become zero or higher on a sustainable basis. A seemingly higher lagged correlation between the shadow interest rate and the CPI inflation rate since early 2001 is likely to capture the commitment effect perceived by the JGB market participants. Third, as of December 2005, the first-hitting time is estimated to be about 10 (11) months under the actual (risk-neutral) probability $P(Q)$.[23] Thus, under both probabilities, the fixed-parameter BGL model implies that the ZIRP will be abandoned within the year 2006, which seems very plausible judging from the current market observations.

3.3.2 Day-to-Day Calibration Results

Next, Ueno, Baba, and Sakurai [2006] calibrate the BGL model to the JGB yield curve on a day-to-day basis from the start of the QMEP through February 28, 2006. This calibration aims to capture a more accurate measure of the first-hitting time by taking account of time-series movement of the BGL model parameters.[24,25] In particular, we are interested in the movement of

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22 Note that the release of the CPI data is delayed by approximately 2 months.

23 Since the market price of risk is estimated to be negative throughout the sample period, the first-hitting time is longer under the actual probability than under the risk-neutral probability, since θ is smaller under the actual probability. The market price of risk is usually negative the yield curve models.

24 Maturity grids we use here are 0.5, 1, 2, 3, 5, 7, 10, 15, 18, and 20 years, instead of overnight (call rate), 0.5, 2. 5, and 10 years in the case of the fixed-parameter BGL model. Thus, the day-to-day calibration is expected to provide more accurate estimates of the BGL parameters in this regard, too.

25 In fact, empirical performance of the BGL model is much better than the original Vasicek model. The sample average of squared errors from the BGL model is less than one-third of that from the original Vasicek model. Also, quite interestingly, the difference in empirical performance between these models narrows when the first-hitting time derived by the BGL model is less than one year, which corresponds to the periods from the middle to the end of 2003 and from the middle of 2005 onwards. See Ueno, Baba, and Sakurai [2006] for more details.

θ, the long-run level of the shadow interest rate, which is likely to reflect the market perceptions about the long-run real economic activity, together with the long-run target level of the call rate for the BOJ perceived by the JGB market participants.

First, Chart 12 plots the long-run level of the shadow interest rate θ under the risk-neutral probability Q, estimated using day-to-day calibration of the BGL model to the JGB yield curve. θ seemingly exhibits a mean-reverting movement. Since September 2001, it had fallen and reached almost zero percent in the middle of 2003, and then it had bounced back to about 3 percent until the middle of 2005. The overall movement of θ is consistent with the following anecdotal market observations. The JGB market participants were deeply concerned about the falling economic growth until the middle of 2003, and since then they have begun to price in the economic recovery.[26]

Second, Charts 13 and 14 exhibit the first-hitting time and the corresponding ending date of the ZIRP estimated by the BGL model, respectively. For comparison, we also show the first-hitting time implied by the euro-yen interest rate futures in Chart 13. The two threshold points in time that we regard as the end of the ZIRP are as follows: (i) when the euro-yen interest rate futures exceeds 0.51 percent, which corresponds to the average rate when the target for uncollateralized overnight call rate was 0.25 percent (August 2000-February 2001); and (ii) when the euro-yen interest rate futures exceeds 0.19 percent, which corresponds to the average rate when only the ZIRP was in place (February 1999-August 2000). As shown in Chart 13, the first-hitting time estimated by the BGL model is basically within the band between the two first-hitting times implied by the euro-yen futures.[27] This result shows the relevance of the BGL model as a tool for monitoring market perceptions about the BOJ's monetary policy. In particular, since around September 2005, the first-hitting time estimated by the BGL model has shown a very close

[26] See Nakayama, Baba, and Kurihara [2004] for these anecdotal JGB market observations.
[27] Missing values of euro-yen futures before the fiscal year 2003 are due to no transactions occurring.

movement and level to the lower bound of the first-hitting time implied by the euro-yen futures. As of February 28, 2006, the first-hitting time estimated by the BGL model is about 3 months under the risk-neutral probability. This means that the JGB market participants expect that the ZIRP ends around the end of April 2006 at the earliest, as shown in Chart 14.[28]

4. The BOJ's Monetary Policy and Risk Premiums for Japanese Banks

This section investigates the effects of the BOJ's monetary policy on the risk premiums for Japanese banks in a wide range of financial markets from the short-term money markets to the long-term CDS and stock markets.

4.1 NCD Interest Rates

4.1.1 Dispersion of NCD Interest Rates across Banks

First, let me review the analysis by Baba *et al.* [2006] that explore the effects of the BOJ's monetary policy on the NCD interest rate. Major Japanese banks recently raise about 30 percent of their total market funding by issuing NCDs. Thus, NCDs can be thought of as one of their principal instruments for meeting liquidity needs.

Interest rates on major banks' newly issued NCDs had served as a main indicator for deregulated interest rates, although they had moved broadly in tandem across banks for some time since the first NCDs were issued in May 1979. That is, the NCD interest rates had not reflected the differences in bank credit risks. Since the 1990s, however, the NCD interest rates had started to reflect the credit risk of individual issuing banks, due mostly to the rising concern over the instability of the Japanese financial system. Such concern heightened during the period from the late 1997 to 1998. This is shown in Chart 15 by substantial spikes in the dispersion as measured by the

[28] Note that under the actual probability, the first-hitting time is longer than that under the risk-neutral probability when the market price of risk is negative.

standard deviation of the weekly NCD interest rates across issuing banks in November 1997.[29] The standard deviations declined significantly, however, after the adoption of the ZIRP in February 1999 and have fallen further following the adoption of the QMEP in March 2001.[30]

4.1.2 Credit Curves of NCD Spreads

Next, let me look at the credit curves of NCD spreads. Here, the NCD credit spread for a bank is defined as the interest rate on NCDs issued by the bank with maturities less than 30 days minus the weighted average of uncollateralized overnight call rate. The data frequency is weekly as before. Then, Baba *et al*. [2006] run cross-sectional time-series regressions of the credit spreads on dummy variables corresponding to sample banks' credit ratings for each of the following three years under study: (i) 1999, a year when the ZIRP was put in place, (ii) 2002, one year after the adoption of the QMEP, and (iii) 2004, the last year of their sample period. The estimation includes end-of-March, September and December dummies to control for seasonal market tightness in annual/semi-annual book-closing months and year-end month. The credit spreads for each credit rating category, derived from the coefficients on credit rating dummies along with the constant term, map out the "credit curve" for each year.

Chart 16 demonstrates how the slope of the estimated credit curve became flatter over time.[31] It seems fair to say that the credit curves flattened after the adoption of the ZIRP in 1999, flattened further following the adoption of the QMEP in 2002, and almost flattened out in 2004.

The estimation result indicates that the credit risk premiums among major banks are

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[29] The standard deviation of the NCD interest rates with maturities less than 30 days is plotted in Chart 15. It is the most liquid maturity zone of the NCDs in Japan. Baba *et al*. [2006] further report a similar result for other maturity zones including less than 60 days and 90 days. Sample banks are 11 city and trust banks for which weekly NCD interest rates are available.

[30] In calculating the averages of standard deviations, the following event dates are excluded for institutional reasons: (i) the end of 1999 (Y2K problem); (ii) the end of 2000 (preparation for the adoption of RTGS (Real Time Gross Settlement); and (iii) the end of fiscal 2001 (the partial removal of blanket deposit insurance). Evidently, significant spikes are observed on these three dates.

[31] Sample banks are the same as in Chart 15.

recently close to zero, and that the differences in credit ratings among them are now hardly reflected in their fund-raising costs in the money market such as NCD market. Therefore, the narrowed dispersion of fund-raising costs among banks, shown in Chart 15, is more likely to be a result of declines in risk premiums across the board in the money market, rather than a result of a lowered dispersion of credit ratings among major banks.

Chart 17 shows the credit curves of commercial paper (CP) spreads with one-month maturity over the uncollateralized overnight call rate as a representative short-term funding measure for non-financial corporations.[32] As in the case with NCD spreads, the credit curves have become flatter over time in credit ratings between a-1+ and a-2. There are, however, significant spreads remaining at ratings of below a-1.[33] Also, note that the difference in CP spreads between a-2 and a-1 amounts to ten times as large as the largest one-notch difference in NCD spreads. This result suggests that monetary policy alone cannot create an almost perfectly accommodate environment for corporate finance unlike for banks, no matter how strong easing policy is put into place.

Although to quantitatively address the role played the BOJ's monetary policy in the flattening NCD credit curves is a formidable task, Baba *et al*. [2006] assess it by a pooled analysis, allowing the slope of the credit curves to depend on the variables related to the BOJ's monetary policy. Let me briefly summarize their analysis below. The policy variables we include are dummy variables corresponding to the ZIRP and QMEP periods, the level of aggregate CABs, and the average maturity of the BOJ's bill-purchasing operations.[34]

Estimation is done for seven banks for which the long-term bond spread data are available.

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32 Number of observations is 2,327 for 2002, 1,975 for 2003, and 2,006 for 2004, respectively.

33 Another interesting finding is the tightened CP spread between a-1+ and a-1. This is due mainly to the market perception that most of the CP eligible for the fund-supplying operations by the BOJ has a-1 or higher ratings.

34 The rationale behind the inclusion of the average maturity of the BOJ's bill-purchasing operations is as follows. At times of low demand for liquidity by financial institutions, the BOJ had to offer longer-dated operations to meet the target on the CABs. In this sense, the variable may be regarded as a proxy for an *ex ante* "excess supply" of liquidity in the money market.

The result shows that even after controlling for the effect of the long-term bank bond spreads, monetary policy variables, particularly the ZIRP and QMEP dummy variables, as well as the average maturity of the BOJ's bill-purchasing operations, significantly contributed to the decline in risk premiums across the board, as well as the flattening of the credit curves in the NCD market.

4.2 Risk Premiums for Japanese Banks in the CDS and Stock Markets

Last, let me look at the CDS market as a longer-term market for bank credit risk, as well as the stock market. There has been a widespread use of the stock prices in assessing the default probabilities for corporations using structural models that have their origin in Merton [1974]. In addition, as argued by Ito and Harada [2004], due to the recent expansion of CDS trading for Japanese banks, CDS spreads are now regarded as reflecting credit risks of Japanese banks much more sensitively than straight bond spreads and the Japan premium (TL spread). The typical maturity of CDS contracts for Japanese entities is 5 years. We can use the so-called reduced-form model to estimate default probabilities from the CDS spreads.

Ueno and Baba [2006a,b] compute the one-year ahead default probabilities for four Japanese mega-banks, namely, Bank of Tokyo-Mitsubishi (BTM), Sumitomo-Mitsui Banking Corporation (SMBC), UFJ Bank (UFJ), and Mizuho Bank (MIZUHO), from CDS spreads and stock prices.[35] Charts 18 and 19 show the results, respectively. Evidently, from late 2001 to 2003, a large and prolonged surge is observed in both markets, in addition to 1998. This is in sharp contrast to the result of NCD interest rate and TL spread, shown in Charts 4 and 5. Putting these results together, we can tentatively conclude that there is something distinct in the perceptions for Japanese

[35] Ueno and Baba [2006b] estimate the default probabilities from the stock prices using the method by Merton [1974]. For the reduced-form model used in Ueno and Baba [2006a] to estimate the default probabilities from the CDS spreads, see Appendix 3. Ueno and Baba [2006a] also estimate expected recovery rates, jointly with the default intensities, using both senior and subordinated CDS spreads. The BTM merged with the UFJ into the Bank of Tokyo-Mitsubishi UFJ in April 2006. Since our sample is up to the end of March 2006, we can separately treat the BTM and the UFJ.

banks in the short-term money market, compared with other markets including the CDS and stock markets.

Ueno and Baba [2006a] further explore the relationship between the "systemic" nature of Japanese bank credit risk and the government.[36] Specifically, our strategy is to extract a latent common factor from the estimated default intensities for the four banks by factor analysis, and compare the common factor with the default intensity for the Japanese government.[37] The result is displayed in Chart 20. Surprisingly enough, these two default risk indices are almost perfectly correlated each other with the correlation coefficient of higher than 0.95. Implications derived from these findings are discussed in the next section.

5. Concluding Remarks

This paper has reviewed the financial market functioning under the ZIRP and the subsequent QMEP conducted by the BOJ. In doing so, particular attention is given to assessing market perceptions about the duration of the BOJ's monetary policy and its effects on risk premiums for Japanese banks. Main findings are as follows.

First, the estimation results of the JGB yield curve using the BGL model show that (i) the shadow interest rate have been negative since the late 1990s, turned around upward in 2003, and has been on an uptrend since then, and (ii) the first-hitting time until the negative shadow interest rate hits zero again under the risk-neutral probability is estimated to be about 10 months as of

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[36] A noteworthy feature of the CDS contracts for Japanese entities is that Japanese sovereign contracts have been traded very actively. As shown by Packer and Suthiphongchai [2003], from 2000 to 2003, total number of CDS quotes for Japanese sovereign bonds amounts to 2,313, which corresponds to the third place only after Brazil and Mexico. This fact, along with successive downgrades of the credit rating on Japanese sovereign bonds, shows investors' deep concerns over the financial standing of the Japanese government itself facing prolonged deflation since the bursting of the bubble economy in the early 1990s, and the ensuing structural problems, such as the fragile financial system.

[37] The estimation result of the factor analysis shows that the first factor whose factor loadings are almost equal across the four banks contributes more than 90 percent of the total variation of the default intensities for the four banks. Thus, it seems quite natural to regard this first factor as the "systemic risk (common) factor."

end-December 2005 from the fixed-parameter model, and about 3 months as of the end of February 2006 from the day-to-day calibration. Second, under the ZIRP and QMEP, the risk premiums for Japanese banks have almost disappeared in the short-term money markets, while they have remained in the long-term markets such as the CDS, as well as the stock market.

Here, the next question we should address is the following: "why the short-term money market prices such as NCD interest rate and TL spread did not show a surge in the period of financial instability under the QMEP, unlike the default probabilities derived from the long-term CDS spreads and stock prices?" Let me conclude this paper by raising two hypotheses to address this question and briefly commenting one by one.[38]

The first hypothesis is raised by Baba *et al.* [2006]. That is, "the participants in the Japanese money markets positively perceive the role of the BOJ's ample liquidity provisions under the QMEP in containing the near-term defaults of banks caused by the liquidity shortage." This hypothesis seems to be supported by the findings about NCD credit curves reviewed in this paper. Let me briefly comment on this issue below.

There are two possible effects of the BOJ's monetary policy on bank credit risk. The first effect is that easy monetary policy raises asset prices and lowers risk premiums. This effect is very general. But, the second one is rather specific to the QMEP conducted by the BOJ. The policy package under the QMEP, namely, the strong commitment to maintain a zero interest rate as well as the provision of ample liquidity, substantially contained the risk that banks fail to meet short-term payment obligations, which is likely to make the near-term chance of a default smaller.

An interesting thing to note here is that the default probabilities observed in the

[38] In this regard, Ito and Harada [2004] raise the following two hypotheses. The first one is that "Japanese banks have been required to put up cash collaterals to raise dollars in the money markets since around 2000-2001." The second one is that "weaker banks have exited from the international money markets." Both of these hypotheses may be the case, but are not necessarily verified. For instance, if the second hypothesis is the case, why had the CDS and equity markets implied high default probabilities for Japanese mega-banks until quite recently?

long-term CDS and stock markets significantly surged during the period of financial instability even under the QMEP. We also find that the common factor derived from the default intensities of the Japanese four maga-banks is almost perfectly correlated with the default intensity of the Japanese government. This empirical result seems to be suggestive of the difference in the role between the government and the BOJ in addressing the problem of financial instability around 2001 to 2003: the government played the leading role in addressing the long-term financial standing (solvency) of the Japanese financial institutions, while the BOJ played the role in addressing the short-term liquidity shortage of the Japanese financial institutions.

The second (somehow negative) hypothesis is that the BOJ's QMEP just have paralyzed the functioning of short-term money markets in that banks do not need to raise short-term liquidity from markets and thus do not need to evaluate their counterparties' risk properly. This is because the BOJ provide too much money to meet the target for the CABs. This hypothesis is hard to be tested. But, Baba *et al.* [2005] imply the validity of this hypothesis, saying that "as financial institutions have become more and more dependent on the BOJ's fund-supplying market operations, the size of the call market, which had already shrunk under the ZIRP, has contracted further since the adoption of the QMEP.[39]

[39] The daily trading volume in the uncollateralized call market was about 7.4 trillion yen before the adoption of the QMEP. Since then, it has gradually declined, reaching 1.3 trillion yen in April 2004. The amount outstanding also declined from 17.9 trillion yen to 5.0 trillion yen during the same period.

Appendix 1: Gorovoi and Linesky's Analytical Solution to the Black Model

This appendix briefly describe the analytical solution by Gorovoi and Linetsky [2004] to the Black model of interest rates as options, as well as the framework by Linetsky [2004] to calculate the first-hitting time until the negative shadow interest rate reach zero.

(i) Analytical Solution to the Black Model

We adopt the Vasicek model for the shadow interest rate under the risk-neutral probability:

$$dr_t^* = \kappa(\theta - r_t^*)dt + \sigma\, dB_t\,,\quad r_0^* = r \tag{A-1}$$

where θ is the long-run level of the shadow interest rate, κ is the rate of mean reversion toward the long-run level, and σ is the volatility parameter.

Note that the discount bond price can be given by

$$P(r,T) = \mathrm{E}_r\left[\exp\left\{-\int_{s=0}^{T} r_s\, ds\right\}\right] = \mathrm{E}_r\left[\exp\left\{-\int_{s=0}^{T} \max[0, r_s^*]ds\right\}\right], \tag{A-2}$$

where $\mathrm{E}_r[\bullet] \equiv \mathrm{E}[\bullet | r_0^* = r]$, and T is time to maturity. (A-2) has the form of the Laplace transform of an area functional of the shadow interest rate diffusion:

$$A_t \equiv \int_0^t \max[0, r_s^*]ds\,. \quad t \geq 0 \tag{A-3}$$

The area functional measures the area below the positive part of a sample path of the interest rate process up to time t. Thus, the discount bond price can be calculated as

$$P(r,T) = \mathrm{E}_r[\exp(-A_T)]. \tag{A-4}$$

To calculate the discount bond price (A-4), the spectral expansion approach is used. The discount bond price $P(r,T)$ as a function of time to maturity T, and the initial shadow interest rate r, solve the fundamental pricing partial differential equation:

$$\frac{1}{2}\sigma^2 P_{rr} + \kappa(\theta - r)P_r - \max[0, r^*]P = P_T\,, \tag{A-5}$$

subject to the initial condition $P(r,0) = 1$. The solution has the eigenfunction expansion:

$$P(r,T) = \mathrm{E}_r[\exp(-A_T)] = \sum_{n=0}^{\infty} c_n \exp(-\lambda_n T)\varphi_n(r), \tag{A-6}$$

$$c_n = \int_{-\infty}^{\infty} \varphi(r)\frac{2}{\sigma^2}\exp\left(-\frac{\kappa(\theta - r)}{\sigma^2}\right)dr\,. \tag{A-7}$$

Here, $\{\lambda_n\}_{n=0}^{\infty}$ are the eigenvalues with $0 < \lambda_0 < \lambda_1 < \ldots, \lim_{n\to\infty}\lambda_n = \infty$, and $\{\varphi_n\}_{n=0}^{\infty}$ are the corresponding eigenfunctions of the associate Sturm-Liouville spectral problem:

$$-\frac{1}{2}\sigma^2 u''(r) - \kappa(\theta - r)\,u'(r) + \max[0, r^*]\,u(r) = \lambda u(r)\,. \tag{A-8}$$

Here, we have the following asymptotics for large times to maturities:

$$\lim_{T\to\infty} R(r,T) = \lim_{T\to\infty}\left(-\frac{1}{T}\ln P(r,T)\right) = \lambda_0 > 0\,. \tag{A-9}$$

As time to maturity increases, the yield curve flattens out and approaches the principal eigenvalue λ_0. Here, the principal eigenvalue is guaranteed to be strictly non-negative.

(ii) First-Hitting Time to Zero Shadow Interest Rate

The first-hitting time is defines as

$$\tau_0 \equiv \min\left[t \geq 0;\, r_t^* = 0\right]. \tag{A-10}$$

Linetsky [2004] calculates the probability distribution function (PDF) of the first-hitting time for the Vasicek process using the eigenfunction expansion method. In this paper, we use the mode value of the estimated PDF as the representative value of market perceptions about the first-hitting time τ.

To calculate the PDF of the first-hitting time, Linetsky [2004] uses the eigenfunction expansion approach. Suppose that $r_0^* = r < 0$ and $t > 0$, the PDF of the first-hitting time can be written as

$$f_{\tau_0}(t) = \sum_{n=1}^{\infty} d_n \gamma_n \exp(-\gamma_n t), \quad t \geq 0, \tag{A-11}$$

where $\{\gamma_n\}_{n=0}^{\infty}$ are the eignvalues with $0 < \gamma_0 < \gamma_1 < \ldots < \lim_{n\to\infty} \gamma_n = \infty$. Here, $\{d_n\}_{n=0}^{\infty}$ are explicitly given as

$$d_n = -\frac{H_{\frac{\gamma_n}{n}}\left(\sqrt{\kappa}(\theta - r)/\sigma\right)}{\frac{\gamma_n}{n}\frac{\partial}{\partial\gamma}\left[H_\gamma\left(\sqrt{\kappa}\theta/\sigma\right)\right]\Big|_{\gamma=\frac{\gamma_n}{n}}}, \tag{A-12}$$

where $H_\gamma(\bullet)$ denotes the Hermite function.

Appendix 2: Fixed-Parameter BGL Model

This appendix briefly describes the basic setup for the fixed-parameter BGL model used in Ichiue and Ueno [2006]. Under the actual probability P, r_t^* is assumed to follow a process given by

$$dr_t^* = \kappa^P\left(\theta^P - r_t^*\right)dt + \sigma\, dB_t^P, \tag{A-13}$$

$$\lambda_t = \delta_0 + \delta_1 r_t^*, \tag{A-14}$$

where λ_t denotes the market price of risk. With this choice of market price of risk, r_t^* follows an Ornstein-Uhlenbeck process under both the actual probability P and the risk-neutral probability Q. Specifically, under Q,

$$dr_t^* = \kappa^Q\left(\theta^Q - r_t^*\right)dt + \sigma\, dB_t^Q, \tag{A-15}$$

where $\kappa^Q = \kappa^P + \delta_1\sigma$ and $\kappa^Q\theta^Q = \kappa^P\theta^P - \delta_0\sigma$.

Discretizing (A13) gives the following transition equation:

$$r_{t+h}^* = \mu + \Phi r_t^* + \eta_{t+h}, \tag{A-16}$$

$$\mu = \theta^P\left(1 - \exp\left(-\kappa^P h\right)\right), \tag{A-17}$$

$$\Phi = \exp\left(-\kappa^P h\right). \tag{A-18}$$

η_t is assumed to be normally distributed with mean zero and standard deviation σ_η, where

$$\sigma_\eta = \sigma\sqrt{\frac{1-\exp\left(-2\kappa^P h\right)}{2\kappa^P}}. \tag{A-19}$$

Let R_t denote a 5-dimensional vector with the observed interest rates at time *t*. We use the observed JGB yields with 0.5- 2-, 5-, and 10-year maturities, as well as the collaterized overnight call rate as R_t. The measurement equation for R_t is then given by

$$R_{t+h} = z\left(r_{t+h}^*\right) + \varepsilon_{t+h}, \quad \mathrm{Var}_t\left(\varepsilon_{t+h}\right) = H_t. \tag{A-20}$$

Here, $z\left(r_{t+h}^*\right)$ is a function that relates the shadow interest rate to the observed rates, and ε_{t+h} is a measurement error vector. The errors are assumed to be normally distributed with mean zero and standard deviation σ_ε for each yield, where σ_ε is a constant to be estimated. Note that the function $z\left(r_{t+h}^*\right)$ is non-linear due to the use of the BGL model.

As in Duffee [1999], we use a Taylor approximation of this function around the one-period forecast of r_{t+h}^* to linearize the model:

$$R_{t+h}^{ON} = \alpha_{t+h} r_{t+h}^* + \varepsilon_{t+h}^{ON}, \tag{A-21}$$

$$\alpha_{t+h} = \begin{cases} 1, & if\ \mu + \Phi r_t^* \geq 0 \\ 0, & otherwise \end{cases}, \tag{A-22}$$

$$\tilde{R}_{t+h} = \left(z\left(\mu + \Phi r_t^*\right) - \mu - \Phi r_t^*\right) + z'\left(\mu + \Phi r_t^*\right) r_{t+h}^* + \tilde{\varepsilon}_{t+h}, \tag{A-23}$$

where $\tilde{R}_{t+h}$ is a vector of JGB yields with 0.5- 2-, 5-, and 10-year maturities. The likelihood function is constructed following De Jong [2000].

Appendix 3: Estimation Method of Default Intensity from the CDS Spreads

This appendix describes the setup for the extended Kalman filter estimation to estimate the default intensity from the CDS spreads in Ueno and Baba [2006a]. The model setup follows Pan and Singleton [2005]. Under the actual measure P, λ_t^Q is assumed to follow a process given by

$$d\lambda_t^Q = \kappa^P\left(\theta^P - \lambda_t^Q\right)dt + \sigma^Q\sqrt{\lambda_t^Q}\,dB_t^P \tag{A-24}$$

$$\eta_t = \frac{\delta_0}{\sqrt{\lambda_t^Q}} + \delta_1\sqrt{\lambda_t^Q} \tag{A-25}$$

With this choice of market price of risk η_t, λ_t^Q follows a square diffusion process under both P and Q. Specifically, under Q,

$$d\lambda_t^Q = \kappa^Q\left(\theta^Q - \lambda_t^Q\right)dt + \sigma^Q\sqrt{\lambda_t^Q}\,dB_t^Q, \tag{A-26}$$

where $\kappa^Q = \kappa^P + \delta_1\sigma^Q$ and $\kappa^Q\theta^Q = \kappa^P\theta^P - \delta_0\sigma^Q$. Discretizing (1) gives the following transition equation:

$$\lambda_{t+h}^Q = \mu + \Phi\lambda_t^Q + \eta_{t+h}, \tag{A-27}$$

where $\mu = \theta^P\left(1-\exp\left(-\kappa^P h\right)\right)$ and $\Phi = \exp\left(-\kappa^P h\right)$. η_t is assumed to be normally distributed with mean zero and standard deviations σ_η, where

$$\sigma_\eta = \sigma^Q\sqrt{\left(\frac{1-\exp\left(-\kappa^P h\right)}{\kappa^P}\right)\left(\frac{\theta^P\left(1-\exp\left(-\kappa^P h\right)\right)}{2} + \lambda_t^Q\exp\left(-\kappa^Q h\right)\right)}\,. \tag{A-28}$$

Now, let CDS_t denote an N_t-dimensional vector of the observed CDS spreads at time *t*. The measurement equation for CDS_t is then given by

$$CDS_{t+h} = z\left(\lambda_{t+h}^Q\right) + \varepsilon_{t+h}, \qquad \mathrm{Var}_t\left(\varepsilon_{t+h}\right) = H_t\,. \tag{A-29}$$

Here, $z\left(\lambda_{t+h}^Q\right)$ maps the default intensity into CDS spreads in which we attempt to identify between the default intensity and the expected recovery due to the property of fractional recovery of face value, inherent in the CDS contract.[40] We further identify the difference in the expected recovery rate between senior and subordinated CDS contracts by assuming the proportionally relation each other. The function $z\left(\lambda_{t+h}^Q\right)$ is nonlinear and ε_{t+h} is a measurement error vector. The matrix H_t is an $N_t \times N_t$ diagonal matrix of which *j*-th diagonal element is $\sigma_\varepsilon\left|Bid_{j,t} - Ask_{j,t}\right|$, where N denotes the maturity of the CDS contract.

As in Duffee [1999], a Taylor approximation of this function around the one-period forecast of λ_t^Q is used to linearize the model and we do not assume that the default intensity processes are not stationary. Therefore, we cannot use the unconditional distribution of λ_t^Q to initiate the Kalman filter recursion. Instead, we use a least-squares approach to extract an initial distribution from the first CDS spread observation. Denote this first date as date 0. Then,

$$z\left(\lambda_0^Q\right) \approx z\left(\lambda_0^Q\right) - Z\theta^Q + Z\lambda_0^Q, \tag{A-30}$$

[40] For fractional recovery of face value, see Duffie and Singleton [2003] for details.

where Z is the linearization of z around θ^Q:

$$Z = \left.\frac{\partial z\left(\lambda_0^Q\right)}{\partial \lambda_0^Q}\right|_{\lambda_0^Q=\theta^Q} \tag{A-31}$$

Base on this linearization, we can write the measurement equation for the first date CDS spreads as

$$CDS_0 = z\left(\theta^Q\right) - Z\theta^Q + Z\lambda_0^Q + \varepsilon_0 . \tag{A-32}$$

This equation can be rewritten in terms of λ_0^Q:

$$\lambda_0^Q = \frac{Z'\left(CDS_0 - z\left(\theta^Q\right) + Z\theta^Q\right)}{Z'Z} - \frac{Z'\varepsilon_0}{Z'Z} . \tag{A-33}$$

Thus, the distribution of λ_0^Q is assumed to have mean $Z'\left(CDS_0 - z_0\left(\theta^Q\right) + Z\theta^Q\right)/\left(Z'Z\right)$ and variance $H_0/\left(Z'Z\right)$. Following De Jong [2000], given this initial distribution of unobserved default intensity, the extended Kalman filter recursion proceeds as follows.

Model:

$$CDS_{t+h} = A\left(\lambda_t^Q\right) + B\left(\lambda_t^Q\right)\lambda_{t+h}^Q + \varepsilon_{t+h}, \quad \mathrm{Var}\left(\varepsilon_{t+h}\right) = H_t , \tag{A-34}$$

$$A\left(\lambda_t^Q\right) = z\left(\mu + \Phi\lambda_t^Q\right) - B\left(\lambda_t^Q\right)\left(\mu + \Phi\lambda_t^Q\right) \tag{A-35}$$

$$B\left(\lambda_t^Q\right) = \left.\frac{\partial z\left(\lambda_{t+h}^Q\right)}{\partial \lambda_{t+h}^Q}\right|_{\lambda_{t+h}^Q=\mu+\Phi\lambda_t^Q} \tag{A-36}$$

$$\lambda_{t+h}^Q = \mu + \Phi\lambda_t^Q + \eta_{t+h} . \tag{A-37}$$

Initial Conditions:

$$\hat{\lambda}_0^Q = Z'\left(CDS_0 - z\left(\theta^Q\right) + Z\theta^Q\right)/\left(Z'Z\right), \tag{A-38}$$

$$\hat{q}_0 = H_0/\left(Z'Z\right). \tag{A-39}$$

Prediction:

$$\lambda_{t|t-h}^Q = \mu + \Phi\hat{\lambda}_{t-h}^Q , \tag{A-40}$$

$$q_{t|t-h} = \Phi^2\hat{q}_{t-h} + \sigma_\eta^2 . \tag{A-41}$$

Likelihood Contributions:

$$u_t = CDS_t - A\left(\hat{\lambda}_{t-h}^Q\right) - B\left(\hat{\lambda}_{t-h}^Q\right)\lambda_{t|t-h} , \tag{A-42}$$

$$V_t = B\left(\hat{\lambda}_{t|t-h}^Q\right)q_{t|t-h}B\left(\hat{\lambda}_{t-h}^Q\right) + H_t , \tag{A-43}$$

$$-2\ln L_t = \ln\left|V_t\right| + u_t'V_t^{-1}u_t . \tag{A-44}$$

Updating:

$$K_t = q_{t|t-h}B\left(\hat{\lambda}_{t-h}^Q\right)'V_t^{-1} , \tag{A-45}$$

$$L_t = I - K_tB\left(\hat{\lambda}_{t-h}^Q\right) \tag{A-46}$$

$$\hat{\lambda}_t^Q = \lambda_{t|t-h} + K_tu_t , \tag{A-47}$$

$$\hat{q}_t = L_tq_{t|t-h} . \tag{A-48}$$

The survival and default probabilities are calculated following Longstaff, Mital, and Neis [2005].

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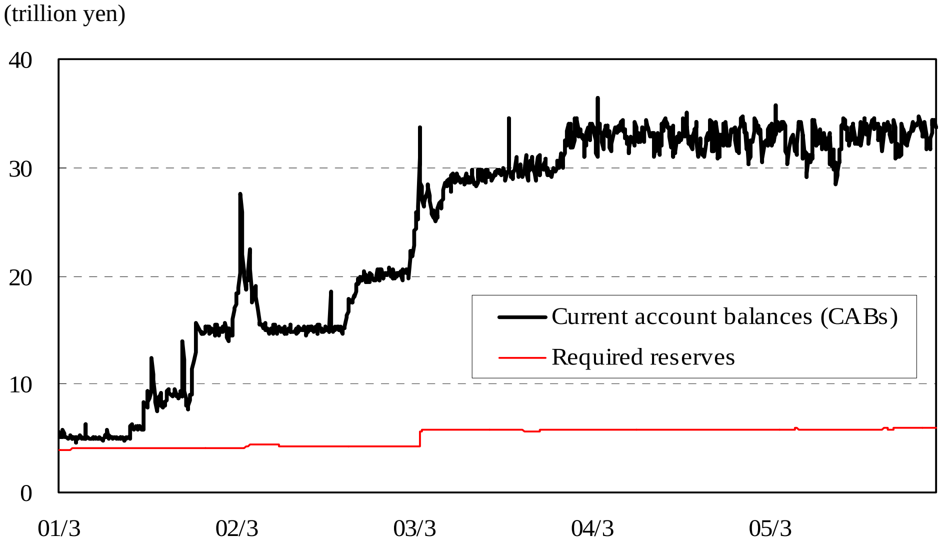
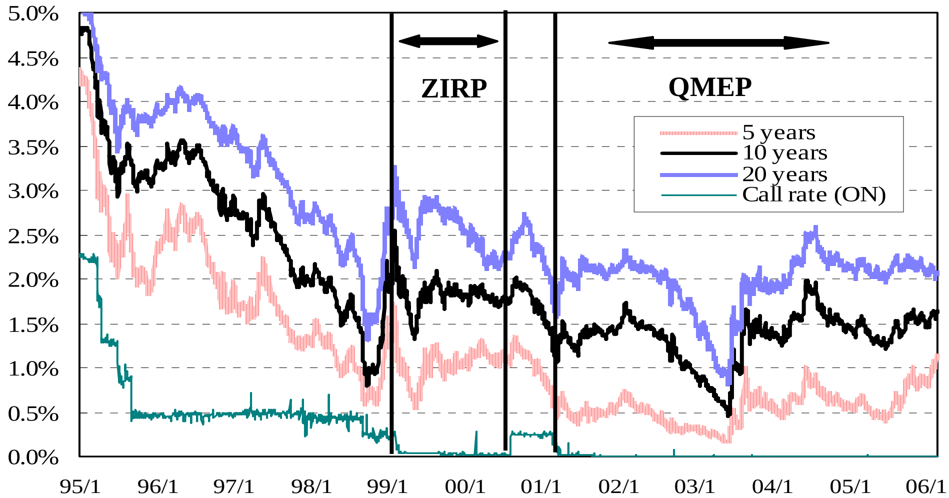
Chart 1: Current Account Balances under the QMEP



Source: Bank of Japan

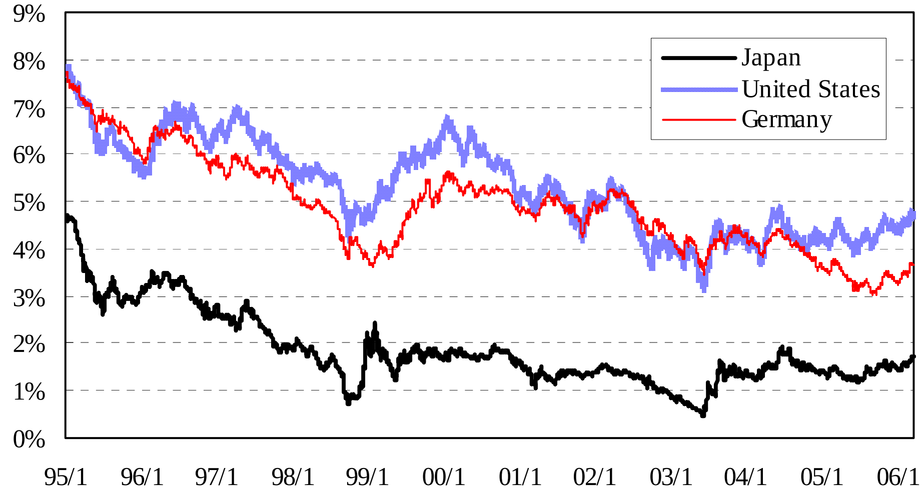
Chart 2: Interest Rate Environment in Japan



Note: 5-, 10-, 20-year interest rates are the zero-coupon government bond yields estimated from the prices of coupon bonds using McCulloch [1971] method. The call rate is the uncollateralized overnight (O/N) call rate.

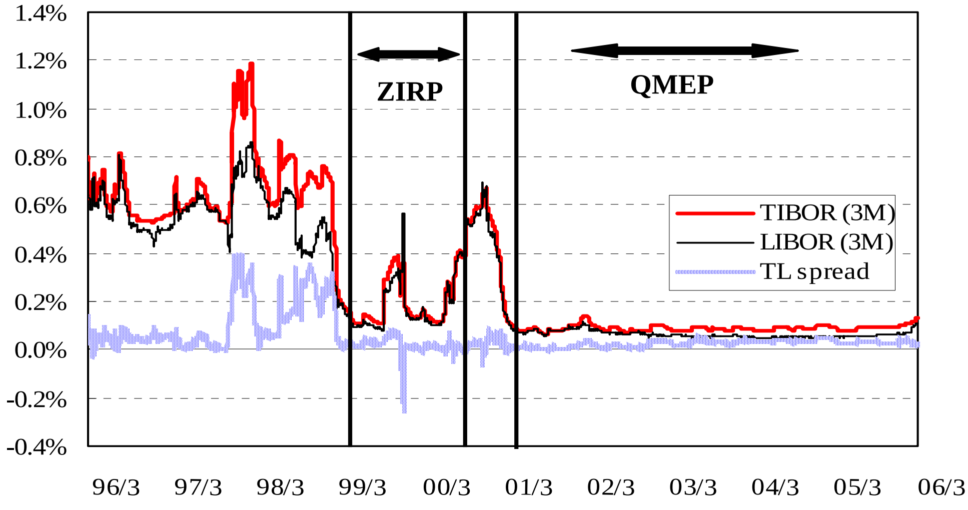
Sources: Japan Securities Dealers Association, Bank of Japan.

Chart 3: International Comparison of 10-year Interest Rates



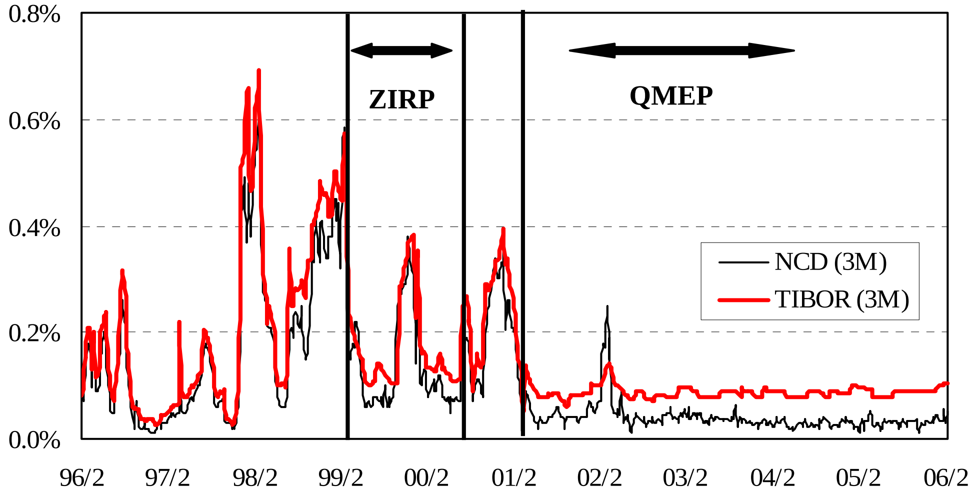
Note: Interest rates are 10-year yields on government bonds in each country.
Source: Bloomberg

Chart 4: TIBOR/LIBOR and TL Spread



Note: TIBOR and LIBOR in this chart are denominated in euro yen.
Source: Bloomberg

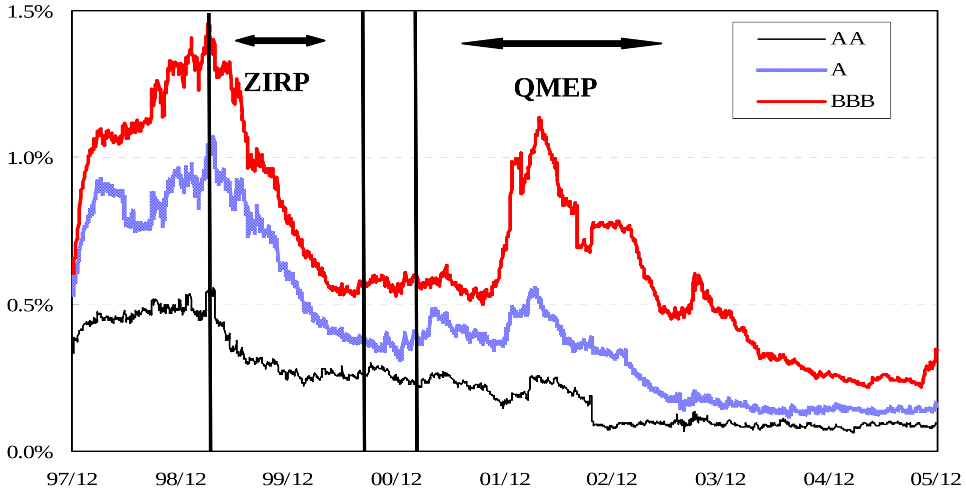
Chart 5: NCD and TIBOR Spread over the Target Call Rate



Note: Spreads are calculated as NCD interest rate/yen-TIBOR minus the target uncollateralized O/N call rate.

Source: Bloomberg

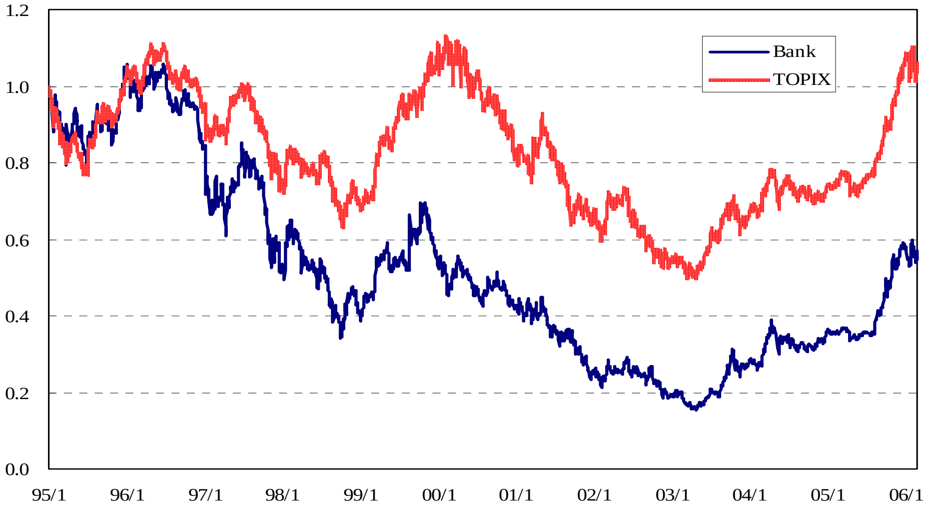
Chart 6: Credit Spreads of Corporate Bonds



Note: The spread is defined as the 5-year corporate bond interest rate minus the JGB yield with the same maturity. Credit rating is of Moody's.

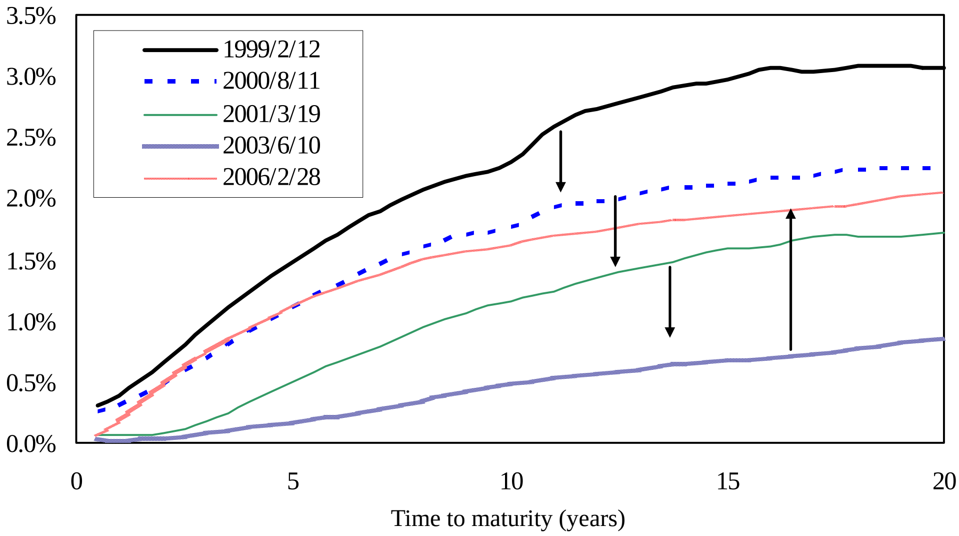
Source: Japan Securities Dealers Association

Chart 7: Stock Prices



Note: The stock price of the banking sector and TOPIX are both normalized 1995/1/4=1.
Source: Bloomberg

Chart 8: Transition of the JGB Yield Curve



Note: Each date corresponds to the following. 1999/2/12: start of ZIRP; 2000/8/11: end of ZIRP; 2001/3/19: start of QMEP; 2003/6/10: peak of QMEP; 2006/2/28: almost end of QMEP (end of sample period).
Source: Japan Securities Dealers Association

Chart 9: Shadow and Nominal Interest Rates

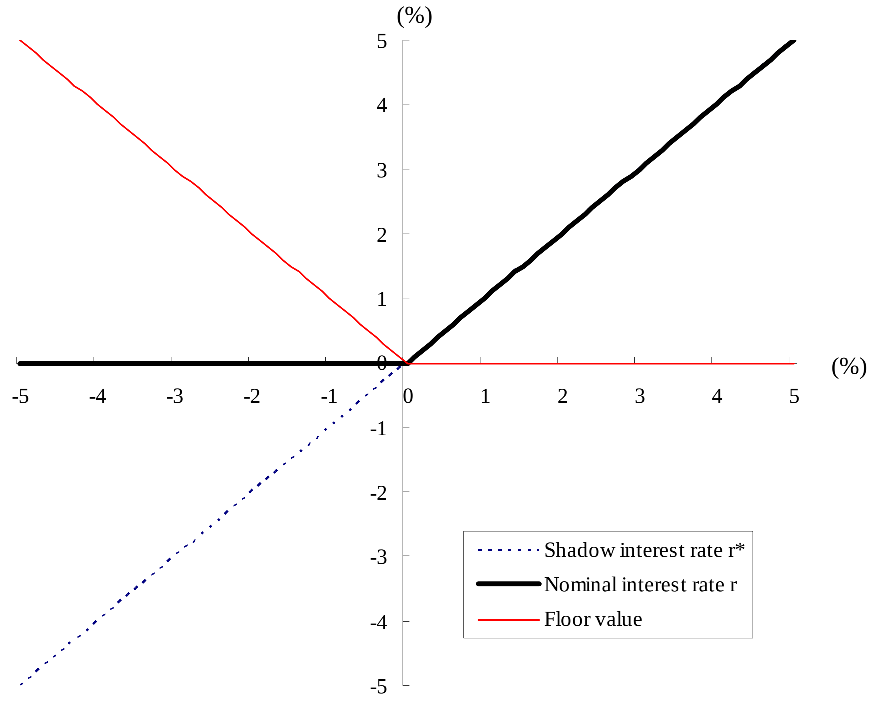


Chart 10: Recessionary Gap and Zero Floor of Nominal Interest Rate

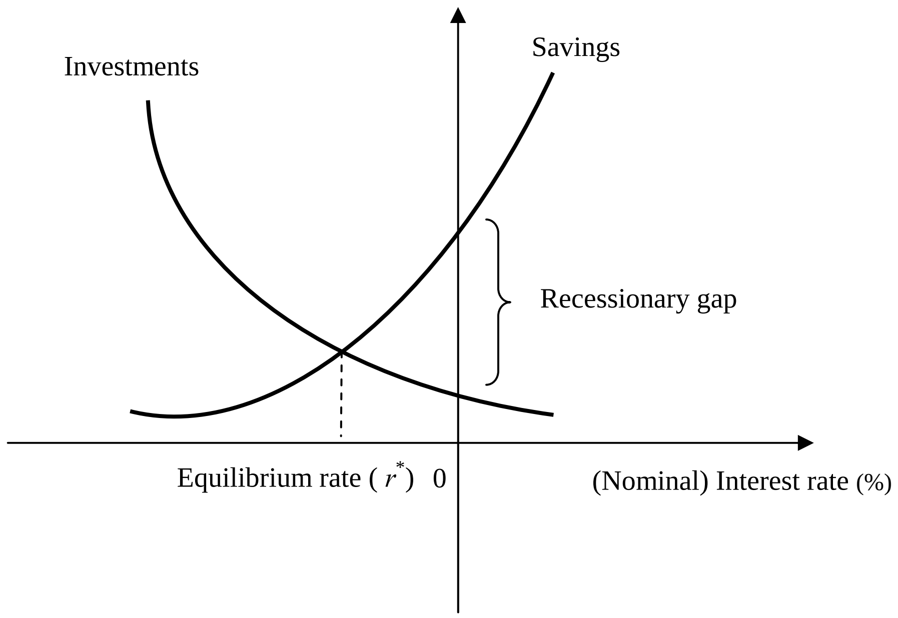


Chart 11: Estimated Results of Fixed-Parameter BGL Model

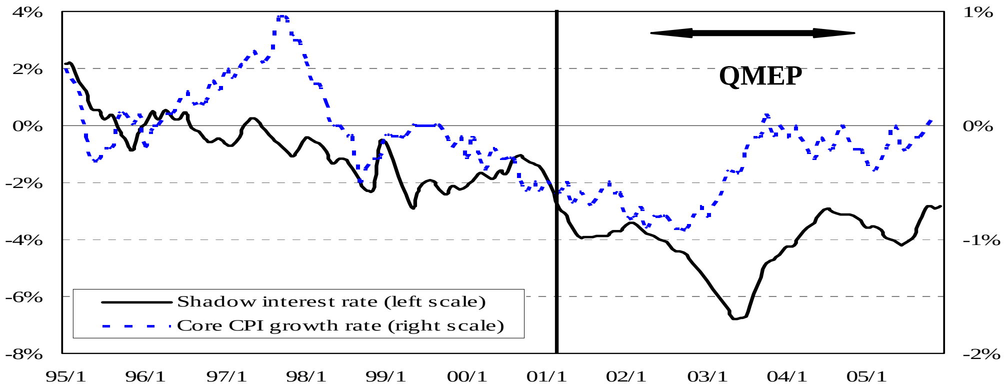
(i) Parameter Estimates

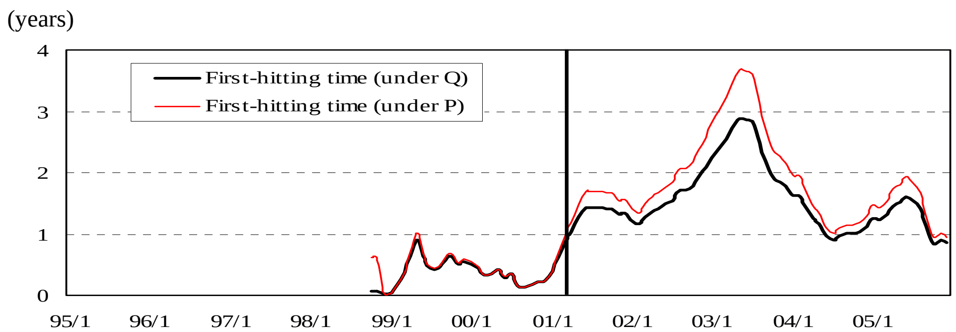
Sample period: January 1995-December 2005 (end of month)
Number of observations: 132

θ^P	0.0145***	σ_ε (call)	0.0032***
	(2.36E-04)		(3.28E-04)
κ^P	0.2145***	σ_ε (0.5 year)	0.0012***
	(1.07E-02)		(1.56E-04)
σ	0.0168***	σ_ε (2 year)	0.0012***
	(1.41E-04)		(6.79E-05)
δ_0	-0.3181***	σ_ε (5 year)	0.0027***
	(1.06E-02)		(4.45E-04)
δ_1	0.1860	σ_ε (10 year)	0.0044***
	(3.07E-01)		(7.19E-04)
θ^Q	0.0389		
κ^Q	0.2176	Log-likelihood	27.471

Notes: 1. The Figures in parentheses are standard errors. ***, **, and * denote the significance level at the 1, 5, and 10% level, respectively. Log-likelihood is the sample average.
2. Superscript P denotes the actual and Q denotes the risk-neutral probabilities, respectively.
3. See appendix 2 for details.

(ii) Estimated Shadow Interest Rate, CPI Growth Rate, and First-Hitting Time

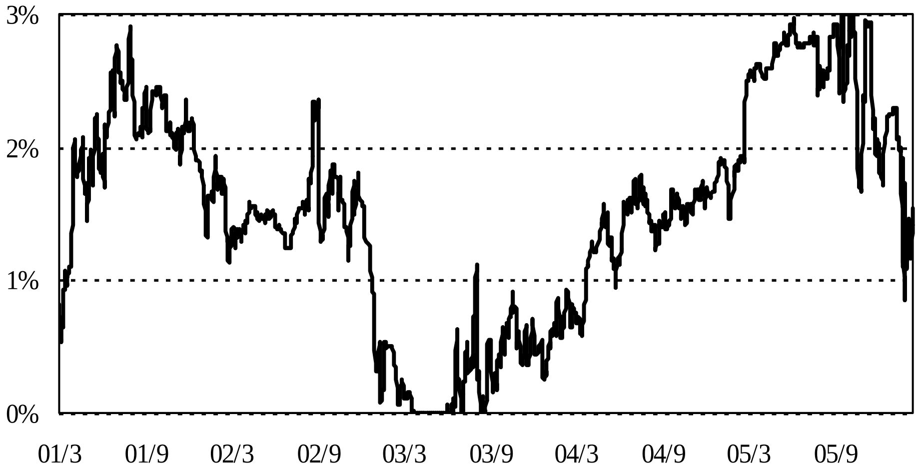




Notes: 1. The core CPI excludes perishables such as food and energy.
2. Superscript P denotes the actual and Q denotes the risk-neutral probabilities, respectively.

Source: Ichiue and Ueno [2006]

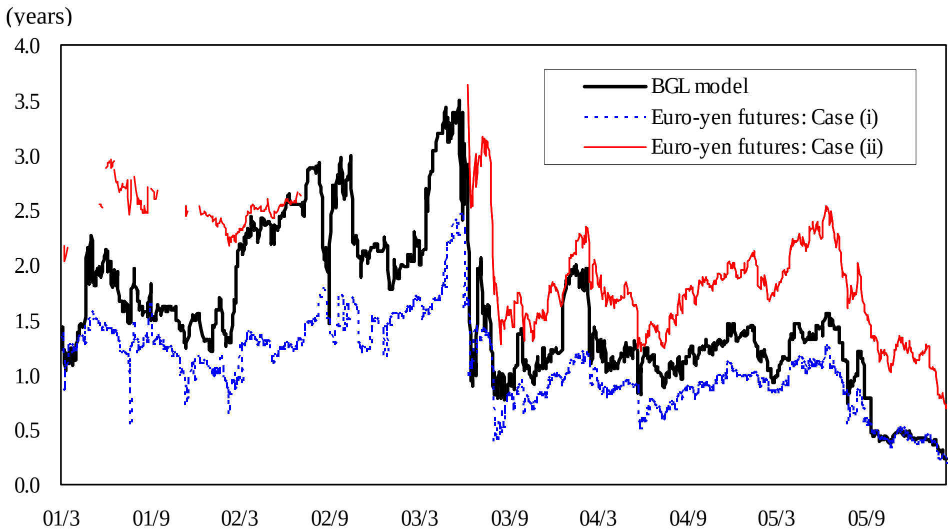
Chart 12: Time-Series Estimates of the Long-Run Mean-Reverting Level θ by the BGL Model



Notse: 1. θ is the estimated by calibrating the BGL model to the JGB yield curve on a day-to-day basis.
2. Sample period is from the start of the QMEP (2001/3/19) through 2006/2/28.

Source: Ueno, Baba, and Sakurai [2006]

Chart 13: First-Hitting Time Estimated by Day-to-Day Calibration of the BGL Model and Euro-Yen Futures



Notes: 1. Black (solid) line is the first hitting time estimated by the BGL model. Blue (dashed) and red (thin) lines are the expected times to end ZIRP implied by euro-yen futures. Case (i): the threshold euro-yen interest rate futures is assumed to be 0.19 percent (average of the ZIRP period); Case (ii): it is assumed to be 0.51 percent (average of the period when the target for uncollateralized call rate was 0.25 percent).
2. Sample period is from the start of the QMEP (2001/3/19) through 2006/2/28.

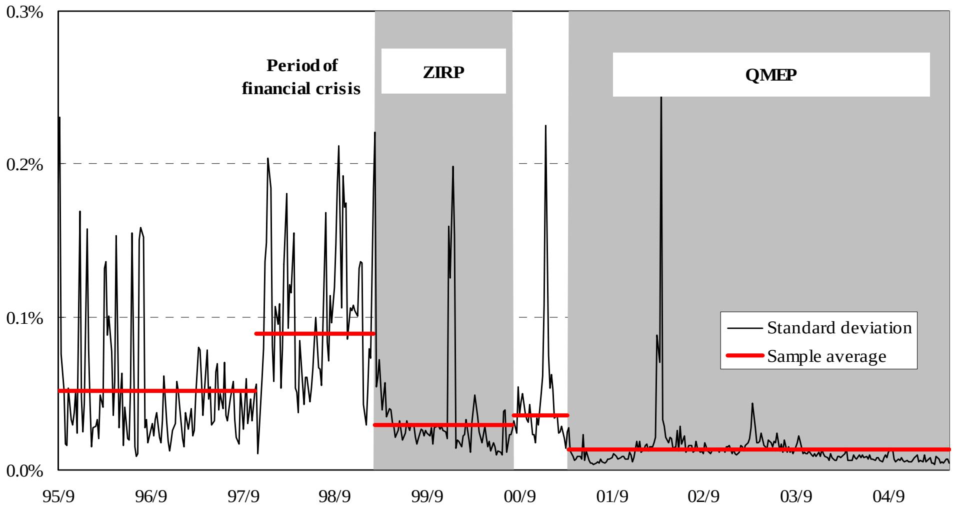
Source: Ueno, Baba, and Sakurai [2006]

Chart 14: Ending Date of the ZIRP Estimated by the BGL Model

Note: Sample period is from the start of the QMEP (2001/3/19) through 2006/2/28.

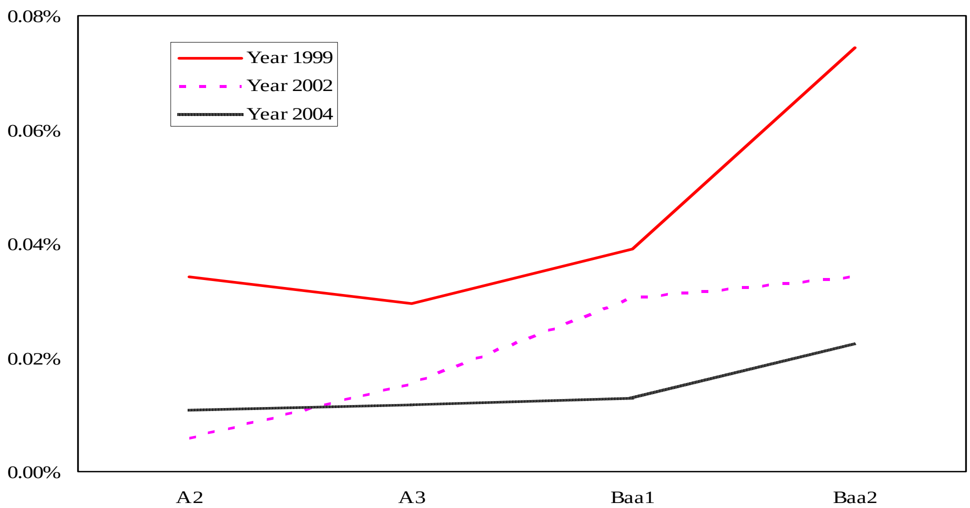
Source: Ueno, Baba, and Sakurai [2006]

Chart 15 Dispersion of NCD Interest Rates



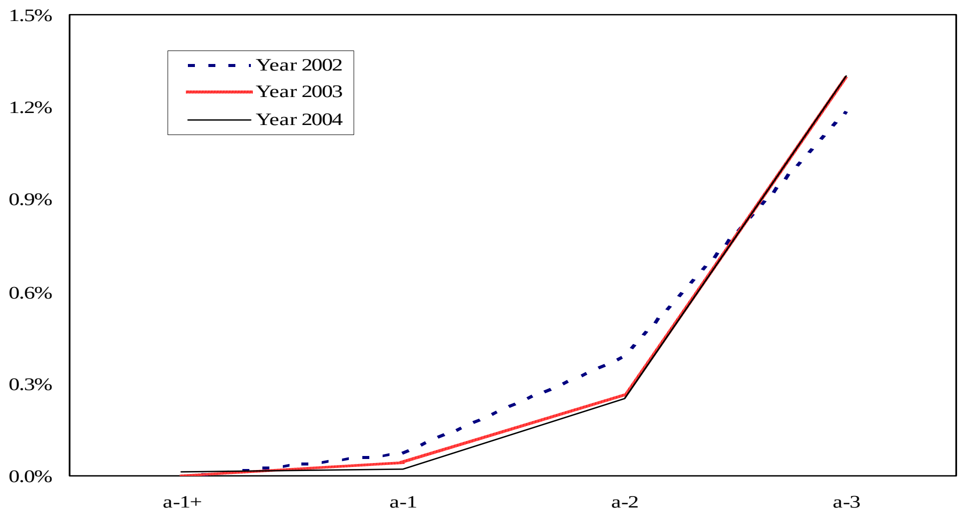
Note: NCD interest rates used here are those with maturities less than 30 days.
Source: Baba, Nakashima, Shigemi, and Ueda [2005]

Chart 16: Estimated Credit Curves of NCD Spreads



Notes: NCD interest rates are those with maturities less than 30 days. Credit ratings are the long-term ratings of Moody's.
Source: Baba, Nakashima, Shigemi, and Ueda [2005]

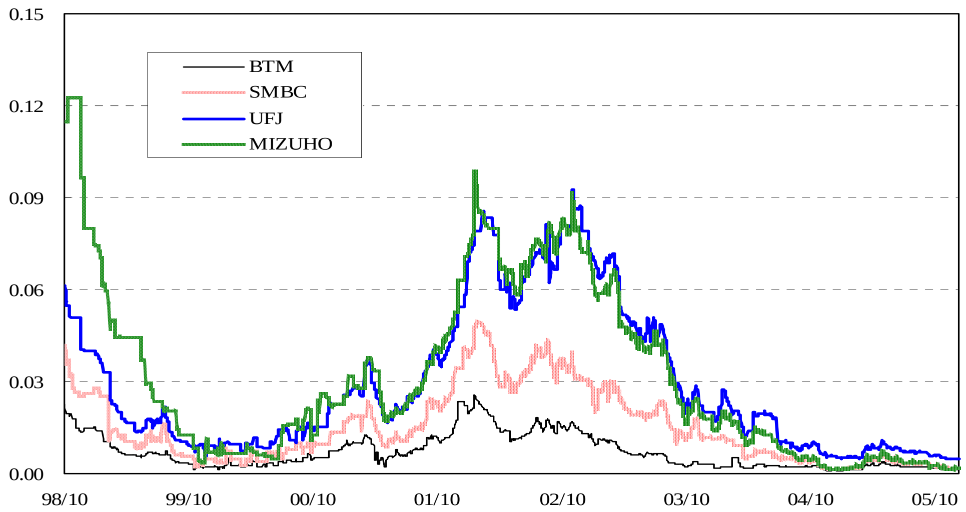
Chart 17: Estimated Credit Curves of CP Spreads



Notes: CP spread is defined as the CP interest rate minus the uncollateralized ON call rate. Credit ratings are the short-term ratings of Moody's.

Source: Baba, Nakashima, Shigemi, and Ueda [2005]

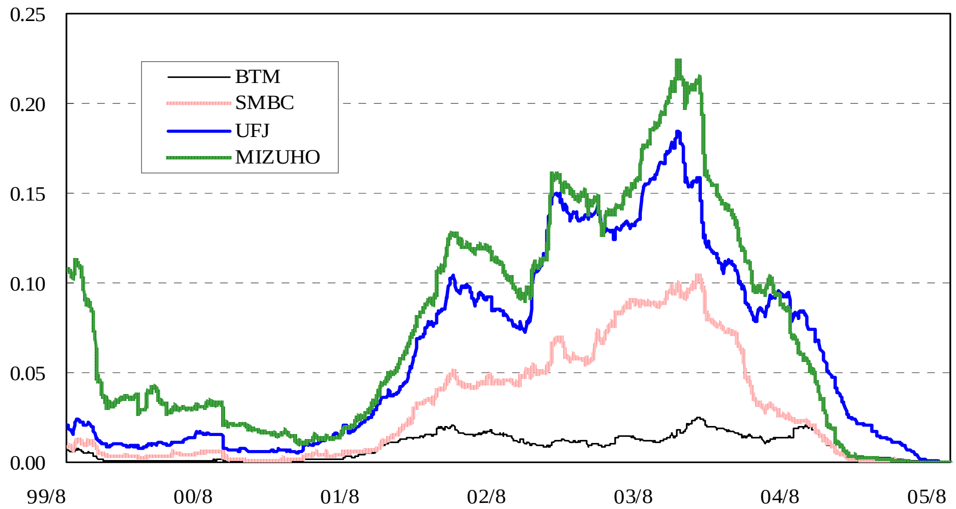
Chart 18: Default Probabilities Implied by CDS Spreads



Notes: 1. The time horizon is assumed to be one year. For details, see appendix 3.
2. BTM: Bank of Tokyo-Mitsubishi; SMBC: Sumitomo-Mitsui Banking Corporation; UFJ: UFJ Bank; MIZUHO: Mizuho Bank.

Source: Ueno and Baba [2006a]

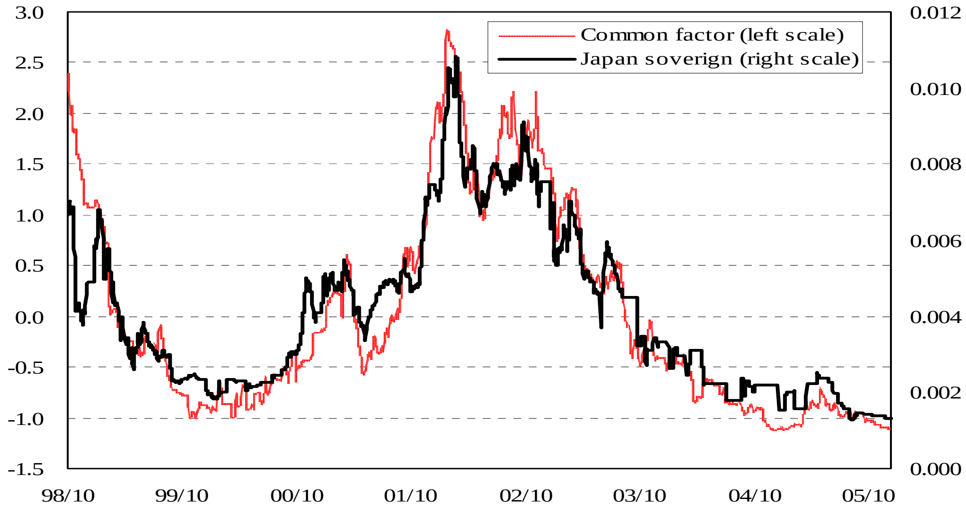
Chart 19: Default Probabilities Implied by Stock Prices



Notes: 1. The time horizon is assumed to be one year. Merton [1974] model is used.
2. BTM: Bank of Tokyo-Mitsubishi; SMBC: Sumitomo-Mitsui Banking Corporation; UFJ: UFJ Bank; MIZUHO: Mizuho Bank.

Source: Ueno and Baba [2006b]

Chart 20: CDS Spread-Implied Default Intensity for Japan Sovereign and Common Factor Derived from Japanese Four Mega-banks' Default Intensities



Notes: 1. The common factor is derived from Japanese four mega-banks' default intensities estimated from the CDS spreads using the factor analysis. The method of principal component is used. The result is the initial solution before a rotation.

2. The common factor is standardized as mean zero and standard deviation one.

Source: Ueno and Baba [2006a]