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The Term Structure of Interest Rates and Monetary Policy During a Zero-Interest-Rate Period

Jun Nagayasu

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Prepared by Jun Nagayasu[1]

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Abstract

This paper empirically evaluates the validity of the term structure of interest rates in a low-interest-rate environment. Applying a time-series method to high-frequency Japanese data, the term-structure model is found to be useful for economic analysis only when interest rates are high. When interest rates are low, the usefulness of the model declines, since the interest spread contains little information that can be used for predicting future economic activity. The term-structure relationship is also weakened by the Bank of Japan's use of interest rate smoothing.

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Author's E-Mail Address: jnagayasu@imf.org

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I. INTRODUCTION

Since the Japanese asset bubble burst in early 1990 and during the subsequent economic recession, expansionary fiscal and monetary polices have been implemented in an attempt to stimulate the Japanese economy. Up to early 2003, however, there had been no strong signal of economic recovery, at least at the macroeconomic level (e.g., in prices and GDP).[2] On the contrary, these policies have generated some difficulties that seem to constrain the authorities from implementing further expansionary measures. Notably, the (net) government debt-to-GDP ratio, which was 13 percent in 1991, exceeded an estimated 72 percent in 2002 (IMF, 2003), making it the highest among the industrialized countries, and continues to grow. With respect to interest rates, short-term rates have hovered around 0 percent since the mid-1990s.

Given the high government debt and the zero lower bound on nominal interest rates, a question frequently posed to policymakers is how to facilitate Japan's economic recovery. Recent debate has centered around the use of monetary policy (e.g., Goodfriend, 2001). This is due to the fact that even though nominal short-term interest rates have almost reached 0 percent and cannot fall further owing to the nonnegativity constraint,[3] it is still possible to conduct more accommodative monetary policies by injecting liquidity into the market (Meltzer, 1999).[4] The effects of such an easing policy could be transmitted through expectations, credit, exchange rate, and portfolio rebalancing channels. This viewpoint has been both theoretically developed and supported by simulation results. But, until very recently, there has been little empirical research in this area using actual data, and, in general, we do not possess detailed knowledge regarding the effectiveness of monetary policy at the intermediate level.[5]

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[2] Kimura, Kobayashi, Muranaga, and Ugai (2002) examine the impact of an increase in the monetary base on the Japanese economy using the autoregressive vector model. By estimating a model with time-varying parameters, they conclude that an increase in Japan's monetary base did not influence price movements significantly during the recent low-interest-rate period. Similarly, a need for substantial and sustainable monetary easing is discussed as a means of combating deflation (Baig, 2003).

[3] Nominal interest rates do not become negative because of the existence of transaction costs and cash. However, there are some instances when short-term rates became negative in the United States during the Great Depression (Cecchetti, 1988).

[4] The influence of monetary policy under low interest rates may be limited, however, because its effectiveness relies heavily on changes in expected inflation (e.g., Blinder, 2000; Goodfriend, 2001; and Reifschneider and Williams, 2000). Furthermore, Jung, Teranishi, and Watanabe (2001) demonstrate that such a zero-interest-rate policy needs to be implemented for a considerable time (even after the economy returns to a normal level) in order to generate higher expected inflation, lower long-term nominal interest rates, and domestic currency depreciation. This study thus indicates that the duration of the implementation of the zero-interest-rate policy was an important factor in making such a policy credible.

[5] Here the effectiveness of monetary policy at the intermediate level refers to the influence of monetary policy on agents' expectations, equities, etc., which are likely to be affected before a change in price or GDP occurs.

The intermediate effects of monetary policy can be examined by looking at the above-mentioned transmission channels, including the interest rate channel, which the Bank of Japan (BoJ) could use to influence the real economy. Recent research has frequently focused on the term structure of interest rates. The term-structure model focuses mainly on the interest rate and expectations channels.[6] For example, Okina and Shiratsuka (2003) studied the expectations channel of recent expansionary monetary policies.[7] By calculating the slope of yield curves for returns on financial assets with different maturities, they provide evidence in favor of the BoJ's commitment to maintaining low interest rates (the policy duration effect). Fujiki and Shiratsuka (2002), in addition, point out the importance of liquidity effects in maintaining low interest rates during a zero-interest-rate period. In contrast, Hosono, Sugihara, and Mihira (2001) conclude that the announcement effect of the zero-interest-rate policy was limited and did not influence long-term rates.[8]

Against this background, this paper analyzes the validity of the term-structure model (i.e., the relationship between interest rates with different maturities) in different sample periods. In contrast to previous research that has often employed an event-study approach, a time-series method is used here in order to obtain the more persistent implications of monetary policy. We provide empirical evidence of a strong relationship between interest rates of different maturity lengths when interest rates are relatively high. This relationship diminishes, however, as interest rates are lowered. This is consistent with economic theory and, we argue, is attributable to there being less information in the yield spread that is useful for predicting future events, as well as to the BoJ's interest rate-smoothing behavior. This implies that the term premium has become a more dominant determinant of long rates, thus making them more difficult for the BoJ to influence (and particularly to reduce). Although this study focuses solely on Japanese experiences, it has policy implications for other industrialized countries that have also reduced interest rates to historically low levels.

The rest of the paper is organized as follows. Section II summarizes recent Japanese monetary policies. Section III reviews the theoretical relationship between interest rates with different maturity lengths and look at literature that empirically investigated this model using Japanese economic data. Section IV explains the statistical methodology, the generalized method of moment (GMM), which is used to estimate the term-structure model. Section V reports a preliminary analysis of our data, while Section VI examines the validity of the term-structure model. The paper concludes with Section VII, which discusses some policy implications related to this paper's findings.

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[6] Needless to say, there are many factors other than interest rates and expectations that could affect the term spreads.

[7] See the next section for a definition of "low interest rate."

[8] Furthermore, Nagayasu (2003) investigates a narrow definition of the portfolio channel by focusing on the relationship between equity returns and interest rates. He shows that the BoJ's ability to affect equity indices has declined substantially since 1999, when short rates reached almost 0 percent.

II. A History of Monetary Policy Since 1990

The Japanese economy went into recession after the bubble burst in 1990. The Nikkei Average, which recorded its highest-ever level (38,916 yen) in December 1989, started to decline in January 1990. The BoJ has implemented several measures in an effort to facilitate economic recovery since that time. These policies can be summarized and categorized broadly into three sub-periods.

1) *The transition period*: This is a period when (short- and/or long-term) interest rates exhibited a declining trend, and includes observations prior to the implementation of the zero interest rate policy. Until 1995, the official discount rate was one of the main instruments used to conduct monetary policy. An expansionary policy started in July 1, 1991 when the official discount rate was dropped from 6.0 to 5.5 percent. This rate continued to fall and became 0.5 percent on September 8, 1995.

On March 31 1995, the BoJ decided that the uncollateral call rate should be an important operating target of monetary policy. On July 7 1995, provisions made to increase liquidity were aimed at leading the call rate to drop below the discount rate.

Furthermore, the failure of several major financial institutions in late 1997 increased market concern regarding credit and liquidity risks.[9] In order to ease the upward market pressure, the BoJ introduced several measures including a so-called dual system through which long-term bonds were purchased and short-term assets (e.g., Treasury bills) were sold simultaneously. In addition, since 1998, the call rate target level has been announced to the public. On September 9, 1998, the uncollateral overnight call rate was targeted to within ±0.25 percent on average of the discount rate.

2) The *zero-interest-rate policy period*: Sluggish economic recovery led the BoJ to implement a zero-interest-rate policy from February 12, 1999, which lowered the target rate for uncollateral overnight calls to close to 0 percent in order to provide adequate liquidity to the market. Under this policy, the BoJ provided ample liquidity to the market in order to keep the short-term rate close to 0 percent. This policy was abandoned on August 11, 2002 and the target level was raised to around 0.25 percent when signs of economic recovery were thought to be in sight.

3) *The quantitative-easing policy period*: However, continued weak economic recovery forced the BoJ to introduce a different operating target for money market operations. This policy, called quantitative-easing, targets the outstanding balance of the BoJ's current account.[10] Even with short-term rates near 0 percent, the BoJ can conduct further expansionary monetary policy by injecting liquidity into the market. This in turn could induce a reduction in long-term rates and cause the yen to depreciate, for instance.

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[9] These institutions included Sanyo Securities, Yamaichi Securities, Hokkaido Takushoku Bank, the Long Term Credit Bank of Japan, and the Nippon Credit Bank.

[10] This mainly constitutes the reserve-deposit balance held by private financial (both depository and non-depository) institutions.

Furthermore, in contrast to a zero-interest-rate policy, in theory, short-term interests are determined endogenously and therefore are expected to exhibit more fluctuation, not necessarily remaining at 0 percent. The quantitative-easing policy is expected to continue until the CPI records a year-on-year increase of 0 percent or more on a sustainable basis (IMF, 2003).

The target level of the current account balance has been increased several times: the initial level of 5 trillion yen was raised to 27-30 trillion yen in May 2003. This expansionary policy resulted in a year-on-year increase in M1 of 3.5 percent in 2000, of 14 percent in 2001, and of more than 20 percent in 2002. However, the increasing trend in M1 was not translated into M2+CDs (broad money) data that exhibited less than a 4 percent increase during these periods (IMF, 2003).

The quantitative-easing policy has been conducted through open market operations by purchasing financial assets. Government debt securities can be bunched into roughly four groups based on their terms to maturity: Treasury bills (a maturity of one year or less), medium-term government bonds (2 to 5 years), long-term government bonds (6 to 10 years), and super-long-term government bonds (more than 10 years). As part of the quantitative-easing policy, the BoJ has been purchasing these Japanese government bonds.[11] Furthermore, the BoJ has been raising its target level for the amount of long-term Japanese government securities it intends to purchase outright. Initially, the amount was targeted at 400 billion yen per year, but was increased to 1.2 trillion yen per month in October 2002. As a result, government debt securities have come to dominate Japan's bond market in recent years.

These recent accommodative policies, which led the short-term interest rates to around 0 percent from 6.0 percent in early 1990 and similarly the yield of the long-term government bonds from 7.0 percent to less than 1 percent, are extremely expansionary in terms of nominal interest rate levels. Certainly, these policies have no precedent in Japanese history and there are few examples worldwide where interest rates have fallen to such a low level.

For convenience, this paper will use the term "low-interest-rate" policy (period) to refer to both "zero-interest-rate" and "quantitative-easing" policies (periods) since they both, directly or indirectly, attempt to keep the call rate at or near 0 percent.

III. Term Structure of Interest Rates

The relationship between interest rates with different maturities can be summarized using the term structure of interest rates, which is frequently used to study the effects of monetary policy. While the rational expectations version of this model has received some criticism (to be reviewed shortly), it has also been used to rationalize

[11] Meltzer (2001) also argues for conducting open market operations by purchasing other assets such as foreign currency government bonds.

recent monetary policies. In this regard, the rational expectations model is a good starting point for this paper's analysis.

For non-coupon financial assets, this model can be derived using the following behavioral equations. First, we define the relationship between the long-term interest rate ($R_{n,t}$) and the forward-interest rate ($f_{j,t}$) as:[12]

$$R_{n,t} = \frac{1}{n}\sum_{j=0}^{n-1} f_{jt} \tag{1}$$

where n ($n > 1$)and j represent a maturity length. Furthermore, when $R_{1,t+j} = r_{1,t+j}$ and $f_{j,t} = E_t(r_{1,t+j}) + \phi_j$, where $r_{1,t+j}$ is a short-term rate at time $t+j$, $E(\ )$ is the expectations operator, and ϕ_j is a forward-term premium that is time-invariant,[13] equation (1) can be written as:

$$R_{n,t} = \frac{1}{n}\sum_{j=0}^{n-1} E_t(r_{1,t+j}) + \phi_n \tag{2}$$

where $\phi_n = \sum_{j=0}^{n-1}\phi_j / n$. Equation (2) states that the long-term rate at time t is the average of the expected future short-term rates plus the term premium. When $\phi_n = 0$, this equation becomes consistent with the pure expectations model. However, since $\phi_n = 0$ represents a very unique situation, this restrictive assumption is relaxed for the subsequent part of this paper.

The ultimate objective of monetary policy is price stabilization which will hopefully facilitate economic growth. However, it is useful to consider two definitions of "successful policy" in understanding the policy implications of the term-structure model. First of all, it could be defined as one that results in a reduction of both expected short-term rates and the long-term rate.[14] This definition is applicable during the transition period when the short-term rates have not yet reached 0 percent. Once a zero-interest-rate policy is implemented and short-term rates are therefore near 0 percent, a successful policy should result in expected future short-term interest rates of 0 percent (i.e., $E_t r_{1,t}$, $E_t r_{1,t+1}$ ... = 0). In this case, the long-term rate becomes equal to the forward-term premium. This is an extreme example of Ruge-Murcia (2002) who shows that the zero lower bound on nominal interest rates induces a nonlinear relation between long- and

[12] Shiller (1979) developed a more generalized relationship between short- and long-term rates, which incorporates a coupon effect.

[13] Shiller (1990) summarizes the definition of three types of risk premiums; namely, the forward term premium, the holding period term premium, and the rollover term premium. The derivation of a risk premium refers by definition to the forward term premium, which is defined as the difference between the forward rate and the expectation of the corresponding future spot rates.

[14] This assumption may be subject to criticism since economic recovery, a goal of monetary policy, is expected to increase expected inflation and thus future short-term interest rates, which in turn will raise long-term interest rates. However, since the zero-interest-rate policy had been in operation for 18 months and the quantitative-easing policy for two years at the time of writing, it seems appropriate to assume that a medium-term or intermediate target of monetary policy is to reduce long-term interest rates through the mechanism explained in equation (2). Ogawa and Takenaka (2001) argue that monetary policy mechanisms take one to two years to achieve their full effect.

short-term interest rates. In other words, the long-term interest rate will asymmetrically respond to a change in the short-term rate. This reduces considerably the central bank's power to influence long-term interest rates during the low-interest-rate period. In contrast, a failure of monetary policy would result in an increase in expected short-term rates, which would tend to raise the long-term interest rate.

Furthermore, the following equation can be derived by manipulating equation (2):

$$R_{n,t} - r_{1,t} = \frac{1}{n}\sum_{j=1}^{n-1}\sum_{i=1}^{j} E_t(\Delta r_{1,t+i}) + \phi_n \tag{3}$$

where $\Delta r_{1,t+i} = r_{1,t+i} - r_{1,t+i-1}$. Like equation (2), this equation contains several important economic implications for monetary policy. First, if monetary policy is successful in reducing changes in expected future short-term rates during the transition period, equation (3) suggests that the yield spread should also decline.[15] When the change in expected short-term rates is 0 percent, the size of the yield spread should approach that of the term premium. In this case, no significant relationship between the long- and short-term interest rates exists.

Equation (3) has two important statistical implications. First, when the first difference of the short-term rate is stationary (i.e., $\Delta r_{1,t+i} \sim I(0)$), so is the yield spread, $R_{n,t} - r_{1,t} \sim I(0)$. It follows that when $R_{n,t}$ follows the unit root process, $R_{n,t}$ and $r_{1,t}$ are cointegrated (Campbell and Shiller, 1987). Another implication of equation (3) is related to the direction of causality between the yield spread and short-term interest rates. It suggests that the current yield spread should contain information useful in predicting future short-term rates. It is important to note that this type of unique causality may exist during the transition period, but we do not expect any unique causality when interest rates are low. This is obvious from equation (2), which can be simplified to show a direct relationship between the long-term rate and the term premium when monetary policy is credible and thus expected short-term rates equal zero.

Generally, there is little evidence to support the standard term-structure model. Campbell and Hamao (1992) study the short-end of term structure and provide evidence to support the expectations theory, particularly in the period preceding 1985. However, the performance of the model deteriorates after 1985 when changes in policy dictated by the Plaza Accord resulted in a regime shift in the data.[16] The poor performance of the standard model is due to the existence of a time-varying term premium (Shikano 1985; and Shirakawa 1987).[17] Using a cointegration method, Nagayasu (2002) studies the long-run implications of the short-end of term structure, providing evidence to support

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[15] This assumes a constant term premium.

[16] Thornton (2003) obtained the same result using a similar approach.

[17] Further possible cause of the failure of the expectations model is identified by Saito et al. (2001) who outline the importance of the liquidity effect of periodic settlement on the term structure. They document that such an effect is prevalent at the end of the settlement months (March, September, and December).

expectations theory while making allowances for the stationary time-varying risk premium.[18]

Previous research has shown the importance of modeling the time-varying term premium. This paper therefore incorporates it and in addition considers the policy reaction function of the BoJ. McCallum (1994) proposes that equation (2) be re-expressed by including the time-varying term premium that follows the AR(1) process.

$$R_{n,t} = \frac{1}{n}\sum_{j=0}^{n-1} E_t(r_{1,t+j}) + \phi_t \qquad \text{where } \phi_t = \rho\phi_{t-1} + \varepsilon_t \tag{4}$$

where $\varepsilon_t \sim IID(0,\ \sigma_\varepsilon^2)$, and $|\rho| < 1$. The parameter, ρ, measures the persistence level of the term premium. Furthermore, the central bank's policy reaction function can be summarized as:

$$r_{1,t} = \alpha r_{1,t-1} + \beta(R_{n,t} - r_{1,t}) + u_t \tag{5}$$

The residual term, u_t, captures indicators other than the yield spread, which also contain some useful information on future economic activities. Here, for simplicity, this residual is assumed to be an *IID* process ($u_t \sim IID(0,\ \sigma_u^2)$). Equation (5) measures the BoJ's attempt to smooth short-term interest rate movements. A value of α close to one suggests that the short-term interest rates between *t* and *t-1* are closely correlated. A positive β reflects the BoJ's action to tighten monetary policy. This is a case where a widening spread indicates higher expected future economic activity and inflation. Kim and Limpaphayom (1997) analyze the ability of the spread to explain economic growth, and Nagayasu (2002) studies the predictability of future inflation based on the yield spread. These studies confirm that a widening yield spread indicates a rise in future economic activity and inflation respectively when interest rates are high. In contrast, $\beta = 0$ signals that the BoJ did not respond to the current state of the yield spread but simply attempted to smooth short-term interest (Mankiw and Miron, 1986). Thus, $\beta = 0$ and α close to one indicates interest rate smoothing being carried out by the BoJ.

Short-term interest rates can be assumed to behave in line with the following process: $r_{1,t} = \theta_1 r_{1,t-1} + \theta_2\phi_{t-1} + \theta_3 u_t$. Using this expression, McCallum (1994) and Kugler (1997) show that expected short-term rates can be expressed as: $Er_{1,t+1} = \theta_1 r_{1,t-1} + \theta_2\phi_t + \theta_3 u_t + \theta_2\rho\phi_t$, $Er_{1,t+2} = \theta_1 r_{1,t-1} + \theta_2\phi_t + \theta_3 u_t + \theta_2\rho\phi_t + \theta_2\rho^2\phi_t$, and $Er_{1,t+j} = \theta_1 r_{1,t-1} + \theta_2(1+\rho+\cdots+\rho^j)\phi_t + \theta_3 u_t$. Based on these expected values and using equations (3), (4), and (5) as well as the minimal-state-variables criterion discussed by McCallum (1994), Kugler (1997) derives solutions for parameters (θ_1, θ_2, and θ_3). Then, the following equations can be obtained:[19]

$$R_{n,t} - r_{1,t} = \rho(R_{n,t-1} - r_{1,t-1}) + \frac{n}{n - \beta\sum_j^{n-1}(n-j)\rho^j}\varepsilon_t \tag{6}$$

[18] Kikugawa and Singleton (1994) caution that coupon effects have significant influence when applying the standard expectations theory to Japanese government bond data.

[19] Kugler (2002) extends this model to allow for a GARCH process in the forward term premium. This study does not estimate such a model because it fails to convert using the maximum likelihood method.

$$r_{1,t} - r_{1,t-1} = \mu(R_{n,t-1} - r_{1,t-1}) + \frac{n\beta}{n - \beta\sum_j^{n-1}(n-j)\rho^j}\varepsilon_t + u_t \quad (7)$$

where $\mu = \rho\beta$. Since equation (3) cannot be directly estimated due to the existence of unobservable components, this paper tests the theoretical implications of monetary policy using equation (7). Obviously, $\mu = 0$ holds when ρ and/or β are equal to zero. In this case, there is evidence of interest rate smoothing (β=0) and /or there is no persistence in the term premium (ρ=0).

Using this framework, Kugler (1997) has found the existence of a persistent term premium as well as a strong tendency of the BoJ to react towards the yield spread variances between 1982 and 1992. While the level of persistence in the term structure (ρ) is very similar across countries in his study, the size of the reaction coefficient (β) is significantly different and is higher for Japan than for countries such as the United States. This paper will estimate equation (7) using the GMM framework.

IV. Methodology

This paper employs the generalized method of moment (GMM) technique, which has been used frequently in finance literature. This method has several advantages over other estimation techniques. First, it encompasses several standard approaches such as the OLS, 2SLS, and IV, and nonlinear simultaneous equation methods (see Hamilton, 1994). Furthermore, compared with classical regression methods such as the OLS, which require a spherical disturbance, the GMM requires relatively weaker assumptions for measuring the residual. By adjusting a covariance matrix, GMM estimators become robust to autocorrelation and heterogeneity in the residual. Similarly, endogeneity bias can also be dealt with by introducing instrumental variables. For estimation, equation (7) can be expressed in compact form as follows:

$$y = X\beta + u \quad (8)$$

where y is a $(T \times 1)$ vector and X is a $(T \times n)$ matrix containing explanatory variables, which are assumed to be covariance stationary processes.[20] The residual is u and $E[Xu] = 0$, and β is a $(n \times 1)$ vector of parameters of interest. When Z is a $(T \times q)$ matrix of instrumental variables and $q > n$, GMM estimators β satisfy the following orthogonal condition.

$$Eg_t(\beta) = E(Z_t(y_t - X_t\beta) = E(Z_t u_t) = 0 \quad (9)$$

The GMM estimator ($\hat{\beta}$) can be obtained by minimizing the following equation.

$$Q(\beta) = \bar{g}(\beta)'W\bar{g}(\beta) \quad (10)$$

where $\bar{g}(\beta)$ is a $(q \times 1)$ vector with a sample mean of $g(\beta)$ (i.e, $\bar{g}(\beta) = T^{-1}\sum_{t=1}^{T} g_t(\beta)$). The W is a $(q \times q)$ symmetric and positive definite weighting matrix, and *plim* ($\hat{W} - W$)=0. The GMM estimators then can be expressed as:

$$\hat{\beta} = (X'ZWZ'X)^{-1}X'ZWZ'y \quad (11)$$

[20] See Ogaki (1999) for one case where non-stationary variables can be estimated by the GMM.

When the residual is *IID*, $\hat{\beta}$ is $\sqrt{T}$ consistent and asymptotically normally distributed. One condition necessary to obtain an asymptotically efficient estimator of β is $W = \Omega^{-1}$ where Ω is a covariance matrix of $g(\beta)$, i.e., $\Omega = \sum_{s=1}^{T}\sum_{t=1}^{T} E(g_t(\hat{\beta})g_s(\hat{\beta})')/T$.

However, financial data often do not follow an *IID* process. In the presence of a residual (u) with possible autocorrelation and heterogeneity, the optimal GMM estimators are obtained by calculating a consistent W. The heteroschedastic and autocorrelation consistent (HAC) robust weighting matrix is obtained using the method developed by Newey and West (1987).

$$\hat{\Omega}_{HAC} = \hat{S}_0 + \left(\sum_{j=1}^{k} w(j)(\hat{S}(j) + \hat{S}(j)' \right) \text{ where } \hat{S}(j) = \frac{1}{T-k} \sum_{t=j+1}^{T} Z_t \hat{u}_t Z_{t-j}^{'} \hat{u}_{t-j} \quad (12)$$

The kernel $w(j)$ is the Bartlett kernel ($w(j) = 1-(j/k+1)$ for $k \geq j \geq 0$) (see Cushing and McGarvey 1999). The estimated weighting matrix (12) is consistent when $k \to \infty$ as $T \to \infty$ and $k/T^{1/2} \to 0$. The Monte Carlo exercises suggest that the choice of the bandwidth parameter k is more important than the type of kernel (Newey and West 1994), and, in this paper, a nonparametric method of Newey and West is used to select the number of auto-covariance.

When there are more instruments than parameters (i.e., $q > n$), the appropriateness of the model, including the choice of instruments, can be checked using the over-identification test (Hansen 1982).

$$J = T\overline{g}_T(\hat{\beta}_T)'W\overline{g}_T(\hat{\beta}_T) \quad (13)$$

This statistic is asymptotically distributed as χ^2 with a degree of freedom equal to $q - n$. Based on this, we can conduct an over-identification test that is used as our standard diagnostic method.

Since there is no established theory by which to determine the composition of instrumental variables, the choice of instruments is often left to the researcher's judgment. However, Hamilton (1994) summarizes that the instruments should be correlated with explanatory variables but not with the residual term. Furthermore, the number of instruments should be parsimonious because the asymmetric efficiency can be improved only when additional instruments bring about extra information. Thus, in addition to the constant term, this paper uses three lagged explanatory variables as instrumental variables.

V. Data and Preliminary Empirical results

Data used in this paper are weekly and cover a sample period from 1990/1/5 to 2003/3/30**.** Given our interest in analyzing the effectiveness of different types of monetary policy, the performance of the term-structure model will be examined in several sub-sample periods. Specifically, the full sample is divided into three phases: 1) the transition period, 2) the zero-interest-rate policy period, and 3) the quantitative-easing policy period (see Section II).

All data were obtained from Bloomberg and are plotted in Figure 1. Short-term interest rates are Gensaki rates with a maturity of one, two, and three months. Among other short-term rates, Gensaki rates are employed in this study since early call market rate data are recorded to only two decimal points[21] and the TIBOR data are only available from 1995 onwards. These data are also used in Shikano (1987), Kim and Limpaphayon (1997), and Nagayasu (2002). To be consistent with previous studies (i.e., Okina and Shiratsuka, 2003), Japanese swap rates of JGB (discount bonds) with maturities of three and five years are used to represent long-term rates here.[22] As mentioned, the JGB market is important with regard to monetary policy in Japan since the purchase of government bonds is an integral part of the quantitative-easing policy adhered to by the BoJ. Data are based on $r\times 100$ and $(R\text{-}r)\times 100$ where R are r are long- and short-term interest rates expressed as percentages per annum. The yield spreads and the first difference of Gensaki rates are shown in Figure 2.

From Figure 1, we can make two observations. First, there was a discrepancy between short- and long-term interest rates during the low-interest-rate period. This gap became even more pronounced during the zero-interest-rate policy, thus indicating that these assets are not a perfect substitute. Second, the data show an increasing trend in JGB returns during the zero-interest-rate period. While ex post returns are on average 0 percent,[23] there was a tendency for expected future interest rates to increase.[24] This can be analyzed by rewriting equation (2) as:

$$R_{n,t} - R_{n,t-1} = \frac{1}{n}\sum_{j=0}^{n-1} E_t(\Delta r_{1,t+j}) + \Delta\phi_t$$

This equation states that an increase in long-term interest rates should be reflected in a rise in the future short-term rates. We have calculated the average (ex post) expected short-term rate using spot Gensaki rates. Our calculation does not include observations between the zero-interest-rate and quantitative-easing policies since the removal of the zero-interest-rate policy was not generally expected according to a survey conducted by Nissei Kiso Kenkyujo.[25] Our calculations are therefore based on:

$$\Delta r_t^{ex} = \frac{1}{70+x}\left(\Delta r_t + \Delta r_{t+1} + \cdots + \Delta r_{t+70+x}\right)$$

$$\Delta r_{t+1}^{ex} = \frac{1}{69+x}\left(\Delta r_{t+1} + \Delta r_{t+2} + \cdots + \Delta r_{t+69+x}\right)$$

$$\vdots$$

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[21] This will result in the first difference of the data being equal to zero in many observations, making model estimates impossible.

[22] We have considered yield spreads based on a ten-year maturity JGB, but the result using these data is not reported here since this variable is found to be non-stationary.

[23] The t statistic to test that the mean of data is equal to zero ranges from –1.118 to 1.261.

[24] Here we ignore the term premium since it is difficult to quantify.

[25] Needless to say, results are sensitive to this assumption.

where x is the number of extra observations left. Figure 3 shows these rates for the first 70 weeks after the implementation of the zero-interest-rate and quantitative-easing policies. An abrupt decline in ex post interest rates reflects a substantial increase in the BoJ's provision of liquidity to the market in an effort to offset millennium computer (Y2K) uncertainty in financial markets.

This figure shows that ex post return data are less than 0 percent at the beginning of the implementation of monetary policies, and thus the zero-interest-rate and quantitative-easing policies were initially perceived as credible and were expected to last for a while. However, this phenomenon changes over time. Apparently, there is usually an increasing trend in the ex post short-term rates during low-interest-rate periods, but this trend was absent during the quantitative-easing policy. This indicates that, while it is statistically insignificant, some investors anticipated a change in the zero-interest-rate policy. This finding is consistent with Marumo *et al.* (2003) who calculate the probability of the zero-interest-rate policy being removed, and conclude that, since August 2000, a shift occurred in the distribution of expectations; investors indeed had anticipated a policy change. In contrast, the relatively constant ex post rate during the quantitative-easing policy indicates that this measure was expected to last some time. The latter observation is generally consistent with previous research (Okina and Shiratsuka, 2003).

Finally, Table 1 summarizes the basic time-series properties of the data. This table suggests that interest rate changes and spreads are statistically indifferent from zero during the low-interest-rate period, and are on average the smallest during quantitative-easing. A change in the short-term rates insignificantly different from zero indicates that the BoJ is making efforts to smooth interest rates. Their low levels during this period furthermore demonstrate that monetary policies were successful in maintaining low short-term rates. In addition, volatility measured using the standard deviation as a benchmark was three to four times higher during the transition period. Additionally, volatility of interest rates and spreads was found to be smaller during the period of the quantitative-easing policy than during the zero-interest-rate policy. In short, both interest rates and yield spreads changed most radically during the transition period.

VI. Empirical Results from the Term-Structure model

Section III of this paper discusses some statistical implications related to the expectations model of the term structure: the order of integration of and causality tendencies of the data. Table 2 reports the results of unit root tests, the ADF and DF-GLS, which were carried out to evaluate the null hypothesis of the unit root (the order of integration). Based on critical values suggested by MacKinnon (1996) and Elliott, Rothenberg, and Stock (1996), the table suggests that the first difference of Gensaki rates is stationary, while the yield spreads are less so. The yield spreads using three-year JGB (JGB3) data are reported to be stationary, but spreads based on JGBs with a five-year maturity (JGB5) follow the unit root process. The former result indicates that α in equation (5) is equal to one and therefore supports the BoJ's efforts to smooth short-term interest rates.

Next, causality between short-term rates and yield spreads is examined using the Granger noncausality test based on VAR(6). This test studies the null hypothesis of noncausality between these data. In order to determine whether or not unique causality exists, this test is implemented to study two null hypotheses: short-term interest rates do not cause a yield spread, and the spread does not cause short-term interest rate dynamics. Obtaining statistical evidence of unique causality from yield spreads to short-term rates requires rejection of the latter hypothesis and acceptance of the former.

According to the results presented in Table 3, only when the test is applied to the transition period, is there sufficient evidence to support the hypothesis that yield spreads cause short-term interest rates. It should be noted that this conclusion is not sensitive to the maturity lengths of Gensaki rates. Once the short-term interest rates near 0 percent (i.e., during the zero-interest-rate and quantitative-easing policy periods) however, there is no evidence for unique causality, a finding consistent with economic theory.

To summarize, we have obtained two findings. First, the standard term-structure model is not suitable for analysis of interest rates when maturity lengths increase (i.e., five years)—a result consistent with Campbell and Hamao (1992). Second, as economic theory suggests, causality between short-term rates and the yield spread becomes opaque when the short-term rates near 0 percent. Following the findings set out in our first conclusion, the analysis in the next section focuses on short-term rate and yield-spread relationships based on the three-year maturity JGB data.

We will now conduct a more formal analysis of the term-structure model. For this purpose, equation (7) is estimated using the GMM with results reported in Table 4. The table shows that the results are indeed sensitive to the sample period. While the parameter, μ, is statistically different from zero before the implementation of the zero-interest-rate policy, it becomes insignificant during the low-interest-rate period. Thus, yield spreads had explanatory power in the early 1990s, but lost their usefulness in explaining the dynamics of short-term interest rates once short-term rates approached 0 percent. The result remains unchanged even if different short-rate maturity lengths are used in the numerator when calculating yield spreads. Notably, the statistical insignificance of the term-structure model during the low-interest period concurs with the conclusion from the Granger noncausality test.

Additionally, we investigate reasons why the performance of the term-structure model has changed over time. This analysis is carried out by breaking down parameter μ into its two components: ρ (the persistence of the term premium) and β (the reaction of the central bank). Our results suggest that whether or not μ=0 depends on how the BoJ has responded to the yield spread (β) since the term premium is always found to be an important determinant in the term-structure model.

Parameter β is evaluated based on the BoJ's reaction function (equation 5). This equation may be in an appropriate form when short-term rates can move up or down with the same probability. But when interest rates are around 0 percent, we can expect that the probability of their going even lower is limited to the extent that nominal interest rates are bounded at 0 percent. In this case, the application of a standard approach such as the OLS will yield biased and inconsistent estimates. Therefore, following Iwata and Wu (2001) and Kato and Nishiyama (2003), equation 5 could be calculated using the censored normal regression model (Tobit). The short-term rates that are censored below 0 percent have the following form:

$$r_{1,t} = \begin{cases} r_{1,t}^{*} = \dfrac{\alpha}{1+\beta} r_{1,t-1} + \dfrac{\beta}{1+\beta} R_{n,t} + \dfrac{1}{1+\beta} u_t & \text{if } r_{1,t}^{*} \geq 0 \\ 0 & \text{if } r_{1,t}^{*} < 0 \end{cases} \tag{14}$$

The first equation in (14) is another form of equation (5), and the residual maintains the normal distribution. Equation (14) is estimated using the maximum likelihood method. The threshold level in this study may be arbitrary, but is within the range that previous researchers have employed (Iwata and Wu, 2001; Kato and Nishiyama, 2003) and appears to be reasonable given that the nominal interest rates reached almost 0 percent. The censored point of 0 percent indicates that we allow a zero probability that nominal interest rates fall below 0 percent.

Table 5 summarizes our findings and also includes results from the OLS for comparison purposes. According to the results presented in this table, the parameter (β) is found to be statistically significant only during the transition period. During the low-interest-rate period, the size of this parameter decreases and is statistically insignificant. This result is not sensitive to the estimation methods used to obtain the parameter. It follows that the short-term rates are largely determined by their own past values alone (i.e., without yield spread considerations), and, together with $\Delta r_{1,t} \approx 0$ (Table 1), this gives support to the BoJ's practice of smoothing short-term interest rate movements. Our estimate of β is lower than that found by Kugler (1997), and based on the policy reaction function of the central bank, we could argue that this result reflects the non-reaction of the BoJ to yield spread changes during the low-interest-rate period.

It is difficult to compare the BoJ's practice of interest rate smoothing between the transition and low-interest-rate periods because of the coexistence of a high value of α and a non-zero β in the transition period. However, it is interesting to compare estimates of α during the low interest rate period (the zero-interest-rate and quantitative-easing periods) since β estimates are both insignificant. Our statistics show that parameter α is higher during the implementation of the quantitative-easing policy and thus suggests a stronger smoothing of interest rates by the BoJ than in the zero-interest-rate policy. The result is in contrast to economic theory that suggests that interest rates are expected to be more volatile since they are endogenously determined when the central bank is targeting money. But it appears consistent with the actual practice of the BoJ.

In contrast to β, parameter, ρ, is statistically significant regardless of which sample period is studied (Table 6). Furthermore, this parameter is close to, but less than one, showing persistence in the term premium regardless of sample period. The value of ρ is in line with that reported by Kugler (1997). Thus, it can be concluded that the BoJ's lack of reaction to the yield spread seems to explain the significance of μ.

To further substantiate our findings, we checked for consistency between our estimates (i.e., $\mu=\beta\rho$) using the Wald test. This test confirms that a combination of estimators, β and ρ, obtained from equations (5) and (6) do indeed have the same value as μ from equation (7) with one exception (Results are reported in Table 7). However, if this parameter is regarded as zero (since it is found to be statistically insignificant), then parameters from (5) and (6) are consistent with those from (7) in all cases. In short, even taking into account the time-varying term premium, we did not obtain evidence to support the term-structure model at a time of low interest rates.

These results indicate that, during the low-interest-rate period, the long-term rate is determined largely by the forward-term premium. Therefore, under the low-interest-rate policy, it is very difficult for the BoJ to control (and in particular to reduce) the long-term rate. This supports a nonlinear relationship between short- and long-rates as discussed in Ruge-Murcia (2002).

VII. Summary and Discussion

This paper has examined recent Japanese monetary policy, including zero-interest-rate and quantitative-easing policies, by applying high-frequency interest rate data to the term-structure model that allows a time-varying risk premium. While some more research is needed, particularly to reflect the fact that interest rates move in response to factors that are not captured by the term-structure model, such as exchange rates and credit channels, this study has come to the following conclusions.

First, the term structure of interest rates proves to be a useful tool with which to analyze Japanese monetary policy, particularly during the high-interest-rate period. During the low-interest-rate period, the short-term rates remain close to 0 percent, their fluctuation becomes less significant, and the yield spread is unable to predict short-term-rate dynamics. This indicates that long-term rates are largely determined by the forward-term premium and that, in general, these rates are increasingly difficult for the BoJ to influence (and particularly to reduce), since the interest rate channel is virtually absent.

Second, we analyzed why, during the low-rate period, the yield spread becomes less relevant to the prediction of short-term interest rates. Based on the theoretical model of McCallum (1994), we conclude that the BoJ's low-level response to the yield spread contributes to this result. Another factor in this effect is the fact that short-term-rate movements become less significant during low-interest-rate periods. These observations seem to add credence to the BoJ's practice of smoothing short-term interest rates and offer evidence that in terms of keeping the short-term rate near 0 percent, the BoJ is successfully implementing monetary policy.

Interest rate smoothing is found to be implemented more forcibly, however, during the quantitative-easing policy than during the zero-interest-rate policy. Since the objective of the quantitative-easing policy is to achieve a target level of (a component of) money that is incompatible with interest-rate smoothing, this paper questions the rationale of such a policy. In this regard, I believe that allowance for more fluctuation in the short-term rates appears to be more appropriate for transmitting the effects of monetary policy through interest rate and expectations channels. The level of long-term rates could be viewed as an intermediate target of monetary policy. Thus, given the virtual absence of the interest rate channel at a time of low interest rates, a variation of short-term rates is expected to reactivate the term-structure relationship and help pass on the BoJ's stance on monetary policy more effectively to long-term-interest-rate data.

Third, according to the ex post expected short-term rates, both the zero-interest-rate and quantitative-easing policies were perceived to be credible immediately after implementation. Although statistically insignificant, however, there was an upward trend in the ex post interest rates during the zero-interest-rate policy period. This indicates that investors began to regard this policy as less credible as time went on. In contrast, such an upward trend was not observed during the quantitative-easing-policy period. In view of the low and declining levels of long-rates during the time of the quantitative-easing policy, this policy seems to be more credible than the zero-rate policy.

Finally, this study suggests there are some limits in analyzing the term structure using a time-series technique. This is due to the fact that although the yield spreads using the longer-term (e.g., five-year-maturity) assets appear to follow the unit root process, a change in the short-term rates is stationary. This may well indicate that an application of the term-structure model consistent with economic theory may pose some problems when analyzing longer-term rates. In addition, thorough analysis of the recent decline in long-term rates is beyond the scope of the term-structure model, since it focuses only on interest rate and expectations channels but not the other channels that are discussed in the introduction. In this connection, a future study aimed at better capturing the stance of monetary policy during the quantitative-easing policy period could be conducted. Although short-term interest rates may hold some of the relevant information, they do not completely explain the effects of the easing policy because of the zero lower bound of nominal interest rates.

Table 1. Data Properties

	Mean	Mean=0 t-value		Std Dev	Mean	Mean=0 t-value		Std Dev
	Full				Transition period			
DGEN1	-0.851	-3.903	**	5.713	-1.206	-3.878	**	6.765
DGEN2	-0.854	-4.134	**	5.414	-1.210	-4.106	**	6.408
DGEN3	-0.862	-4.361	**	5.179	-1.221	-4.335	**	6.126
JGB3-GEN1	38.263	20.756	**	48.318	41.147	15.787	**	56.686
JGB5-GEN1	80.287	33.494	**	62.828	87.210	26.175	**	72.461
JGB3-GEN2	39.422	21.757	**	47.491	42.824	16.760	**	55.571
JGB5-GEN2	81.446	34.107	**	62.589	88.887	26.850	**	71.998
JGB3-GEN3	40.114	22.488	**	46.754	43.842	17.464	**	54.599
JGB5-GEN3	82.138	34.536	**	62.338	89.905	27.315	**	71.583
	Zero-interest-rate policy				Quantitative-easing policy			
DGEN1	-0.117	0.305		1.320	-0.048	-1.966		0.255
DGEN2	-0.112	-1.042		0.945	-0.037	-1.952		0.191
DGEN3	-0.105	-1.090		0.852	-0.037	-1.877		0.199
JGB3-GEN1	49.281	29.299	**	14.855	17.513	40.587	**	4.400
JGB5-GEN1	92.211	48.593	**	16.759	42.832	39.854	**	10.96
JGB3-GEN2	49.290	29.466	**	14.773	17.506	40.501	**	4.408
JGB5-GEN2	92.220	48.778	**	16.698	42.825	39.811	**	10.97
JGB3-GEN3	49.233	29.597	**	14.691	17.492	40.506	**	4.404
JGB5-GEN3	92.164	48.941	**	16.632	42.812	39.799	**	10.97

Source: Bloomberg.
Note: ** Statistics significant at the 1 percent level.
* Statistics significant at the 5 percent level.

Table 2. Unit Root Tests

	ADF	DF-GLS
DGEN1	-15.601 (0) **	-1.942 (8) *
DGEN2	-14.697 (0) **	-2.203 (8) *
DGEN3	-14.289 (0) **	-1.996 (8) *
JGB3-GEN1	-2.179 (1)	-2.130 (1) *
JGB5-GEN1	-1.910 (1)	-1.432 (1)
JGB3-GEN2	-2.173 (1)	-2.097 (1) *
JGB5-GEN2	-1.883 (1)	-1.370 (1)
JGB3-GEN3	-2.149 (1)	-1.997 (1) *
JGB5-GEN3	-1.859 (1)	-1.261 (1)

Source: Bloomberg.
Notes: ** Statistics significant at the 1 percent level.
* Statistics significant at the 5 percent level.

Table 3. Granger Noncausality Tests

Ho		Ho	
JGB3-GEN1 -\-> DGEN1		DGEN1-\->JGB3-GEN1	
Full period	38.477 **		14.681 *
Transition period	27.841 **		10.041
Zero-interest-rate	4.490		8.044
Quantitative-easing	21.936 **		39.777 **
JGB3-GEN1 -\-> DGEN2		DGEN2-\->JGB3-GEN2	
Full period	38.287 **		14.010 **
Transition-period	27.799 **		9.523
Zero-interest-rate	4.698		9.316
Quantitative-easing	27.561 **		35.235 **
JGB3-GEN1 -\-> DGEN2		DGEN3-\->JGB3-GEN3	
Full period	44.074 **		13.413 *
Transition-period	32.044 **		8.897
Zero-interest-rate	4.724		8.347
Quantitative-easing	30.326 **		34.610 **

Source: Bloomberg.
Notes: ** Statistics significant at the 1 percent level.
* Statistics significant at the 5 percent level.

Table 4. The Term-Structure Model (Equation 7)

	Const	μ	N-W	J-statistics
Full sample				
JGB3-GEN1	-1.540 [0.609] *	0.023 [0.009] *	16	2.052
JGB3-GEN2	-1.607 [0.630] *	0.022 [0.009] *	16	1.598
JGB3-GEN3	-1.653 [0.654] *	0.023 [0.009] *	17	1.595
Transition period				
JGB3-GEN1	-1.958 [0.701] *	0.023 [0.009] **	12	1.925
JGB3-GEN2	-2.042 [0.758] **	0.023 [0.009] *	13	1.606
JGB3-GEN3	-2.122 [0.783] **	0.023 [0.009] *	13	1.578
During the zero-interest-rate policy				
JGB3-GEN1	-0.190 [0.353]	0.002 [0.006]	1	0.340
JGB3-GEN2	-0.194 [0.286]	0.002 [0.006]	0	0.558
JGB3-GEN3	-0.184 [0.267]	0.002 [0.006]	2	0.296
During the quantitative-easing policy				
JGB3-GEN1	0.068 [0.076]	-0.005 [0.005]	7	1.963
JGB3-GEN2	0.066 [0.082]	-0.006 [0.006]	7	1.067
JGB3-GEN3	0.066 [0.085]	-0.006 [0.006]	7	0.291

Source: Bloomberg.
Notes: ** Statistics significant at the 1 percent level.
* Statistics significant at the 5 percent level.

Table 5. The Term-Structure Model (Equation 5)

	OLS Const	α/(1+β)	β/(1+β)	ADF
Full sample				
JGB3-GEN1	-0.024 [0.004] **	0.969 [0.004] **	0.033 [0.005] **	-19.488 **
JGB3-GEN2	-0.024 [0.004] **	0.970 [0.004] **	0.032 [0.005] **	-18.352 **
JGB3-GEN3	-0.023 [0.003] **	0.970 [0.004] **	0.031 [0.005] **	-10.561 **
Transition period				
JGB3-GEN1	-0.048 [0.007] **	0.958 [0.006] **	0.048 [0.007] **	-16.537 **
JGB3-GEN2	-0.049 [0.006] **	0.958 [0.006] **	0.048 [0.006] **	-15.610 **
JGB3-GEN3	-0.049 [0.006] **	0.958 [0.005] **	0.049 [0.006] **	-15.033 **
Zero-interest-rate policy				
JGB3-GEN1	0.011 [0.006]	0.752 [0.055] **	-0.005 [0.010]	-7.514 **
JGB3-GEN2	0.007 [0.005]	0.795 [0.042] **	-0.001 [0.007]	-7.301 **
JGB3-GEN3	0.006 [0.004]	0.806 [0.037] **	0.001 [0.006]	-8.259 **
Quantitative-easing policy				
JGB3-GEN1	0.001 [0.001]	0.836 [0.023] **	-0.000 [0.004]	-6.266 **
JGB3-GEN2	0.000 [0.001]	0.889 [0.018] **	0.001 [0.003]	-3.869 **
JGB3-GEN3	0.000 [0.000]	0.893 [0.018] **	-0.001 [0.003]	-3.979 **

	Tobit Const	α/(1+β)	β/(1+β)	σ
Full sample				
JGB3-GEN1	-0.024 [0.004] **	0.969 [0.007] **	0.033 [0.007] **	0.040 [0.004] **
JGB3-GEN2	-0.024 [0.004] **	0.970 [0.006] **	0.032 [0.006] **	0.037 [0.004] **
JGB3-GEN3	-0.023 [0.004] **	0.970 [0.006] **	0.031 [0.006] **	0.035 [0.004] **
Transition period				
JGB3-GEN1	-0.031 [0.005] **	0.978 [0.008] **	0.032 [0.008] **	0.041 [0.004] **
JGB3-GEN2	-0.040 [0.006] **	0.961 [0.006] **	0.050 [0.007] **	0.035 [0.002] **
JGB3-GEN3	-0.034 [0.005] **	0.968 [0.005] **	0.041 [0.006] **	0.033 [0.002] **
Zero-interest-rate policy				
JGB3-GEN1	0.011 [0.008]	0.752 [0.123] **	-0.005 [0.008]	0.012 [0.008] **
JGB3-GEN2	0.007 [0.004]	0.796 [0.055] **	-0.001 [0.005]	0.012 [0.002] **
JGB3-GEN3	0.006 [0.004]	0.807 [0.044] **	0.001 [0.005]	0.018 [0.010] **
Quantitative-easing policy				
JGB3-GEN1	0.001 [0.001]	0.836 [0.085] **	-0.000 [0.004]	0.001 [0.000] **
JGB3-GEN2	-0.000 [0.001]	0.908 [0.032] **	0.002 [0.004]	0.010 [0.001] **
JGB3-GEN3	0.000 [0.001]	0.893 [0.026] **	-0.001 [0.003]	0.001 [0.000] **

Source: Bloomberg.
Notes: The Tobit model is based on the following log-likelihood function:

$$\ln L = \sum_{y>0} -0.5\left[\ln(2\pi) + \ln\sigma^2 + \frac{(y_t - \beta' x_t)^2}{\sigma^2}\right] + \sum_{y_t=0} \ln\left[1 - \Phi\left(\frac{\beta' x_t}{\sigma}\right)\right]$$

where $\Phi(\cdot)$ is the standard normal cumulative distribution function, y denotes a change in short-term interest rates, x is a vector containing the LHS variables of the equation, and β is a vector of parameters.
Notes: ** Statistics significant at the 1 percent level.
* Statistics significant at the 5 percent level.

Table 6. The Term-Structure Model (Equation 6)

	Const	ρ	Chi^2(1) Ho: ρ=1	N-W	J-statistics
Full sample					
JGB3-GEN1	0.772 [0.525]	0.974 [0.009] **	8.140 **	2	3.264
JGB3-GEN2	0.819 [0.511]	0.974 [0.009] **	8.206 **	2	2.960
JGB3-GEN3	0.853 [0.503]	0.973 [0.010] **	8.773 **	3	3.376
Transition period					
JGB3-GEN1	0.833 [0.689]	0.977 [0.010] **	5.873 *	4	3.282
JGB3-GEN2	0.901 [0.664]	0.976 [0.010] **	6.371 *	3	2.717
JGB3-GEN3	0.997 [0.665]	0.973 [0.010] **	7.647 **	2	2.799
Zero-interest-rate policy					
JGB3-GEN1	4.558 [3.281]	0.894 [0.064] **	2.765 +	6	2.924
JGB3-GEN2	4.333 [3.164]	0.898 [0.062] **	2.721 +	7	2.823
JGB3-GEN3	4.447 [3.110]	0.896 [0.061] **	2.929 +	8	2.617
Quantitative-easing policy					
JGB3-GEN1	2.545 [0.895]	0.839 [0.048] **	11.190 **	5	1.212
JGB3-GEN2	2.545 [0.824] **	0.839 [0.044] **	13.149 **	5	1.340
JGB3-GEN3	2.556 [0.816] **	0.838 [0.044] **	13.519 **	5	1.352

Source: Bloomberg.
Notes: ** Statistics significant at the 1 percent level.
* Statistics significant at the 5 percent level.
+ Statistics significant at the 10 percent level.

Table 7. Parameter Consistency Test

	Chi^2(1)
Full sample	
JGB3-GEN1	0.944
JGB3-GEN2	0.92
JGB3-GEN3	0.679
Before the zero-interest-rate policy	
JGB3-GEN1	0.688
JGB3-GEN2	6.703 **
JGB3-GEN3	3.177
During the zero-interest-rate policy	
JGB3-GEN1	1.016
JGB3-GEN2	0.272
JGB3-GEN3	0.035
During the quantitative-easing policy	
JGB3-GEN1	0.840
JGB3-GEN2	1.599
JGB3-GEN3	0.711

Source: Bloomberg.
Notes: ** Statistics significant at the 1 percent level.
* Statistics significant at the 5 percent level.

Figure 1. Short-term Interest Rates and JGB Yields

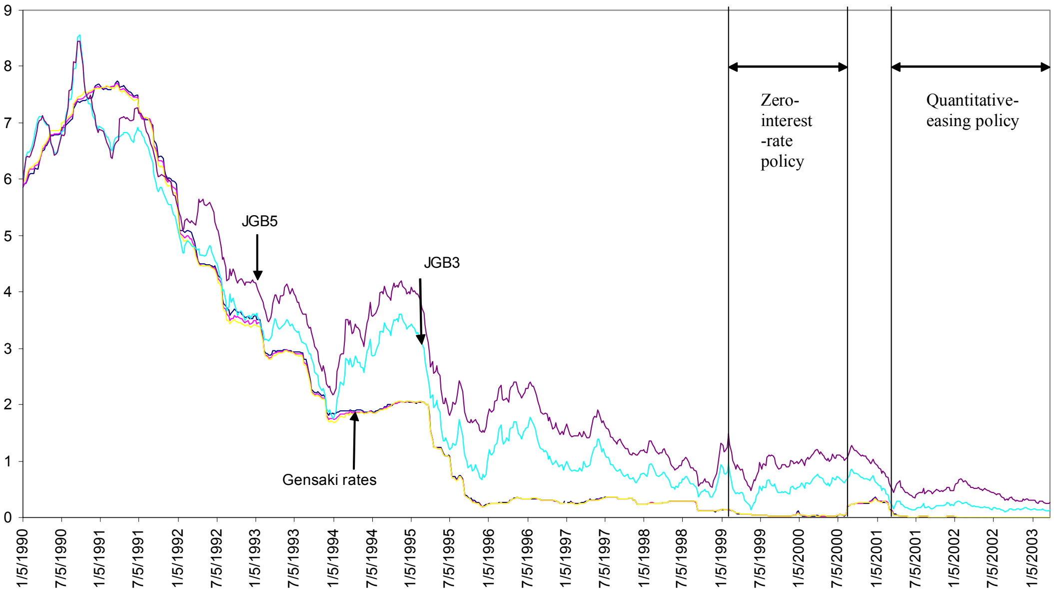


Figure 2. Short-Term Rates and Yield-Spread Dynamics

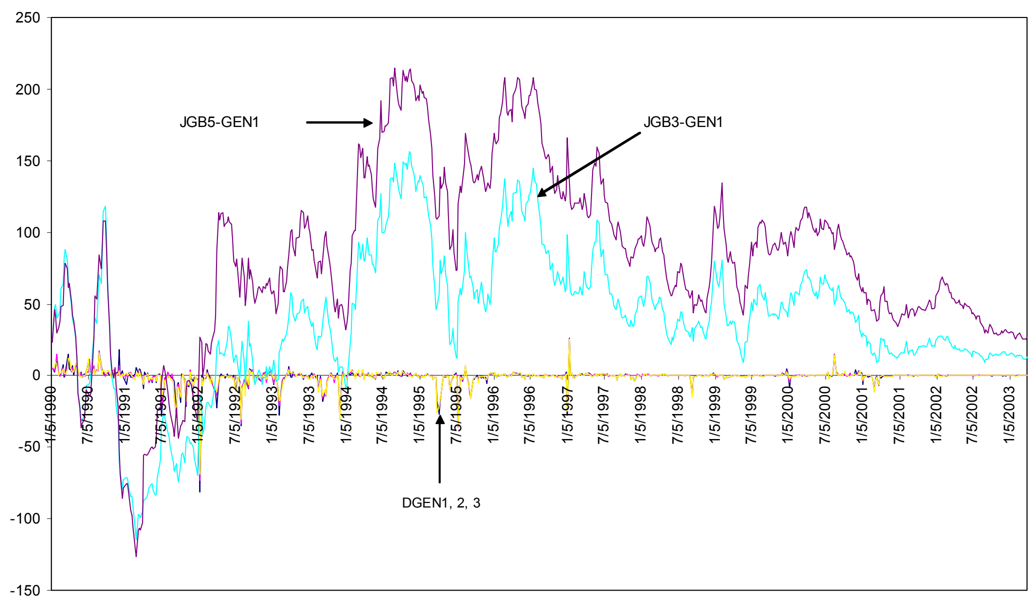


Figure 3a. A Change in Ex Post Gensaki1M (Average)

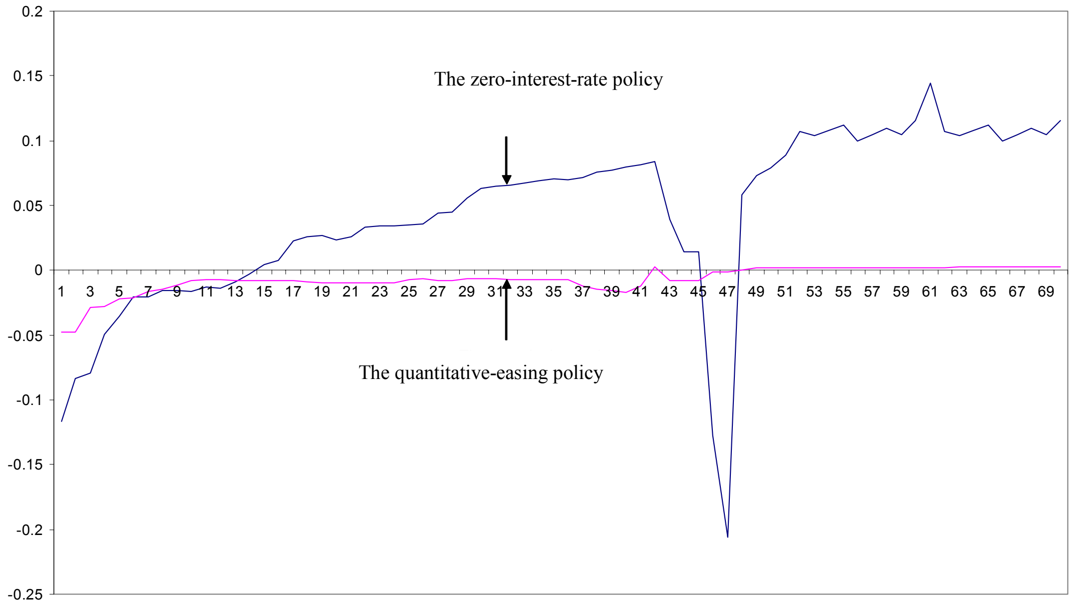


Figure 3b. A Change in Ex Post Gensaki2m (Average)

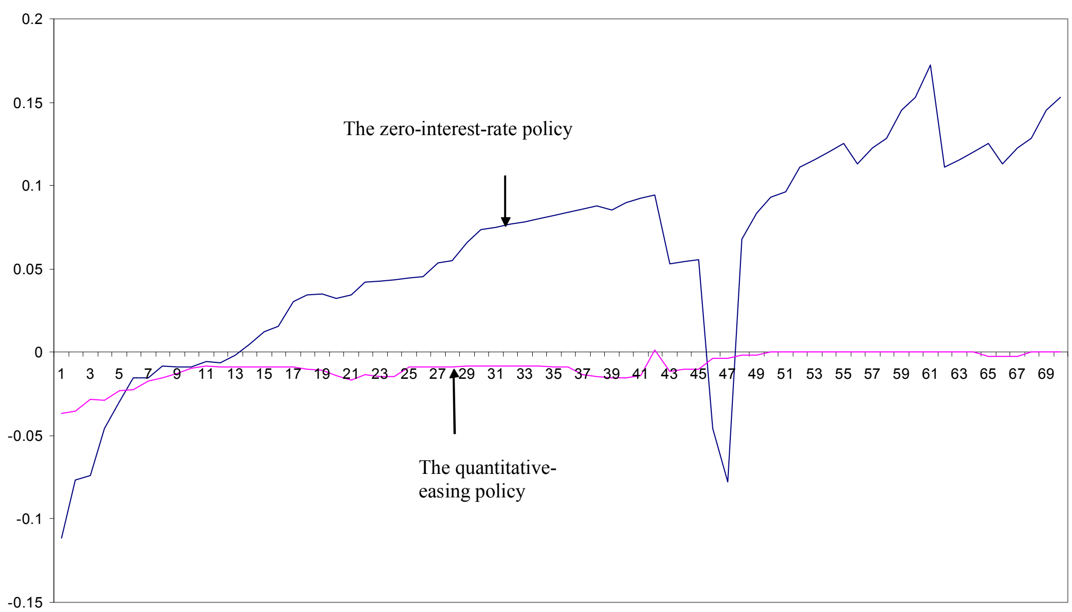
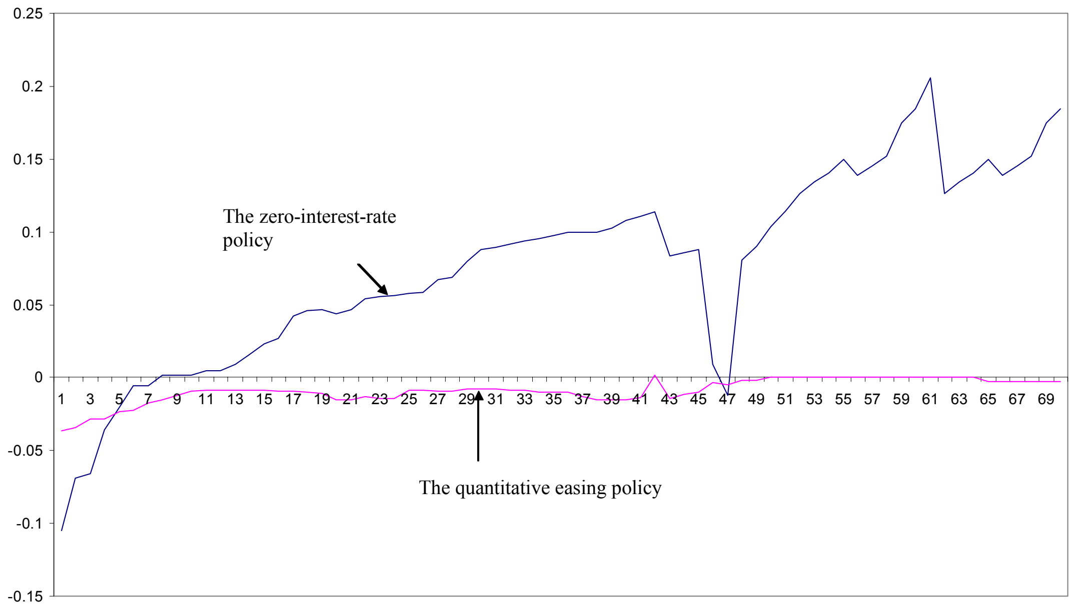


Table 3c. A Change in Ex Post Gensaki3m (Average)



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