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Monetary Policy and the Term Structure of Interest Rates in Japan

R. Anton Braun
The University of Tokyo

Etsuro Shioji
Yokohama National University

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By
R. Anton Braun
The University of Tokyo
and

Etsuro Shioji
Yokohama National University

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Abstract

This paper uses Japanese data to investigate the relationship between monetary policy and the yield curve. We compare and contrast the role of monetary policy under two perspectives. Under the liquidity effect maintained hypothesis monetary policy is an ineffective tool in altering long-term bond yields and doesn't account for much of the long-term variation in bonds of any maturity. Under the sticky price maintained hypothesis, however, monetary policy has large and persistent effects on the yield curve producing large hump-shaped responses in yields of all maturities. Moreover, under this hypothesis shocks to monetary policy and other macroeconomic variables are important sources of variation in long-term yields jointly accounting for 50% of the long-run variance of the 5-year yield.

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1 Introduction

This paper investigates the relationship between the Japanese yield curve and monetary policy. In the 1980s and 1990's average bond yields have risen from 5% to 8% and then fallen to 2% and the slope of the yield curve has swung from positive to negative to positive. We are interested in understanding the role of monetary policy in explaining these movements in the yield curve because the yield curve summarizes market expectations about future interest rates.

Currently, there are two perspectives about what monetary policy can and should do in Japan. One perspective is that with current short-term interest rates hovering at about zero that the monetary authority has used up all of its ammunition. An alternative perspective is that the monetary authority still has some ammunition left. In particular, it can still influence economic activity by taking actions that affect market expectations about the future time path of variables such as interest rates, inflation or exchange rates. One way to assess these two perspectives is to look retrospectively and ascertain the extent to which previous monetary policy surprises have affected bond yields of different maturities. If monetary policy is indeed a potent tool for altering expectations then this should show up in the responses and variance decompositions of medium and long-term bonds yields to suitably identified shocks to monetary policy.

In order to isolate the effects of monetary policy on the yield curve we must first identify monetary policy shocks. Our strategy for identifying monetary policy combines zero restrictions as in Christiano, Eichenbaum, and Evans (1996), Bernanke and Mihov (1996), Leeper, Sims and Zha (1996), Miyao (2002) and Shioji (1997) with sign restrictions on the impulse response functions as in Faust (1999) and Uhlig (1999). An advantage of our empirical strategy is that it is straightforward to investigate the robustness of any conclusions to the maintained assumptions about how monetary policy affects the macro-economy.

We consider two distinct maintained hypotheses. The *liquidity effect hypothesis* maintains that a surprise tightening in monetary policy increases short-term nominal interest rates, and lowers output, prices, and monetary aggregates. This hypothesis reflects the consensus view about how monetary policy affects the U.S. economy (See e.g. the recent survey article by Christiano, Eichenbaum and Evans (1999)). We also consider the *sticky price hypothesis*. This hypothesis maintains that a surprise tightening in monetary policy lowers interest rates, lowers money supply, lowers output and lowers prices. It is consistent with the implications of sticky price models with monopolistic competition as in: Rotemburg (1996), Christiano, Eichenbaum and Evans (1997), Ireland (1997), and Aiyagari and Braun (1998). Braun and Shioji (2002) find that Japanese data are more consistent with the sticky price hypothesis. Here we report results under each of the two maintained hypotheses in order to compare their implications for the Japanese yield curve.

The choice of maintained hypothesis has important implications for the interaction of monetary policy and the yield curve. Under the liquidity effect hypothesis innovations in monetary policy have highly transient effects on short-term interest rates and the slope and curvature of the yield curve. Moreover, monetary policy shocks only account for a small fraction of the long-run variance in yields. Under the sticky price hypothesis, in contrast, there is a rich set of interactions between monetary policy and the yield curve. Monetary policy shifts the level of the yield curve and produces large hump-shaped responses in yields of all maturities. Monetary policy also accounts for a substantial fraction of the long-term variance in long-term yields.

Our analysis is related to recent work by Ang and Piazzesi (2003) and Evans and Marshall (2001). Ang and Piazzesi (2003) consider the role of alternative macroeconomic shocks in explaining movements in U.S. Treasury yields using an affine model of the term structure and find that economic activity accounts for only a small fraction of the variance in long term bonds. Evans and Marshall (2001), in contrast, use a common factor model of the term structure and identify a variety of macroeconomic shocks. They find that demand shocks account for a significant fraction of the variance in long term bonds. Our work complements these papers in several ways. We describe how the implications of monetary policy for the yield curve vary across maintained hypotheses about the economic effects of monetary policy shocks. We also consider the role of financial shocks in explaining movements in macroeconomic variables. Finally we investigate these issues for Japan, which has a different institutional and economic environment from the United States.

2 The Model

2.1 Reduced form Vector Auto-Regression

The reduced form econometric model consists of a vector auto-regression or VAR

$$x_t = C_0 + C_1 \cdot x_{t-1} + C_2 \cdot x_{t-2} + \cdots + C_J \cdot x_{t-J} + u_t \tag{2.1}$$

where *J* denotes the number of lags, x_t is an (mx1) vector of variables and u_t is an (mx1) vector of disturbances. Denote the covariance matrix of u_t as Σ. The baseline VAR specification includes 6 lags of monthly data on four macroeconomic variables: the Consumer Price Index less food (*CPI*), Industrial Production (*Y*), the monetary base adjusted for reserve requirements (*M*), and the one month TIBOR rate (*R*). The sample period is October 1987 through May 1999. All variables are expressed in log-levels with the exception of *R*, which is expressed in levels.[1] The price level and industrial production are included because they summarize the two principal objectives of monetary policy: promoting price stability and stabilizing fluctuations in output. The Monetary base and the one month TIBOR rate are both included to help discriminate between the implications of the liquidity effect hypothesis and the sticky price hypothesis. Under the

[1] We chose to estimate the VAR in levels. This produces consistent estimates even in situations where the data are integrated or cointegrated. On the other hand, neither cointegration nor first difference specifications produce consistent estimates under the alternative that the data is stationary in levels.

liquidity effect hypothesis narrow money and the short rate move in opposite directions in response to an innovation in monetary policy. The sticky price hypothesis, in contrast, implies that these two variables move in the same direction in response to an innovation in monetary policy. This identification issue is discussed in more detail in Section 2.

A number of other variables have also been considered elsewhere in the literature. Most prominently commodity prices have been shown to render U.S. data more consistent with the liquidity effect hypothesis (see e.g. Sims (1992) and Christiano, Eichenbaum and Evans (1996)). Given the important role that exports play in the Japanese economy, the exchange rate may also be either an important information variable for the Bank of Japan or possibly a target of monetary policy. Finally, Japan imports most of its oil and economic activity may be sensitive to fluctuations in the price of oil. To explore these possibilities we also report results below in which the baseline list of macroeconomic variables is augmented to include alternatively the commodity price index (*PCOM*), the yen/$ exchange rate (*YENDOL*) or an oil price index (*POIL*).

To complete the list of variables two common factors ($F1$, $F2$) are included that in conjunction with R summarize the dynamics of the yield curve. Previous work has found that the yield curve is well-summarized by three factors that respectively shift its level, its slope and its curvature (see e.g. Litterman and Scheinkman (1988), Singleton (1994) and Hiraki, Shiraishi and Takezawa(1996)). We also assume a three-factor model of the Japanese yield curve. However, in contrast to the previous literature, the first factor is taken to be the one-month TIBOR rate. The remaining two common factors, $F1$ and $F2$ are estimated by principal components. This insures that they are by construction orthogonal to the one-month rate and to each other.[2]

2.2 identification of monetary policy

We identify monetary policy by combining a set of block recursive restrictions with sign restrictions on the impulse responses. Assume that the disturbances are driven by m structural shocks that are mutually orthogonal:

$$u_t = P^{-1} \cdot \varepsilon_t, \tag{2.2}$$

where P is a (mxm) matrix, and the covariance matrix of ε_t is a (6x6) identity matrix. Suppose further that the monetary policy shock is the fourth element in the vector ε_t. Under these assumptions identifying monetary policy amounts to determining the values of the elements in the fourth column of the matrix P^{-1}.

Recursive restrictions

We start by partitioning the model variables into three groups. For the baseline economy prices and output are assigned to the first partition, monetary base and the nominal interest rate are assigned to the second partition and the two yield curve common factors are assigned to the third partition. Assume further that P^{-1} is block triangular:

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[2] More details on the construction of the common factors is provided in section 3.

$$P^{-1} = \begin{pmatrix} P_{11}^{-1} & 0 & 0 \\ P_{21}^{-1} & P_{22}^{-1} & 0 \\ P_{31}^{-1} & P_{32}^{-1} & P_{33}^{-1} \end{pmatrix} \tag{2.3}$$

Under these assumptions shocks to variables in the first partition affect all variables contemporaneously, shocks to variables in partition 2 affect only variables in the second and third partition, and shocks to variables in the third partition have no contemporaneous impact on variables in either the first or second partitions.

This block recursive structure partitions the time t information set of the monetary authority into two parts: variables that the monetary authority observes prior to setting current period monetary policy and variables that the monetary authority doesn't observe contemporaneously. In particular, we assume that the monetary authority observes the current shocks to output and prices prior to setting monetary policy but, does not observe the period t shocks to either financial sector variable. The former restriction is relatively common in the literature (See e.g. Christiano and Eichenbaum (1992), Bernanke and Blinder (1992), and Gertler and Gilchrist (1994)) and is also consistent with the implications of dynamic general equilibrium models of money such as Christiano, Eichenbaum and Evans (2001).

The latter restriction is imposed to mitigate the risk of an identification problem raised by Leeper, Sims and Zha (1996). They give an example of a monetary policy feedback rule that reacts to multiple current period interest rates and show that this rule can induce indeterminacy of equilibrium and can also render identification infeasible.

Our assumptions also imply that demand for the monetary base does not respond contemporaneously to shocks in the two common factors. We think of demand for base money as coming from three main sources; exchange credit that facilitates trade among firms as in Kahn and Roberds (2002); transactions demand by households- carrying cash can be convenient if ATM machines are not nearby or closed[3]; and money is needed to settle tax payments with the government. We are assuming that each of these three demands for money is insensitive to current shocks to the yield curve.

Given this block recursive structure, identification of the innovation to monetary policy involves pinning down the coefficients in P_{22}^{-1} and P_{32}^{-1}. In a technical appendix available on request from the authors, it is shown that the identification of P_{22}^{-1} does not depend on the values of P^{-1} in partitions 1 and 3.[4] It is also shown that

$$P_{32}^{-1} = \Theta \cdot P_{22}^{-1} \tag{2.4}$$

where Θ is a two by two matrix that is uniquely determined from Σ. Once P_{22}^{-1} is identified, P_{32}^{-1} is also identified. Thus, identification of sector 2 shocks can proceed without making any further assumptions about how the shocks in the other two sectors are identified.

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[3] In Japan many ATM machines close on weekends and/or evenings.

[4] In particular, it is shown that P_{22}^{-1} can be derived without referring to any of the elements of the other partitions.

Sign restrictions

We turn next to describe the identification of P_{22}^{-1}. The general strategy is to use simulation methods to produce a pseudo-random sequence of VAR parameters and P_{22}^{-1}'s, and then to use these objects to construct a pseudo-random sequence of impulse response functions. Given this sequence of impulse response functions rejection methods are used to select the subset of the sequence that satisfies identification restrictions that come from theory.

As in Uhlig (1999), we start by taking k_1 random draws from the posterior distribution of the reduced form VAR coefficients, $C \equiv [C_0, C_1, ...C_J]$, and the covariance matrix of disturbances, Σ. The posterior distribution is derived under the assumption of a diffuse Jeffries prior over the parameters of the VAR. Following Zellner (1971), if the joint distribution of the VAR disturbances is i.i.d. normal and the elements of C are independent of the elements of Σ then a Jeffries prior implies C has a normal conditional posterior distribution and Σ has an Inverse Wishart conditional posterior distribution (See Chapter 8 of Zellner (1971), Doan (2000) or Uhlig (1999) for more details). Given a draw from the posterior distribution of the VAR parameters, the next step is to construct P_{22}^{-1}. Our interest centers on the second column of P_{22}^{-1} because it corresponds to a shock in monetary policy. The elements of P_{22}^{-1} are related to Σ, in the following way:

$$\Omega \equiv \Sigma_{22} - \Sigma_{21} \cdot \Sigma_{11}^{-1} \cdot \Sigma_{21}' = P_{22}^{-1} P_{22}^{-1}'.^{5} \tag{2.5}$$

Denote the eigen-values of Ω as μ_1 and μ_2, and the corresponding eigenvectors by v_1 and v_2. Then, *a*, the second column of P_{22}^{-1} is given by:

$$a = \sum_{i=1}^{2} \alpha_i \cdot \sqrt{\mu_i} \cdot v_i \tag{2.6}$$

where the α 's are the weights attached to each of the two eigen-values. Without loss of generality suppose that the α 's sum to one. Then (2.6) implies that an innovation to monetary policy is only identified up to a one-dimensional continuum that is indexed by α_1.

As in Uhlig (1999), we use rejection methods to impose restrictions from theory and thereby restrict attention to a subset of this one-dimensional continuum. This is accomplished by drawing k_2 random α_1's from a uniform [0,1] distribution, setting α_2 so that the α 's sum to one, calculating impulse response functions to monetary policy and rejecting the draw if it violates the sign restrictions that we describe next.

We consider two distinct sets of sign restrictions. Each set of sign restrictions corresponds to a maintained hypothesis about how monetary policy affects economic activity. The first maintained hypothesis is referred to as the *Liquidity Effect Hypothesis*. Under this hypothesis we assume that

[5] This derivation is reported in the technical appendix, which is available on request from the authors.

(1) the response of the price level is negative in a majority of the first 7 months following the arrival of a contractionary shock to monetary policy; [6]

(2) the response of output is negative in a majority of the first seven months following the arrival of the shock;

(3) the response of the monetary base is negative in a majority of the first six months;

(4) the response of the one-month rate is positive in a majority of the first six months.

The liquidity effect maintained hypothesis is designed to reflect the consensus view about how monetary policy affects the economy. Friedman (1968) suggests that liquidity effects might last for up to a year. And results reported in the survey article by Christiano, Eichenbaum and Evans (1999) are consistent with these restrictions with the possible exception of the price level.[7]

The second maintained hypothesis is referred to as the *Sticky Price Hypothesis.* The sticky price hypothesis consists of the following sign restrictions:

(1) the response of the price level is negative in a majority of the first 7 months following the arrival of an innovation to monetary policy;

(2) the response of output is negative in a majority of the first seven months following the arrival of a shock to monetary policy;

(3) the response of the monetary base is negative in a majority of the first six months following the arrival of a shock to monetary policy;

(4) the response of R is negative in a majority of the first six months following the arrival of a shock to monetary policy.

This second hypothesis is consistent with the implications of monopolistically

[6] In what follows, the month in which the shock arrives is labeled 0.

[7] They describe the price level response as small, but not necessarily negative in early periods. This aspect of the maintained hypothesis is explored in detail in Braun and Shioji (2002) who find that relaxing the sign restriction on prices produces a large, persistent and statistically significant price puzzle in Japanese data.

competitive sticky price models such as Rotemberg (1996), Christiano, Eichenbaum and Evans (1997), Ireland (1997) and Aiyagari and Braun (1998). In these models a surprise contraction in monetary policy reduces output in the short-run because prices are now high relative to future periods, gradually lowers prices, lowers the growth rate of monetary aggregates and lowers nominal interest rates due to an expectation that inflation in future periods will fall. While these responses are consistent with some leading sticky price models of money, not all sticky price models have this property. Christiano, Eichenbaum and Evans (2001), for example, develop a sticky price model in which the responses of the economy to shocks in monetary policy are consistent with the liquidity effect hypothesis. Instead, it is probably best to view this hypothesis as reflecting effects that are *plausible* in the sense that they are the dominant effect in the dynamic general equilibrium models listed above.

Our algorithm places restrictions on both the choice of *P and* the parameters of the reduced form VAR. This approach to identification differs from the standard approach in this literature, which seeks to identify *P* conditional on a particular choice of the model parameters. In Section 3 we compare and contrast the two approaches.

Observe also that the form of the sign restrictions is based entirely on the sign and assigns no weight to the magnitude of the responses. On the one hand, count restrictions better reflect the nature of the consensus about how monetary policy affects the economy. Statements of the consensus perspective focus more on signs than magnitudes (see e.g.

Christiano, Eichenbaum and Evans (1999)). On the other hand, it is possible that sign counts rule out identifications that, for instance, produce big but highly transient liquidity effects. Below we will show that the empirical results are robust to the choice of imposing the hypotheses as sign count restrictions or, alternatively, restrictions on the mean responses over the first 6-7 periods.

3 Estimation results

3.1 Estimation and simulation of the model

Estimation and identification of the model proceeds in three steps. First, the common factors of the term structure are estimated. Second, the VAR is estimated and third, monetary policy is identified using the simulation based rejection method described above.

The underlying data consists of zero-coupon equivalent yields with 11 different maturities. Common factors are constructed from the yield data in the following manner. Each of the eleven yields was regressed on the 1-month rate. Then a principal component analysis was performed on the eleven residual series. This analysis indicated that the components corresponding to the two largest eigen-values explain 95.1% of the total variation in the eleven residual series. As a check of the ability of the 1-month rate and the two common factors to summarize movements in yields of alternative maturities, each of the 11 yields was regressed on these three variables. The R square from the regressions was greater than 0.990 in all cases.

The weights the 1-month rate and the two common factors receive on each yield are reported in Table 1. Inspection of Table 1 indicates that the patterns of the estimated coefficients do not bear much resemblance to the level, slope and curvature factors. The magnitude of the first factor (1-month TIBOR rate) falls by nearly half as the maturity of the yield rises from 2 months to 10 years. In addition, the sign changes that one would associate with slope or curvature factors are not present in the coefficients for the first factor. The coefficients for the second factor show a change of sign but the magnitude of the 2 month yield and 120 month yield are not very close in absolute value.

Given this difficulty in interpreting these factors it is perhaps helpful to explain why we chose to proceed in this manner. The main consideration is parsimony. Since the VAR already includes the one-month rate, treating the one-month rate as a common factor and adding two additional factors summarizes the same information as a conventional three factor model and reduces the number of estimated coefficients by 92.

When estimating the VAR we treat the two estimated common-factors as data as in e.g. Bernanke and Boivin (2003). Moreover, responses of yields also condition on the weights reported in Table 1. Our two step procedure understates the inherent uncertainty in the model. An alternative strategy would be to directly include additional yields in the VAR instead of the two common factors. We chose not to pursue this alternative strategy because of a concern about the numerical stability of the estimates. Yields of different maturities are highly correlated. For our dataset, the contemporaneous correlation coefficients range between 0.95 and 0.99. In such a situation including multiple yields in the same VAR can have a large effect on the condition number of the data matrix that one inverts in the course of OLS estimation of the model.[8] For Japanese data this problem is compounded by the fact that the sample period over which yields are available is relatively short and comovements in the data are strongly influenced by the rise and fall of stock and land prices in the late 1980's and 1990's.

With the common factors in hand, the VAR is estimated and the restrictions of the liquidity effect maintained hypothesis are imposed. Following the discussion in Section 2, the first step is to take a pseudo-random draw from the posterior distribution of the VAR coefficients. Next we take 100 draws from the free elements of P_{22}^{-1} and check to see if they satisfy the sign restrictions for the sticky price hypothesis. For successful draws we tabulate partial sums of the impulse response functions and variance decompositions. This process is repeated for 500 draws from the posterior distribution of the VAR coefficients producing a total of 50,000 trials. Finally, the averages and standard deviations of the impulse responses, and variance decompositions are calculated. This same set of procedures is then repeated for the sticky price maintained hypothesis.

3.2 What are the effects of monetary policy on economic activity and yields under

[8] When the 12 month 36 month and 50 month yields are included instead of the common factors, the condition number of the data matrix exceeds 30,000,000,000.

the two hypotheses?

Impulse responses: liquidity effect hypothesis

The left panels of Figure 1 and 2 report impulse responses to a tightening in monetary policy under the liquidity effect maintained hypothesis. Figure 1 contains responses for the VAR variables and also *LEVEL*, *SLOPE*, *CURVATURE* and the real interest rate. Figure 2 shows responses of 2-month, 12-month and 60-month yields and term premia.[9] The responses for prices, output, and monetary base are expressed in percent (.01=1%) and the other variables are expressed as annualized basis points.

The results reported in Figure 1 are based on an overall total of 486 successful draws or about 1% of the 50,000 trials. Only 8.4% of the outer-loop draws from the posterior produce one or more valid draw. And on average each successful draw from the posterior distribution produces about 12 valid α_1's.

Under the liquidity effect maintained hypothesis monetary policy has large but highly transient effects on economic activity. The response of output is large and immediate. A one standard deviation (10 basis point) tightening in the 1-month rate produces a peak decline in the level of output of 20/100th's of a percent in the second month following the tightening. However, neither the output response nor the 1-month rate response is very

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[9] The impulse responses reported in these and all other figures are the average of the impulse responses across valid draws. The other two lines in each figure are upper and lower two standard deviation error bands.

persistent. Both variables are within 2 standard deviations of zero within four months after the shock arrives and damp quickly. The two common factors also respond significantly on impact but then damp quickly thereafter. Prices don't respond much in early periods but gradually fall over time. None of the price responses are more than two standard deviations from zero. The monetary base is the only variable with a persistent response that is precisely estimated. Monetary base drops on impact and is more than two standard deviations from zero in most periods.

Figure 1 also reports the responses of *LEVEL, SLOPE, CURVATURE* and the real 1-month interest rate. The definitions of *LEVEL, SLOPE,* and *CURVATURE* follow the example of Ang and Piazessi (2003). *LEVEL* is the average response of the 1-month rate, the 12-month yield and the 60-month yield. *SLOPE* is the response of the 60-month yield minus the 1-month rate and *CURVATURE* is defined as the response of the 1-month rate plus the 60-month rate minus the twice the 12-month rate. Finally, the real interest rate is the 1-month rate net of the expected inflation rate. A comparison of *LEVEL*, *SLOPE* and *CURVATURE* with respectively the 1-month rate, $F1$ and $F2$ indicates that the shapes and statistical significance of the responses are very similar. The biggest difference concerns the impact response of *LEVEL* and the 1-month rate. Monetary policy innovations induce a larger impact response in the 1-month rate. This difference may explain why the coefficients on the 1-month rate in Table 1 are declining in maturity.

The response of the real interest rate is large but imprecisely estimated. On impact, the response is 18 basis points and rises to a maximum of 23 basis points. In subsequent periods it continues to fluctuate but with no distinct pattern. The error bands are also very large though indicating that the precision of these estimates is very low.

Figure 2 reports the response of the yield curve, term premia and two standard deviation confidence bands to the same innovation for maturities of 6-months, 12-months and 5-years.[10] Term premia are calculated as departures from the Expectations Hypothesis as in Evans and Marshall (1998).[11]

Figure 3 has three noteworthy features. First, the magnitude and statistical significance of the impact responses fall with maturity. While the response of the 6-month yield is about 6 basis points and about two standard deviations away from zero, the response of the 5-year yield is less than 4 basis points and within one standard deviation of zero. Second, the effect of monetary policy shocks on the yield curve under the Liquidity Effect hypothesis disappears after about 7 months. Third, term premia responses are small, transient and similar to the responses of yields. This follows from transient nature of the 1-month rate responses. Averages of future 1-month rate responses are about zero. These results imply that innovations in monetary policy only have transient effects on short end of the yield curve under the liquidity effect maintained hypothesis.

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[10] These confidence bands are likely to overstated the precision of these estimates due to our two step estimation procedure.

[11] The period t term premium response for a J period bond is: $tprem_{t,J} = y_{t,J} - \frac{1}{T}\sum_{j=0}^{J-1} y_{t+j,1}$.

Impulse responses: Sticky price hypothesis

Figure 1 also reports impulse response functions for the sticky price hypothesis. The results are based on the same number of replications as for the liquidity effect hypothesis. Here the total number of successful draws rises to 8532 or about 17% of the total draws. Over 66% of the draws from the posterior distribution of the parameters produce at least one valid identification and the average number of valid α_1's per successful draw from the posterior distribution of parameters exceeds 25.

These impulse responses correspond to a *contractionary* surprise in monetary policy, that is, a monetary policy shock that lowers output. By comparing the left and right panels of Figure 1 we see that the sticky price maintained hypothesis produces responses that are larger in magnitude and more persistent. The response of output (industrial production) is bowl-shaped and falls by a maximum of 0.04% in the twelfth month following a one standard deviation (12 basis point) decline in the one-month rate. Prices and the one-month rate also fall persistently. These responses also exhibit higher precision than under the alternative liquidity effect maintained hypothesis. Price responses are about two standard deviations below zero from month seven and on. And the responses of output are more than two standard deviations below zero in 6 out of the first 12 months following the shock.

Once again the responses and precision of *LEVEL*, *SLOPE* and *CURVATURE* are quite similar to the responses of respectively the one-month rate, *F*1 and *F*2. Now monetary policy shocks have potent dynamic effects on the level of the yield curve. *SLOPE* first falls and then rises and curvature goes up in early periods.

The response of the real interest rate is also now somewhat smaller but more persistent. It declines by 21 basis points on impact and gradually rises to -6 basis points by month 24. As before, the real interest rate responses are imprecisely estimated.

Responses of yields and term premia to an innovation in monetary policy are reported in the right panel of Figure 2. From the perspective of the sticky price hypothesis monetary policy has big and persistent effects on yields of all maturities. All yields have bowl-shaped responses that bottom out at about month seven at 18-20 basis points. The responses are also more precisely estimated as compared to the left panel of Figure 2. Yields with maturities of 6 and 12-months are both more than two standard deviations below zero for more than a year and the 5-year yield is more than two standard deviations below zero for 9 months. The increased persistence in the 1-month rate response also produces persistent responses in term premia. Twenty-four months after the shock term premia for all three yields are still between 5 to 6 basis points below zero.

Variance decompositions

Table 2 reports the fraction of variance in output, prices, monetary base, interest rates, the two common factors and the 12-month and 5-year yields accounted for by innovations in monetary policy. The numbers in parentheses are standard errors. Under the liquidity effect maintained hypothesis monetary policy explains only about 5% of the variance in prices, 4% of the variation in output and 6-7% of the variance in yields. Interestingly, monetary policy does explain a significant fraction of the variance in monetary base and the 1-month rate at step 1. Clarida, Gertler and Gali (2000) suggest that one property of an optimal monetary policy is to insulate the economy from money demand shocks by sterilizing the effects of these shocks on short-term interest rates. The pattern of variance-decompositions reported here are suggestive of what one might expect to find if this was the primary objective of monetary policy.

Under the sticky price maintained hypothesis monetary policy continues to be an important source of variation in monetary base and short-term rates. However, monetary policy is also more important for understanding movements in other variables. Now, the fraction of variance in output and prices accounted for by innovations in monetary policy is bigger. At step 60 monetary policy explains 16% of the variance in prices and 16% of the variance in output. Under the sticky price maintained hypothesis monetary policy is also important for understanding movements in yields of all maturities at all forecast horizons. At step 12, monetary policy accounts for 40% of the variation in the 12-month yield and 35% of the variation in the 5 year yield. And at step 60 monetary policy explains 28% of the variation in both yields.

3.2 Is Japanese data more consistent with the liquidity effect hypothesis or the sticky price hypothesis?

A possible concern about our method for identifying monetary policy is that good draws are sufficiently rare that they may be coming from the tail of the posterior distribution of parameter coefficients and in this sense may not be representative of the data. Some of the diagnostics presented above suggest that this is more of an issue for the liquidity effect hypothesis. For instance, only 8% of the draws from the posterior distribution of the VAR parameters produce one or more draws that are consistent with this hypothesis. For the sticky price hypothesis the corresponding figure is 66%.

In order to investigate this issue further we conditioned on the estimated parameters of the VAR as is the convention in the structural VAR literature and took 50,000 draws from α_1. For the sticky price hypothesis the fraction of successful draws was 28%. Moreover, the impact responses of monetary base and the 1-month rate are precisely estimated.[12] However, for the liquidity effect hypothesis no successful draws were found.

We then increased the number of replications to 100,000 and still found no successful draws.[13] We draw three conclusions from these results. First, the sticky price maintained hypothesis is more consistent with Japanese data than the liquidity effect alternative.[14] Second, if one conditions on the estimated parameters of the VAR when conducting a

[12] The average impact response of monetary base is -0.35% with a standard error of .089% and the 1-month rate response is -13 b.p. with a standard error of 2.1 b.p.

[13] We also checked the robustness of this conclusion to the variants of the model reported in Section 4 below. However, if we condition on the estimated VAR coefficients and perform 50,000 replications, no successful draws are found under the liquidity effect hypothesis.

[14] See Braun and Shioji (2002) for a detailed investigation of the plausibility of the two

specification search for monetary policy, it is likely to be quite difficult to find any specification that is consistent with the liquidity effect hypothesis. Third, for those who place strong faith in the liquidity effect hypothesis, allowing for parameter uncertainty in the VAR coefficients provides a way to reconcile this prior with Japanese data. Based on these results and in order to conserve space, the remainder of the paper will just report results for the sticky price maintained hypothesis.

4 Additional implications of the sticky price maintained hypothesis

4.1 Are macroeconomic shocks important sources of variation in the yield curve?

Ang and Piazessi (2003) using U.S. Data find that macroeconomic shocks are important for explaining movements in short-term yields but not important for understanding movements in long-term yields. Evans and Marshall (2001), in contrast, find that macroeconomic shocks explain most of the long-run movements of yields. Variance decomposition results reported in Table 3 allow us to assess the role of macroeconomic shocks in explaining the dynamics of Japanese yields. This table reports the variance decomposition of the 12-month and 60-month yield using the baseline Sticky price specification. At short-forecast horizons, monetary policy and the two common factors explain most of the variance in the yield curve. At step 1, about 56% of the variance in the 12-month yield and 73% of the variance in the 5-year yield is explained by the combination of the two common factors. At longer horizons, though the macroeconomic

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hypotheses.

shocks are more important. At step 60, the combination of output and prices accounts for about 38% of the variance in the 12-month yield and about 25% of the variance in the 5-year yield. Monetary policy explains another 30% of the movements in these two yields. Overall, our results for Japan are more consistent with the findings of Evans and Marshall (2001). However, monetary policy is more important in Japan for understanding long-run movements in long-term yields. This finding is consistent with some other facts about the Bank of Japan. As compared to the Federal Reserve, the Bank of Japan holds a much larger fraction of long-term bonds on its balance sheets. About 60% of Japanese Monetary Base is backed by long-term government bonds. In addition, the overall size of the Bank of Japan's balance sheets is substantially larger than those of the Federal Reserve.

4.2 Are financial shocks important sources of variation in macroeconomic activity?

Estrella and Hardouvelis (1991) using U.S. data find that the slope of the yield curve is a predictor of future economic activity in the 1970's and 1980's. Table 4 reports decompositions of the variance of output and prices under the sticky price maintained hypothesis. Financial shocks don't explain much of the variance in either prices or output at short and medium (1 year) horizons. At long horizons financial sector shocks are somewhat more important. $F1$ and $F2$ explain a combined fraction of 17% of the variance in prices and 26% of the variance in output at step 60.

4.2 Are the results robust?

Here we explore the robustness of the results in our baseline specification along three dimensions: the choice of variables, the specification of the nominal interest rate and the method of imposing the sign restrictions.

Figures 3 and 4 report the impulse responses for specifications in which we add a seventh variable to the VAR. Our interest here is determining whether our conclusions depend in an important way on the choice of variables. The first panel of each figure reports results for the baseline VAR variables plus *PCOM*, a commodity price index ordered third in the first block. The center panel reports results for the baseline variables plus *POIL*, the price of oil ordered third in the first block and the right panel reports results for the baseline variables with the yen/$ exchange rate (*YENDOL*) ordered first in the third block of variables. A comparison of these results with the baseline specification results reported in Figures 1 and 2 suggests that adding these variables does not have much of an effect on the results reported above. The main difference is that including the yen/$ exchange rate dampens the response of the real interest rate. The implications for the yield curve though are virtually the same as the baseline specification.

Given that nominal interest rates in Japan are very low and simple arbitrage arguments suggest that zero is a lower bound, it is also interesting to consider ways to impose this restriction on the specification and investigate whether such restrictions affect our results. We considered two ways to impose this restriction. First, we add an additional test to the Monte Carlo simulations that requires that the unconditional mean of the 1-month rate was restricted to be non-negative. This doesn't rule out negative realizations of the nominal interest rate but does rule out the possibility of a negative average nominal interest rate. When we do this the number of successful draws falls to 3450. However, imposing this restriction has virtually no impact on the impulse response functions.[15] Second, we considered the following nonlinear transformation of the mean of the nominal interest rate:

$$\tilde{R}_t = \begin{cases} R_t, & R_t > 1\% \\ \ln(R_t)+1, & R_t <= 1\% \end{cases} \tag{2.7}$$

where the one month rate is expressed as an annualized percentage. This transformation rules out negative realizations of the 1-month rate in situations where the mean of the 1-month rate is less than 1%. The fraction of successful draws based on this specification is 19% and the impulse response functions are also close to those from the baseline specification.[16]

Finally, we performed runs in which the mean response during the first 6 periods was restricted instead of the sign. In this case, the fraction of successful draws for the baseline specification rises to 24% but the impulse responses are again qualitatively and quantitatively similar to the baseline case.[17]

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[15] For instance, the peak decline of the 5 year yield is –18.61 in the baseline case and –18.91 when R is restricted to be non-negative.
[16] Here the peak decline in the 5 year yield is –16.03.
[17] The maximum decline in the 5 year yield is –18.1.

5 Concluding remarks

In this paper we have considered the effect of monetary policy on the Japanese yield curve. We have found that the effectiveness of monetary policy in affecting future expectations depends importantly on the maintained hypothesis about how monetary policy affects the economy. According to the liquidity effect hypothesis monetary policy is an ineffective tool at manipulating expectations about future nominal interest rates. Neither long-term bonds nor term premia respond persistently to monetary policy shocks. The alternative of the sticky price maintained hypothesis, paints an entirely different picture. According to this perspective shocks to monetary policy in the 1980's and 1990's were important sources of variation in bonds of all maturities. Moreover, this hypothesis implies that the monetary authority has lots of ammunition. Monetary policy surprises that act to drive up short rates will alter expectations about future interest rates by shifting the level of the yield curve up in a persistent way and thereby stimulate the Japanese economy for a period of about two years.

In future work we plan to consider a broader array of assets and undertake a more complete identification of other macro shocks. This will allow us to quantitatively assess the role of various macroeconomic shocks in explaining events such as the collapse of the Japanese asset price boom in 1990.

Data Appendix

Our data for the Consumer Price Index and Industrial Production (both seasonally adjusted, 1990 average = 100) come from the Nikkei NEEDS Macroeconomic Database. Our data for the Monetary Base (adjusted for reserve requirement ratio changes, monthly average, seasonally adjusted) were downloaded from the Bank of Japan's web site.

The yield data used to estimate the two common factors consists of TIBOR rates with maturities of 2, 3, 6, 9 and 12 months and off-shore swap rates with maturities of 24, 36, 48, 60, 95, and 120 months. All yields are expressed on a zero coupon equivalent basis. The source of this data is Datastream.[18]

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[18] TIBOR and off-shore swap rate data are used because there is more liquidity at the various maturities in these markets than in the Japanese Government Bond (JGB) market. Volume in the JGB market is thin at many maturities and most transactions are concentrated in the market for the 10 year bell-weather bond.

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Table 1

Weights of nominal interest rate and two common factors on yields

yield	1 month rate	factor 1	factor 2
2 month	0.999	0.032	-0.074
3 month	0.996	0.052	-0.118
6 month	0.986	0.109	-0.188
9 month	0.971	0.158	-0.216
12 month	0.963	0.191	-0.23
24 month	0.907	0.359	-0.172
36 month	0.851	0.439	-0.078
48 month	0.793	0.494	0.011
60 month	0.746	0.515	0.066
85 month	0.660	0.542	0.148
120 month	0.595	0.498	0.167

Table 2a

Percentage of variance explained by monetary policy: Liquidity effect maintained hypothesis

variable	Step 1	Step 12	Step 60
Prices	0.30	0.99	5.38
	(0.38)	(1.15)	(4.06)
Industrial Production	2.89	3.19	3.92
	(2.30)	(2.05)	(2.43)
Monetary Base	57.93	46.79	17.37
	(26.16)	(12.78)	(13.55)
One month rate	28.56	10.05	6.71
	(25.31)	(12.72)	(9.39)
First common Factor	4.13	5.87	5.61
	(2.33)	(3.28)	(3.49)
Second Common Factor	11.29	11.00	7.44
	(5.85)	(4.87)	(5.12)
12 month yield	8.67	8.36	6.21
	(11.80)	(10.87)	(8.45)
5 year yield	4.75	7.61	6.85
	(6.42)	(8.68)	(8.38)

Table 2b

Percentage of variance explained by monetary policy: Sticky Price maintained hypothesis

Variable	Step 1	Step 12	Step 60
Prices	0.28	6.52	16.07
	(0.41)	(5.43)	(10.92)
Industrial Production	2.77	11.37	15.52
	(2.20)	(8.74)	(10.21)
Monetary Base	41.61	20.99	25.16
	(26.57)	(12.76)	(15.42)
One month rate	45.17	41.90	28.17
	(24.41)	(16.00)	(13.29)
First common Factor	2.87	12.24	17.31
	(1.98)	(7.72)	(9.39)
Second Common Factor	6.49	15.46	23.26
	(3.83)	(5.80)	(10.74)
12 month yield	26.83	39.97	27.77
	(12.52)	(15.30)	(12.92)
5 year yield	13.97	35.07	27.56
	(8.08)	(14.16)	(13.05)

Table 3a

Percentage of variance in 12 month yield explained by VAR shocks under sticky price hypothesis

innovation to:	**Step** 1	12	60
Prices	2.69	4.98	13.12
	(2.40)	(4.72)	(9.54)
Industrial Production	1.54	6.37	15.00
	(2.10)	(6.52)	(10.68)
Monetary Base	12.69	10.50	8.17
	(11.80)	(11.31)	(7.42)
Monetary Policy	26.83	39.97	27.77
	(12.52)	(15.30)	(12.92)
First common Factor	41.80	16.27	11.55
	(7.49)	(8.62)	(7.24)
Second Common Factor	14.45	21.91	24.39
	(3.38)	(11.20)	(13.20)

Table 3b

Percentage of variance in 5 year yield explained by VAR shocks under sticky price hypothesis

innovation to:	**Step** 1	12	60
Prices	2.62	6.86	11.71
	(2.50)	(5.42)	(8.91)
Industrial Production	2.12	8.51	13.83
	(2.38)	(10.47)	(8.27)
Monetary Base	8.26	35.07	27.56
	(7.46)	(14.16)	(13.05)
Monetary Policy	13.97	35.07	27.56
	(8.08)	(14.16)	(13.05)
First common Factor	72.31	29.07	18.49
	(7.52)	(10.25)	(8.73)
Second Common Factor	0.71	9.63	19.20
	(0.38)	(7.20)	(12.04)

Table 4a

Percentage of variance in macroeconomic variables explained by first common factor

Variable	**Step** 1	12	60
Prices	0.41	2.78	6.48
	(0.58)	(2.74)	(5.48)
Industrial Production	0.77	16.06	13.82
	(1.01)	(8.50)	(8.26)
Monetary Base	0.79	10.04	8.72
	(0.95)	(6.99)	(8.17)
One month rate	8.04	10.89	9.28
	(3.96)	(8.14)	(7.23)

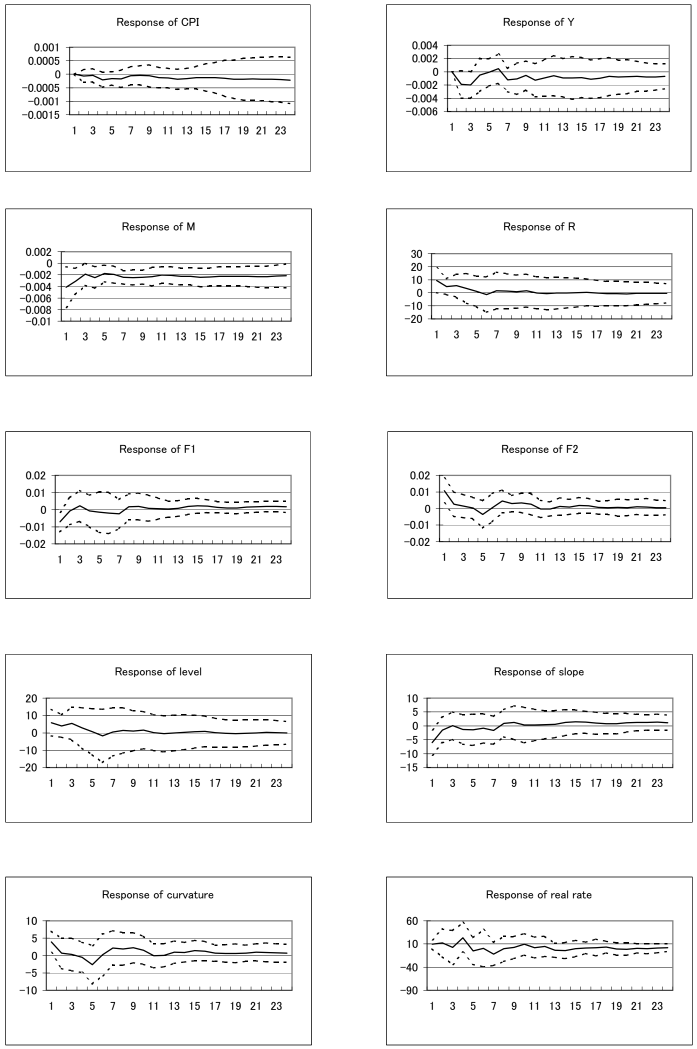
Table 4b

Percentage of variance in macroeconomic variables explained by second common factor

Variable	**Step** 1	12	60
Prices	1.20	3.51	10.06
	(1.15)	(2.60)	(8.75)
Industrial Production	3.55	7.10	12.29
	(2.45)	(5.71)	(8.12)
Monetary Base	0.57	5.56	22.46
	(0.82)	(4.70)	(14.44)
One month rate	7.25	23.65	24.78
	(3.12)	(11.37)	(13.73)

Figure 1

Response of VAR variables to
shock to Monetary Policy
Liquidity Effect Maintained Hypothesis
500 outerloop draws, 100 innerloop draws
Baseline specification



Response of VAR variables to
shock to Monetary Policy
Sticky Price Maintained Hypothesis
500 outerloop draws, 100 innerloop draws
Baseline specification

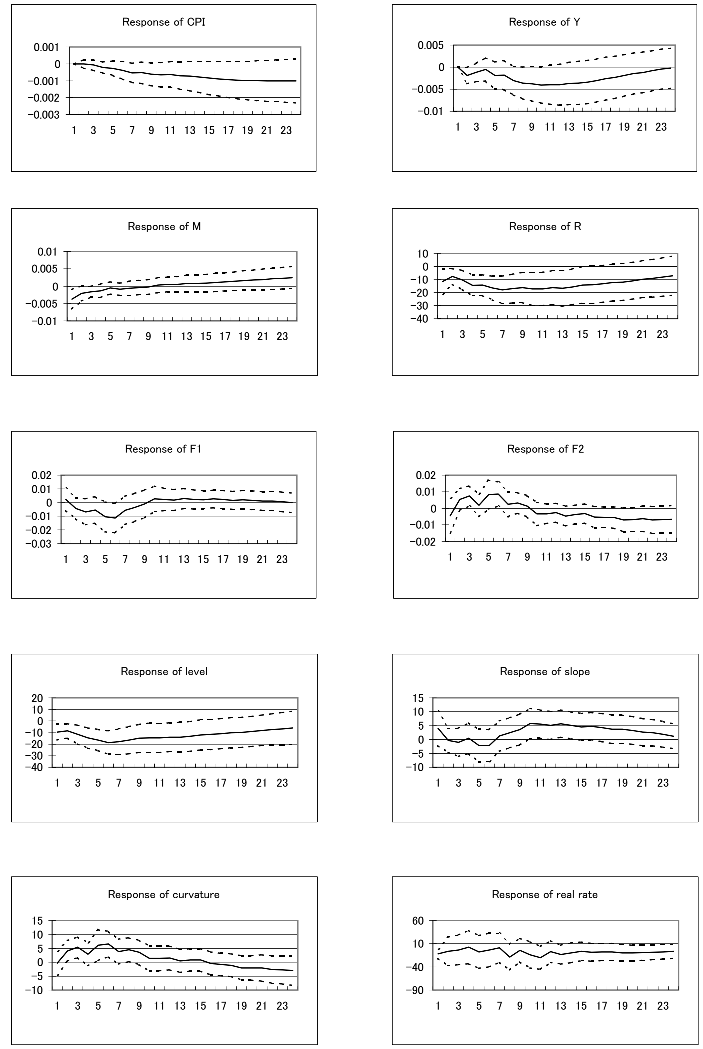
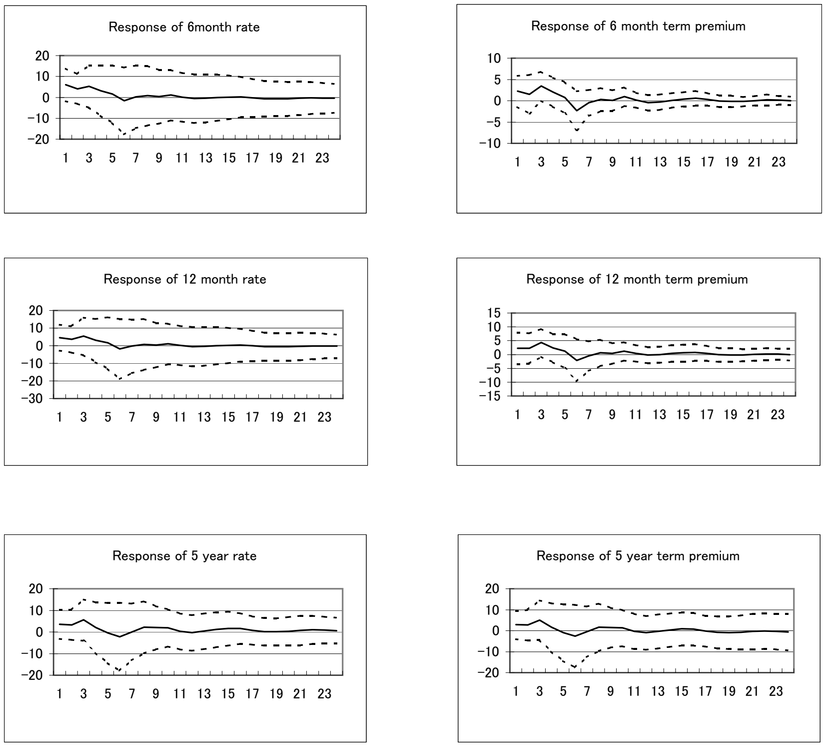


Figure 2

Response of VAR Yield Curve to
shock to Monetary Policy
Liquidity Effect Maintained Hypothesis
500 outerloop draws, 100 innerloop draws
Baseline specification



Response of VAR Yield Curve to
shock to Monetary Policy
Sticky Price Maintained Hypothesis
500 outerloop draws, 100 innerloop draws
Baseline specification

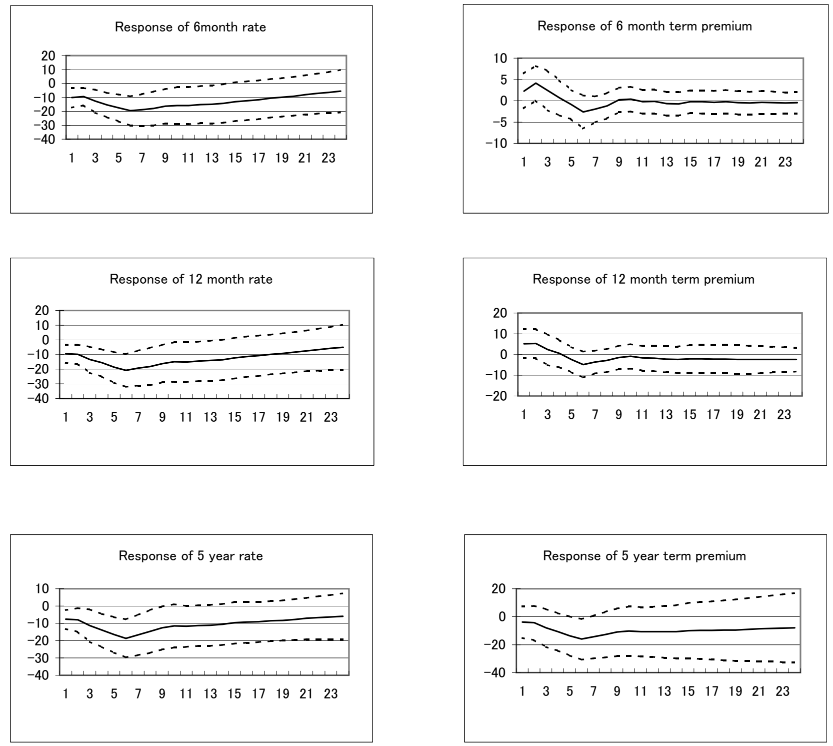
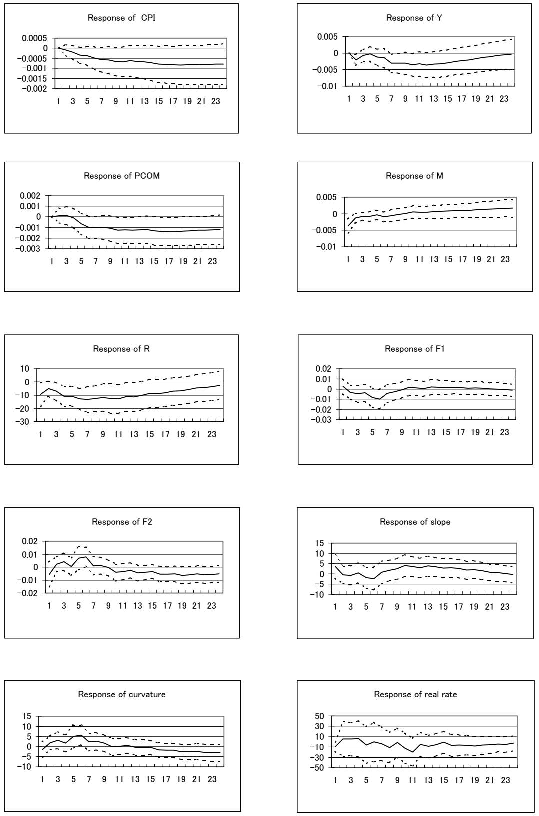
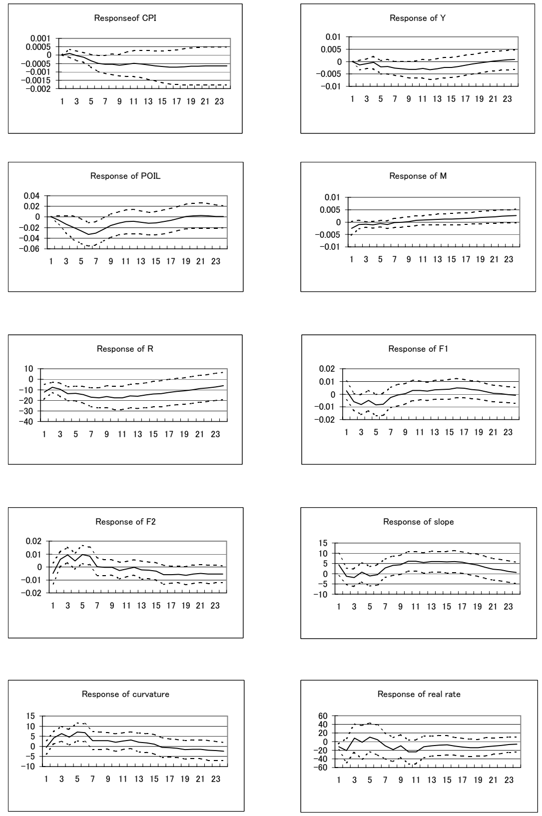


Figure 3

Response of VAR variables to
shock to Monetary Policy
Sticky Price Maintained Hypothesis
500 outerloop draws, 100 innerloop draws
baseline variables and pcom (ordered 3rd)



Response of VAR variables to
shock to Monetary Policy
Sticky Price Maintained Hypothesis
500 outerloop draws, 100 innerloop draws
baseline variables and POIL (ordered 3rd)



Response of VAR variables to
shock to Monetary Policy
Sticky Price Maintained Hypothesis
500 outerloop draws, 100 innerloop draws
baseline variables and yen-dollar exchange rate ordered 5th

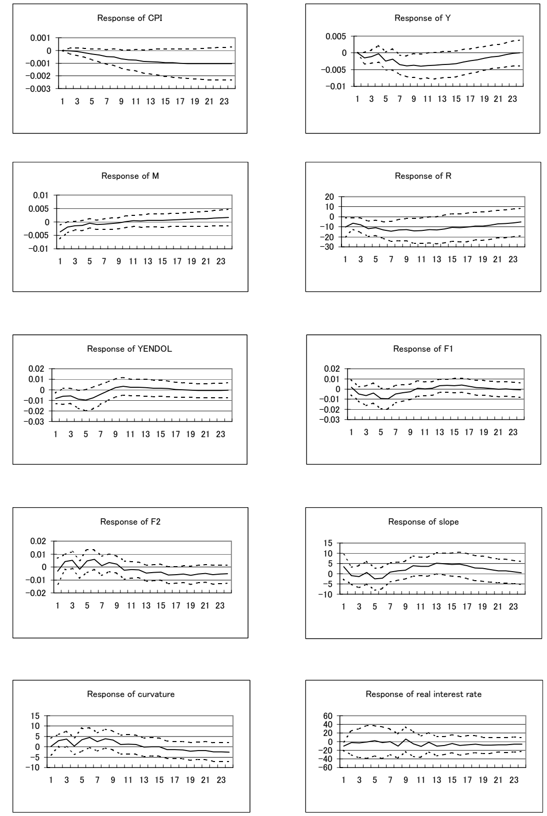
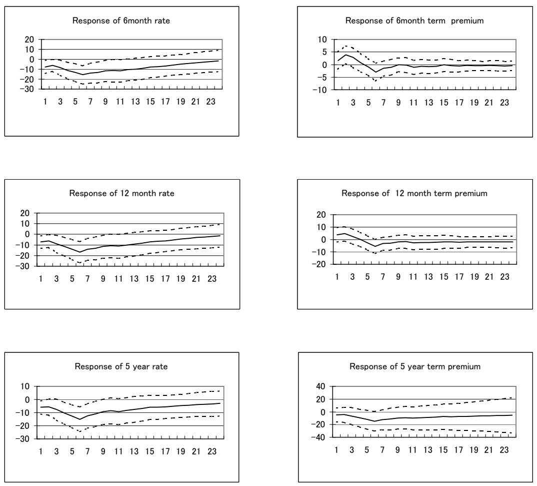
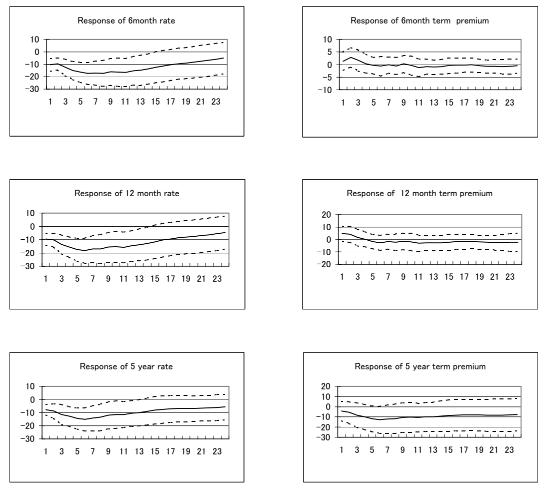


Figure 4

Response of Yield Curve to
shock to Monetary Policy
Sticky Price Maintained Hypothesis
500 outerloop draws, 100 innerloop draws
baseline variables and pcom (ordered 3rd)



Response of Yield Curve to
shock to Monetary Policy
Sticky Price Maintained Hypothesis
500 outerloop draws, 100 innerloop draws
baseline variables and POIL (ordered 3rd)



Response of Yield Curve to
shock to Monetary Policy
Sticky Price Maintained Hypothesis
500 outerloop draws, 100 innerloop draws
baseline variables and yen-dollar exchange rate ordered 5th