The Bank of Japan's Operating Procedures and the Identification of Monetary Policy Shocks: A Reexamination using the Bernanke-Mihov Approach

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Abstract

This paper reexamines the operating procedures of the Bank of Japan (BOJ) and identifies the monetary policy shock up to June 1995 by employing the structural VAR approach of Bernanke and Mihov (1998). This approach identifies exogenous components of monetary policy by setting up equilibrium models of the reserve market. In this way, it presents two equilibrium models, the Implicit Cost (IC) model and the Credit Rationing (CR) model, which are distinguished by opposing views about the BOJ's discount-window borrowing policy. The IC model has the feature that the BOJ endogenously accommodates the demand for discount-window borrowing by private banks. In contrast, the CR model has the feature that the BOJ exogenously controls the level of discount-window lending. This paper demonstrates that the CR model is superior to the IC model in describing the BOJ's operating procedures up to June 1995.

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1 Introduction

Analyzing monetary policy indicators that are controlled by central banks and are closely related to the real economy has been one of the most important issues in macroeconomics. Some economists have studied short-term interest rates such as the call rate and the federal funds rate, while others have considered money supply variables such as M2+CD or high-powered money. However, before we analyze monetary variables that some economists presume as prospective policy indicators, the following questions arise. How should we deal with the macroeconomic problem of specifying adequate policy indicators, which precisely reflect central banks' past policy decisions? Could we specify the policy indicators using single monetary variables? If not, how should we specify them? This paper is motivated by these questions. In particular, the present paper empirically explores the best policy indicator of the Bank of Japan (BOJ) and identifies the policy shock by employing the structural VAR approach of Bernanke and Mihov (1998). This approach allows us to specify adequate policy indicators of central banks and clarify operating procedures by setting up equilibrium econometric models of the reserve market. In general, central banks aim to stabilize the macroeconomy by intervening in the reserve market and setting short-term interest rates or reserves within a target range. The approach is convincing because it assumes that monetary variables that are affected by the operating procedures of central banks in the reserve market embody the decisions of central banks.

In a traditional structural VAR framework, the most convenient identification scheme for exogenous components of monetary policy since the work of Sims (1980) is the one based on Cholesky decompositions. If we employ this identification scheme, we must a priori select a single measure of monetary policy and also specify a recursive structure for the macroeconomy. In VAR literature on Japanese monetary policy, Miyao (2000; 2002), Ogawa (1999), and Hatakeda (1997) assume that the policy stance of the BOJ can be measured by the call rate in order to examine Japan's business fluctuations and the role of monetary policy. [1]

In more recent work, Sims and Zha (1998) suggest an identifying methodology that does not depend on the recursive assumption and that imposes a contemporaneous restriction on all economic variables in a VAR system. On

[1] In VAR literature on U.S. monetary policy, Christiano et al. (1996), Christiano and Eichenbaum (1992; 1995), Bernanke and Blinder (1992), and Sims (1992) use the federal funds rate or non-borrowed reserves as an policy indicator of the Federal Reserve in order to investigate the effects of monetary policy on the U.S. economy.

the other hand, Sims (1986), Gordon and Leeper (1994), Leeper, Sims, Zha (1996) impose a contemporaneous restriction on all economic variables in a VAR system, particularly assuming that at least a subset of goods market variabe are predetermined. We call this type of identification scheme which imposes a contemporaneous restriction on all economic variables in a VAR system the "Sims scheme".

Bernanke and Mihov (1998) suggest an identifying methodology that divides the macroeconomy into a policy sector and a non-policy sector, and that, assuming a block recursive structure between the two sectors, imposes a contemporaneous restriction on monetary variables in the policy sector. We call this identification scheme the "Bernanke-Mihov scheme".

These identification schemes are more sophisticated than the Cholesky approach in that they can quantitatively clarify a central bank's operating procedures and specify the policy indicator in the process of identifying the policy shock. To investigate Japanese monetary policy, Shioji (2000) uses the Sims scheme, while Kasa and Popper (1997) employ the Bernanke-Mihov scheme. Shioji reports that the BOJ had targeted both the money supply, such as M2+CD, and the short-term interest rates such as the call rate until June 1995. Kasa and Popper point out that the BOJ had targeted both non-borrowed reserves and the call rate. These studies conclude that the BOJ had not targeted a single variable, but a mixed monetary variable. According to this view, if we use a single monetary variable as the policy indicator of the BOJ, conjectures about the monetary transmission mechanism would be erroneous. This paper, presenting an econometric model of the Japanese reserve market that is significantly different from that of Kasa and Popper, reexamines the policy indicator of the BOJ.

When examining the BOJ's operating procedures and modeling the Japanese reserve market, it should be noted that short-term interest rates such as the call rate had remained above the discount rate until June 1995. [2] This led to two views on the BOJ's discount-window policy and caused difficulties in understanding its operating procedures and in modeling the reserve market. One is the "Implicit Cost Hypothesis", which assumes that the BOJ endogenously accommodates the demand for borrowing by private banks. The other is called the "Credit Rationing Hypothesis", which assumes that the BOJ exogenously controls the level of discount-window lending. From the 1980s to the early 1990s, economists and policy makers discussed which

[2] Strictly speaking, there are exceptional periods in which the call rate is below or equal to the discount rate, such as from May 1972 to September 1972. However, since these periods are short, they have practically no influence on the subsequent analysis. For details, see Honda (1984).

of these views was true, but failed to reach an agreement. Further, since lowering the call rate below the discount rate in July 1995, the BOJ has adopted the new framework for its operating procedures. Therefore, there is no consensus about how the BOJ implemented its operations in the reserve market up to June 1995, and we have very little knowledge about how the BOJ influenced the macroeconomy by operating in the market. [3] In this paper, we present two equilibrium models of the Japanese reserve market, which are differentiated by opposing views about the BOJ's discount-window policy, and deal with the following three problems in economics:

1. How did the BOJ implement its operations in the reserve market until June 1995?
2. How can we characterize the policy shock and indicator of the BOJ up to June 1995?
3. To what extent did the policy shock of the BOJ influence the macroeconomy?

This paper is organized as follows. Section 2 discusses how we should understand the BOJ's discount-window policy up to June 1995 in order to model the reserve market. Furthermore, in this section, we briefly review the studies of Shioji and Kasa-Popper. Section 3 demonstrates the VAR-based methodology suggested by Bernanke and Mihov. Section 4 presents two alternative equilibrium models of the Japanese reserve market, which are differentiated by opposing views about the BOJ's discount-window policy. Section 5 discusses the estimation method and the results, and explores the best policy indicator of the BOJ. Section 6 discusses the extent to which our identified policy shock influences the macroeconomy by deriving impulse responses functions. Finally, Section 7 concludes.

2 Issues

2.1 Debates About the BOJ's Discount-Window Policy

In general, central banks have two ways of controlling the supply of high-powered money. One is via open-market operations and the other is via

[3] Nakashima (2004) examines the BOJ's operating procedures from July 1995 by employing the Bernanke-Mihov approach. He concludes that the BOJ equally targeted the call rate and reserves. Further, he asserts that an equally weighted average of the call rate and reserves should be used as the BOJ's policy indicator from July 1995.

discount-window lending. In particular, the problems of modeling the Japanese reserve market involve how we should understand the BOJ's discount-window policy. This is because the discount rate remained below short-term interest rates such as the call rate until June 1995. This led to two different views on the BOJ's discount-window policy.

One view assumes that there are surveillance costs of discount-window borrowing for private banks other than the discount rate. According to this view, the BOJ implicitly imposed surveillance costs, which increase with the amount of discount-window borrowing, on private banks. Further, the view is that private banks borrowed from the BOJ to the point at which the sum of the implicit costs and the discount rate equaled the call rate. This type of hypothesis about the BOJ's discount-window policy is generally called the "Implicit Cost Hypothesis".

The other view assumes that the cost of discount-window borrowing to private banks is only the discount rate. According to this view, if the BOJ had not rationed discount-window lending among private banks, rational behavior by the private banks would have equated the call rate and the discount rate because of financial substitution of discount-window borrowing from call money. Further, the view is that the fact that the call rate remained above the discount rate indicates that the BOJ exogenously rationed discount-window lending and regulated the quantity of borrowing. This type of hypothesis about the BOJ's discount-window policy is generally called the "Credit Rationing Hypothesis".

The implicit cost hypothesis is the standard view on the discount-window policy of the Federal Reserve (FED). [4] In the context of the BOJ's discount-window policy, Furukawa (1985) supports this view on the basis of theoretical and empirical analysis. On the other hand, Hamada and Iwata (1980) and Honda (1984) each developed theoretical models of the credit rationing view, and the former used empirical analysis to support this view.

This overview of the controversy about the BOJ's discount-window pol-

[4] Strongin (1995) and Bernanke and Mihov (1998) construct econometric models of the U.S. reserve market based on the implicit cost hypothesis. This is because, in addition to the fact that the federal fund rate is above the discount rate, "Regulation A" for discount-window borrowing is applicable. This regulation requires that discount-window borrowing involves exercising a non-transferable option to borrow again in the near future and that private banks do not have unlimited borrowing privileges. Further, the regulation does not allow private banks to lend in the federal funds market and borrow from the discount window at the same time. Because of these restrictions, private banks are reluctant to borrow from the discount window. In particular, Regulation A corresponds to the implicit costs hypothesis in their analyses of U.S. monetary policy. See Sawayama (1990, Chapter 2) and Ichikawa (1994) on Regulation A.

icy up to June 1995 strongly suggests that we should empirically judge the two views by constructing econometric models of the short-run money market that are differentiated by the opposing views, rather than to a priori judge the views.

2.2 The Problems of Shioji (2000)

Shioji (2000) analyzes the operating procedures of the BOJ up to June 1995 by employing the Sims scheme, which imposes a contemporaneous restriction on all economic variables in a VAR system. As regards operating procedures, he addresses the issue of whether the BOJ influenced the high-powered money market using high-powered money both via open-market operations and discount-window lending, or whether the BOJ influenced the market by changing the composition of the supply of high-powered money, particularly in the form of discount-window lending. He calls the former the "H (High-Powered Money) model" and the latter the "BL (Bank of Japan Loans) model" and finds empirical support for the H model. As for the policy indicator of the BOJ, he points out the possibility that the BOJ targeted not a single monetary variable, but both short-term interest rates such as the call rate and monetary aggregates such as M2+CD. Thus, he characterizes the BOJ's policy rule as a "partial accommodation rule". The problem with Shioji's analysis is that he does not refer to the "Implicit Cost Hypothesis" or the "Credit Rationing Hypothesis" despite presenting econometric models that are differentiated by these opposing views of the BOJ's discount-window policy. Both the "Implicit Cost Hypothesis" and the "Credit Rationing Hypothesis" have microfoundations and have been discussed by academics. It is not clear whether his models correctly reflect these two hypotheses or what type of theoretical models he assumes.

2.3 The Problems of Kasa and Popper (1997)

Kasa and Popper (1997) applied the Bernanke-Mihov approach to Japanese monetary policy. They defined "Moral Suasion" as the spread between interbank rates such as the Tegata rate and open-market rates such as the CD rate, and characterized the gap between the two types of rates as implicit regulations that prohibited arbitrage between the markets. They included "Moral Suasion" in their VAR model to examine the BOJ's operating procedures. There are three problems with their analysis. Firstly, they use the concept of "non-borrowed reserves", which are total reserves (member-bank deposits + vault cash) less discount-window borrowing. Non-borrowed reserves are a key instrument of the FED's operating procedures, but the BOJ has never used the concept of non-borrowed reserves. Thus, they do not take account of institutional differences between Japan and the U.S. Secondly, the trends in prices (the consumer price index) and the exchange rate are eliminated by taking first differences, while those in output (the industrial production indicator) and reserves are eliminated by using a quadratic time trend. Therefore, their analysis adopts arbitrary transformations of macroeconomic variables. Thirdly, since they do not derive impulse response functions, it is difficult to assess the reliability of the identified monetary policy shock.

In this section, we have discussed problems for identifying the policy shock of the BOJ. In the following sections, we apply the Bernanke-Mihov approach to Japanese monetary policy and identify the policy shock of the BOJ.

3 The Bernanke-Mihov Approach

To derive the Bernanke-Mihov approach formally, we follow them in supposing that the economy is described by the linear structural model given in equations (1) and (2):

$$\boldsymbol{Y}_t = \sum_{i=0}^{k} \boldsymbol{B}_i \boldsymbol{Y}_{t-i} + \sum_{i=0}^{k} \boldsymbol{C}_i \boldsymbol{P}_{t-i} + \boldsymbol{A}^y \boldsymbol{v}_t^y \tag{1}$$

$$\boldsymbol{P}_t = \sum_{i=0}^{k} \boldsymbol{D}_i \boldsymbol{Y}_{t-i} + \sum_{i=0}^{k} \boldsymbol{G}_i \boldsymbol{P}_{t-i} + \boldsymbol{A}^p \boldsymbol{v}_t^p \tag{2}$$

where variables in bold type denote vectors or matrices.

Also, following Bernanke and Mihov, we refer to $\boldsymbol{Y}$ and $\boldsymbol{P}$ as "non-policy" and "policy" variables, respectively. The set of policy variables includes variables that are potentially useful as direct indicators of the stance of monetary policy, e.g., short-term interest rates and reserve measures. Non-policy variables include other economic variables, such as output and inflation, the responses of which to monetary policy shocks we would like to identify. In equations (1) and (2), the $\boldsymbol{v's}$ are mutually uncorrelated "structural" or "primitive" disturbances. As in Bernanke and Mihov, these structural disturbances are pre-multiplied by general matrices $\boldsymbol{A}$, which permit any disturbance in the $\boldsymbol{Y}$ block to enter into any equation in that block, and similarly for the $\boldsymbol{P}$ block. Thus, no restrictions are placed on the covariance matrices of composite error terms within a block. In particular, we focus on the elements of the vector $\boldsymbol{v}_t^p$ in order to identify monetary policy shocks, and assume that $\boldsymbol{v}_t^p$ includes the following structural shocks:

1. Treasury demand shock, v_t^{gd};
2. Currency demand shock to the macroeconomy, v_t^{cu};
3. Reserve demand shock of private banks, v_t^d;
4. Demand shock of discount-window borrowing by private banks, v_t^b, (Supply shock of discount-window lending by the BOJ); [5]
5. High-powered money supply shocks via open-market operations by the BOJ, v_t^s.

To identify these structural shocks and the responses of variables in the system to monetary policy shocks, we make a timing assumption. Following Bernanke and Mihov, we assume that the structural shocks do not affect variables in the non-policy block within the period, i.e., $\boldsymbol{C_0} = 0$. Under this assumption, the system (1)-(2) can be written in standard VAR format as:

$$\boldsymbol{Y}_t = \sum_{i=1}^{k} \boldsymbol{H}_i^y \boldsymbol{Y}_{t-i} + \sum_{i=1}^{k} \boldsymbol{H}_i^p \boldsymbol{P}_{t-i} + \boldsymbol{u}_t^y \tag{3}$$

$$\boldsymbol{P}_t = \sum_{i=1}^{k} \boldsymbol{J}_i^y \boldsymbol{Y}_{t-i} + \sum_{i=1}^{k} \boldsymbol{J}_i^p \boldsymbol{P}_{t-i} + [(\boldsymbol{I} - \boldsymbol{G}_0)^{-1} \boldsymbol{D}_0 \boldsymbol{u}_t^y + \boldsymbol{u}_t^p] \tag{4}$$

where u_t^y denote the VAR residuals corresponding to the $\boldsymbol{Y}$ block and u_t^p are the residuals corresponding to the $\boldsymbol{P}$ block, orthogonalized with respect to u_t^y. Bernanke and Mihov show that:

$$\boldsymbol{u}_t^p = (\boldsymbol{I} - \boldsymbol{G}_0)^{-1} \boldsymbol{A}^p \boldsymbol{v}_t^p \tag{5}$$

where the right-hand-side parameters and disturbances are as defined in structural equation (2). Alternatively, dropping subscripts and superscripts, we can write equation (5) as:

$$(\boldsymbol{I} - \boldsymbol{G})\boldsymbol{u} = \boldsymbol{A}\boldsymbol{v} \tag{6}$$

Equation (6) is a standard structural VAR system, which relates observable VAR-based innovations, $\boldsymbol{u}$, to unobservable structural shocks, $\boldsymbol{v}$.

[5] As shown below, in the IC model, we define v_t^b as the demand shock of discount-window borrowing by private banks. In the CR model, we define v_t^b as the supply shock of discount-window lending by the BOJ.

Table 1: BOJ's Balance Sheet with the IC model

Assets	Liabilities
Discount-window Lending (u^{br})	Government Deposits (u^{gd})
Assets Held via Open-Market Operations	Currency Held by the Public (u^{cu})
(Security, Float, Other Net Assets) (u^{mo})	Member-Bank Deposits (u^{re})

In the next section, we present two equilibrium models of the Japanese reserve market that are differentiated by opposing views on the BOJ discount borrowing policy to identify the elements of the vector $\boldsymbol{v}$.

4 Two Equilibrium Models of the Reserve Market

In this section, we present two equilibrium models of the Japanese reserve market that are differentiated by opposing views on the BOJ's discount borrowing policy up to June 1995. The model characterized by the implicit cost hypothesis is the "Implicit Cost (IC) model", while the one characterized by the credit rationing hypothesis is named the "Credit Rationing (CR) model".

4.1 The Implicit Cost (IC) Model

We present the following system (7)-(12) as the Implicit Cost (IC) model.

$$u^{re} = u^{br} + u^{mo} - u^{gd} - u^{cu} \tag{7}$$
$$u^{gd} = v^{gd} \tag{8}$$
$$u^{cu} = -\alpha u^{r} + v^{cu} \tag{9}$$
$$u^{re} = -\beta u^{r} + v^{d} \tag{10}$$
$$u^{br} = \gamma(u^{r} - u^{dr}) + v^{b} \tag{11}$$
$$u^{mo} = \theta^{gd} v^{gd} + \theta^{cu} v^{cu} + \theta^{d} v^{d} + \theta^{b} v^{b} + v^{s} \tag{12}$$

where gd, cu, re, br, and mo denote government deposits, currency, reserves, borrowed reserves and assets held via open-market operations by the BOJ, respectively, and r and dr denote the call rate and discount rate, respectively.

Equation (7) is the market equilibrium condition for bank reserves, which is based on an identity between assets and liabilities on the BOJ's balance sheet (see Table 1). Equation (8) states that the BOJ accommodates fluctuations in the demand for government funds, v^{gd}. Equation (9) relates innovations in the demand for currency, u^{cu}, to innovations in the call rate, u^{r}, and an autonomous shock to the currency demand, v^{cu}. Similarly, equation (10) is the banks' demand for reserves, expressed in the form of innovations: it states that innovations in the demand for reserves, u^{re}, depend negatively on innovations in the call rate, u^r, and on a demand disturbance, v^d.

Equation (11) provides a contrast to the CR model, and states that the BOJ passively accommodates the demand for discount-window borrowing by private banks. In particular, note that the equation has two aspects: one is a demand function of private banks, which indicates that innovations in the demand for discount-window borrowing, u^{br}, depend on the spread between innovations in the call rate, u^r, and innovations in the discount rate, u^{dr}, and on a shock to desired discount-window borrowing, v^b. The other aspect is the behavior function of the BOJ, which indicates that the BOJ endogenously accommodates the demand for discount-window borrowing by private banks.

Equation (12) is the behavior function of the BOJ, which indicates how the BOJ supplies high-powered money using open-market operations. In the IC model, only open-market operations are used by the BOJ to proactively supply high-powered money. Therefore, the high-powered money supply shock, v^s, is defined as the monetary policy shock of the BOJ in the IC model.

Figure 1 illustrates the reserve market up to June 1995. For simplicity, we assume that the interest elasticity of currency demand is equal to that of the demand for reserves. Therefore, a negatively sloped demand curve for high-powered money can be drawn (line D). The supply curve for high-powered money in the IC model is drawn as line S-IC. When the call rate (R) is higher than the discount rate (DR), the demand for discount-window borrowing by private banks is positive. Hence, the demand curve for discount-window borrowing in the IC model starts where the level of high-powered money issued via open-market operations (MO) and the level of the discount rate (DR) intersect. Note that $\gamma > 0$ is required in equation (11) and the inverse of γ corresponds to the level of surveillance costs for the BOJ.

Following Bernanke and Mihov, we make the simplifying assumption that the innovation to the discount rate, u^{dr}, is zero. [6] Consequently, we can write the IC model in the form of equation (6) as follows:

[6] Bernanke and Mihov point out that the linear VAR framework may not be appropriate for modeling the discount rate, which is an infrequently changed administered rate. Further, they show that estimates from a model with a non-zero discount rate innovation are quite consistent with those from a model with a zero discount rate innovation.

$$\boldsymbol{I}-\boldsymbol{G}=\begin{bmatrix}1&0&0&0&0\\0&1&0&\alpha&0\\0&0&1&\beta&0\\1&1&1&-\gamma&-1\\0&0&0&0&1\end{bmatrix},\quad \boldsymbol{A}=\begin{bmatrix}1&0&0&0&0\\0&1&0&0&0\\0&0&1&0&0\\0&0&0&1&0\\\theta^{gd}&\theta^{cu}&\theta^{d}&\theta^{b}&1\end{bmatrix}$$

$$\boldsymbol{u}'=\begin{bmatrix}u^{gd}&u^{cu}&u^{re}&u^{r}&u^{mo}\end{bmatrix},\quad \boldsymbol{v}'=\begin{bmatrix}v^{gd}&v^{cu}&v^{d}&v^{b}&v^{s}\end{bmatrix}$$

One can also invert the above relationship to determine how the monetary policy shock, v^s, depends on the VAR innovations:

$$\begin{aligned}v^s &= -(\alpha\theta^{cu}+\beta\theta^d-\gamma\theta^b)u^r+(\theta^b+1)u^{mo}\\&\quad-(\theta^b+\theta^d)u^{re}-(\theta^b+\theta^{cu})u^{cu}-(\theta^b+\theta^{gd})u^{gd}\end{aligned}\tag{13}$$

The IC model described by the above structural VAR system has 12 unknown parameters (including the variances of five structural shocks) to be estimated from 15 covariances, Hence there are three overidentifying restrictions.

4.2 The Credit Rationing (CR) Model

We present the following system (14)-(19) as the Credit Rationing (CR) model.

$$u^{re} = u^{br}+u^{mo}-u^{gd}-u^{cu}\tag{14}$$
$$u^{gd} = v^{gd}\tag{15}$$
$$u^{cu} = -\alpha u^r+v^{cu}\tag{16}$$
$$u^{re} = -\beta u^r+v^d\tag{17}$$
$$u^{br} = \phi^{gd}v^{gd}+\phi^{cu}v^{cr}+\phi^d v^d+\phi^s v^s+v^b\tag{18}$$
$$u^{mo} = \theta^{gd}v^{gd}+\theta^{cu}v^{cu}+\theta^d v^d+\theta^b v^b+v^s\tag{19}$$

Compared with the IC model, the CR model has a different structure in equation (18). Indeed, equation (14) is the market equilibrium condition for bank reserves, and equation (15) implies that the BOJ passively accommodates fluctuations in the demand for government funds. Equations (16) and (17) indicate the currency and reserve demand functions, respectively. Equation (19) is the function showing the open-market operations behavior of the BOJ.

Table 2: The BOJ's Balance Sheet with the CR Model

Assets	Liabilities
Discount-window Lending + Assets Held via Open-market Operations (u^{md})	Government Deposits (u^{gd}) Currency Held by the Public (u^{cu}) Member-bank Deposits (u^{re})

Equation (18) characterizes the CR model, and states that the BOJ controls the level of discount-window lending and rations lending to private banks. Hence, we can interpret this equation as a second behavior function for the BOJ. In particular, it should be noted that v^b represents the supply shock of discount-window lending in the CR model, while it indicates the demand shock of discount-window borrowing by private banks in the IC model. Therefore, v^b can be considered the second monetary policy shock of the BOJ, with v^s in equation (19) being the first.

Consider again Figure 1. The BOJ lending function, given by equation (18), can be drawn parallel to the vertical line MO, which is the high-powered money supply curve corresponding to open-market operations. As a result, the high-powered money supply curve for the BOJ can be drawn as the vertical line S-CR in the CR model.

In contrast to the IC model, the CR model implies that the BOJ affects the short-run money market and the macroeconomy both via open-market operations and discount-window lending, because the model has two BOJ behavior functions. Further, the two BOJ behavior functions are essentially equivalent in that they are high-powered money supply functions of the BOJ. Therefore, in the CR model, the quantity of high-powered money is important when considering the monetary transmission mechanism, whereas the difference between open-market operations and discount-window lending, as measures of supplying high-powered money, is not. [7] Hence, adding equations (18) and (19) yields the following system, which is essentially equivalent to the CR model.

$$u^{re} = u^{boj} - u^{gd} - u^{cu} \tag{20}$$

$$u^{gd} = v^{gd} \tag{21}$$

$$u^{cu} = -\alpha u^r + v^{cu} \tag{22}$$

[7] This is also apparent from the fact that a vertical high-powered money supply curve is drawn in the CR model. As expected from this vertical supply curve, the BOJ can influence the interest rate by changing the quantity of high-powered money. Further, private banks are indifferent to the form in which high-powered money is supplied.

$$
\begin{aligned}
u^{re} &= -\beta u^{r} + v^{d} && (23)\\
u^{md} &= \psi^{gd} v^{gd} + \psi^{cu} v^{cr} + \psi^{d} v^{d} + v^{md} && (24)
\end{aligned}
$$

Here, the VAR innovation u^{md} is defined as follows:

$$u^{md} = u^{br} + u^{mo}$$

Equation (20) is the market equilibrium condition for bank reserves, which is based on an identity between assets and liabilities on the BOJ's balance sheet (see Table 2). Equation (24) is the function showing how the BOJ supplies high-powered money using open-market operations and discount window lending. Consequently, the above system can be represented in the form of equation (6) as follows:

$$
\boldsymbol{I} - \boldsymbol{G} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & \alpha & 0 \\ -1 & -1 & \beta & 1 \\ 0 & 0 & 0 & 1 \end{bmatrix}, \quad \boldsymbol{A} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ \psi^{gd} & \psi^{cu} & \psi^{d} & 1 \end{bmatrix}
$$

$$
\boldsymbol{u}' = \begin{bmatrix} u^{gd} & u^{cu} & u^{r} & u^{md} \end{bmatrix}, \quad \boldsymbol{v}' = \begin{bmatrix} v^{gd} & v^{cu} & v^{d} & v^{md} \end{bmatrix}
$$

Inverting the above relationship shows how the monetary policy shock, v^{md}, depends on the VAR innovations:

$$
v^{md} = -(\alpha\psi^{cu} + \beta\psi^{d})u^{r} - (\psi^{d} - 1)u^{re} - (\psi^{cu} - 1)u^{cu} - (\psi^{gd} - 1)u^{gd} \quad (25)
$$

We estimate the CR model and identify the monetary policy shock, v^{md}. The CR model described by the above system has nine unknown parameters (including the variances of four structural shocks) to be estimated from 10 covariances. Hence, there is one overidentifying restriction. The IC and CR models are non-nested within each other. Therefore, by testing the overidentifying restrictions, we compare each model statistically.

4.3 Alternative Models for BOJ Operating Procedures

The structural parameters in the BOJ behavior functions, given by equation (12) in the IC model and by equation (24) in the CR model, define how the BOJ controls the market for bank reserves in each model. Hence, by imposing parametric restrictions on equations (12) and (24), respectively, we propose three alternative models that are nested within the IC and CR models.

The CL Model (Call Rates Targeting Model)

Imposing the following four parametric restrictions on the BOJ behavior function in the IC model, equation (12),

$$\theta^{gd} = 1, \quad \theta^{cu} = 1, \quad \theta^{d} = 1, \quad \theta^{b} = -1,$$

the monetary policy shock becomes $v^s = (\alpha + \beta + \gamma)u^r$. On the other hand, imposing the following three parametric restrictions on the BOJ behavior function in the CR model, equation (24),

$$\psi^{gd} = 1, \quad \psi^{cu} = 1, \quad \psi^{d} = 1,$$

the monetary policy shock becomes $v^{md} = -(\alpha + \beta)u^r$. These parametric restrictions imply that the BOJ fully offsets demand shocks such as treasury and currency demand shocks in the market for bank reserves and stabilizes the call rate. Therefore, the model indicates that the BOJ targets the call rate, and that the best policy indicator of the BOJ is the call rate. We call this model the "CL model". Further, we perform tests of the overidentifying restrictions and hypothesis tests on the structural parameters in the process of estimating the model.

The HP Model (High-Powered Money Targeting Model)

Imposing the following three parametric restrictions on the BOJ behavior function (24) in the CR model,

$$\psi^{gd} = 1, \quad \psi^{cu} = 0, \quad \psi^{b} = 0,$$

the monetary policy shock becomes $v^{md} = u^{re} + u^{cu} = u^{hp}$. The model indicates that the BOJ targets high-powered money, and that the best policy indicator of the BOJ is high-powered money. We call this model the "HP model". As already discussed, the IC model assumes that the quantity of BOJ discount-window lending, which is a specific component of high-powered money, is determined by private banks. Thus, in the IC model, only the total quantity of high-powered money cannot theoretically be a policy instrument of the BOJ. Consequently, the HP model is not derived from the IC model. [8]

[8] This can been seen from the fact that the monetary policy shock, v^s, cannot reduce to the unanticipated change in high-powered money in equation (13). According to the implicit cost hypothesis, central banks cannot control the amount of high-powered money, but can influence call rates. See Horiuchi (1980, Chapter 2) for a discussion.

The MIX Model

By imposing the following three parametric restrictions on the BOJ behavior function (12) in the IC model,

$$\theta^{gd} = 1, \quad \theta^{cu} = \theta^{d}, \quad \theta^{b} = -1,$$

the monetary policy shock becomes $v^s = -\{(\alpha+\beta)\theta^{cu}+\gamma\}u^r+(1-\theta^{cu})u^{hp}$. Imposing the following two parametric restrictions on the BOJ behavior function (24) in the CR model,

$$\psi^{gd} = 1, \quad \psi^{cu} = \psi^{d},$$

the monetary policy shock becomes $v^{md} = -\{(\alpha+\beta)\psi^{cu}\}u^r + (1-\psi^{cu})u^{hp}$. The model implies that as the values of $\theta^{cu} = \theta^d$ or $\psi^{cu} = \psi^d$ approach unity, the importance of the call rate to the BOJ increases, while as the values approach zero, the importance of high-powered money to the BOJ increases. [9] We call the above model the "MIX model".

In the following section, we examine the BOJ's operating procedures by estimating the above three alternative models as well as the IC and CR models.

5 Estimation and Results

In this section, we estimate the models of the market for bank reserves and report the results.

5.1 Estimation and VAR Models

For estimation of the structural VAR system (6), we use a two-step procedure. The first step is equation-by-equation estimation by OLS of the coefficients of the reduced-form VAR system (3)-(4). The VAR innovations of the policy sector $\boldsymbol{u^p}$ are given by the orthogonal complement of the projection of the OLS residuals of the policy sector on the OLS residuals of the non-policy sector. In the second step, full information maximum likelihood estimation (FIML) is applied. The log likelihood function to be maximized is as follows:

$$\begin{aligned} L(\boldsymbol{I}-\boldsymbol{G},\boldsymbol{A},\boldsymbol{\Sigma_v}) &= -(T/2)\{log|\boldsymbol{I}-\boldsymbol{G}|^2 - log|\boldsymbol{A}|^2 - log|\boldsymbol{\Sigma_v}|^2\} \\ &\quad -(T/2)trace\{(\boldsymbol{I}-\boldsymbol{G})'(\boldsymbol{A}^{-1})'\boldsymbol{\Sigma_v}^{-1}\boldsymbol{A}^{-1}(\boldsymbol{I}-\boldsymbol{G})\boldsymbol{\Sigma_u}\} \end{aligned} \quad (26)$$

[9] Even if the value of $\theta^{cu} = \theta^d$ approach zero, the mix model within the IC model does not reduce to the HP model, in which the BOJ targets only high-powered money.

where $\mathbf{\Sigma}_{\boldsymbol{u}}$ is the estimate of the covariance matrix of the VAR innovations of the policy sector, and $\mathbf{\Sigma}_{\boldsymbol{v}}$ is the diagonal matrix that diagonally locates the variances of the structural shocks. We apply the two-step procedure to estimate the two models of the market for bank reserves, and to identify the monetary policy shocks. [10]

As we discussed in section 3, the Bernanke-Mihov methodology accommodates the inclusion of both policy variables and non-policy variables in the VAR system (3)-(4). For estimation of both the IC and CR models, the industrial production index (IIP, 1995 = 100, seasonally adjusted), the consumer price index (CPI, 1995 = 100), the Nikkei commodity prices index (PCOM, 42 items), money stock (M2+CD, seasonally adjusted), and the exchange rate (EX, yen per U.S. dollar) are included as the non-policy variables. The index of commodity prices is included to capture the expected future course of inflation. [11] We take natural logs of the non-policy variables. CPI and PCOM are seasonally adjusted by using the X12-ARIMA method.

Next, we discuss the variables of the policy sector in the VAR system. As we explained in section 4, the development of equilibrium models of the market for bank reserves involves the use of the identitical relations between assets and liabilities in the BOJ's balance sheet (see Table 1 and 2). Further, the estimation of the IC model requires the five VAR innovations of the policy sector (u^{gd}, u^{cu}, u^{re}, u^{r}, u^{mo}), and that of the CR model requires the four VAR innovations of the policy sector (u^{gd}, u^{cu}, u^{r}, u^{md}). We must carefully pick out monetary variables of the policy sector to generate these VAR innovations via the first-step OLS estimation.

In the IC model, government deposits (GD), currency (CU) and reserves (RE) are used for liabilities. In addition, "the assets held via open-market operations (MO)", which comprise bills, bonds and overseas assets acquired

[10] Bernanke and Mihov (1995; 1998) apply the efficient generalized method of moments (GMM) in the second-step estimation, while Kasa and Popper apply FIML. If the VAR innovations are normally distributed, estimates by efficient GMM are asymptotically equivalent to those obtained by FIML. For details, see Bernanke and Mihov (1995, Appendix2) and Watson (1994). Equation (26) is estimated with the BFGS algorithm in the Constrained Maximum Likelihood Estimation (CML) package of GAUSS.

[11] As is well known, the exclusion of indicators of future inflation such as the commodity prices index and the oil price index tends to lead to the "price puzzle", which is the finding that monetary tightening leads to a rising rather than a falling price level. Finding indicators of future inflation is an important issue in macroeconomics. However, following Sims (1992), Kasa and Popper (1997), and Bernanke and Mihov (1998), among others, we use the commodity prices index as an indicator of future inflation. For details of the price puzzle, see Sims (1992).

by the BOJ through these operations, are used for assets. [12] In addition to these four variables, the call rate (R) is included in the policy sector. Therefore, in the IC model, we estimate the ten-variable VAR system composed of the five non-policy variables (IIP, CPI, PCOM, M2+CD, EX) and the five monetary variables in the policy sector (GD, CU, RE, R, MO).

The estimation of the CR system (20)-(24) and the identification of the monetary policy shocks, v^{md}, require the preparation of the four VAR innovations of the policy sector: u^{gd}, u^{cu}, u^{r} and u^{md}. Here, we propose two identification schemes to generate these four innovations. One involves estimating the ten-variable VAR system of the IC model, and using the five generated innovations of the policy sector: u^{gd}, u^{cu}, u^{re}, u^{r} and u^{mo}. Firstly, we generate u^{br} with equation (7). Next, after generating u^{md} by adding u^{br} and u^{mo}, we estimate the CR system of equations (20)-(24) through FIML. This identification scheme does not allow us to fully identify the entire system of the CR model, or to derive estimated impulse response functions from the CR model, because we have no choice to indirectly identify the monetary policy shocks, v^{md}, via estimation of the ten-variable VAR system of the IC model. Nonetheless, the identificaton scheme enables us to compare the IC system of equations (7)-(12) and the CR system of equations (20)-(24), focusing particularly on the contemporaneous restriction on the the structural VAR system (6); hence the identification scheme is useful for a head to head comparison between the IC and CR systems. We call this identification scheme the “Partial Identification (PI)”, and call the CR model estimated under the PI scheme the “Partially Identified CR (PI-CR) model”. In the following subsections (section 5.2 and 5.3), we mainly use the PI-CR model to compare the performance of the IC and CR systems, and to examine the BOJ’s operating procedures to June 1995.

The other identification scheme involves constructing another VAR system which is diffrent from the VAR system of the IC model only for the CR model. Firstly, in the VAR system of the CR model, GD and CU are used for liabilities. Furthermore, “ the assets held via open-market operations and discount-window lending (MD)”, which are formed by adding BOJ loans to MO, are used for assets. [13] In addition to the above three

[12] For details of MO, see Appendix A.

[13] For details of MD, see Appendix A. Normalizing the policy-sector variables except for R raises the problem of the normal method of using log levels that violate the identical relation between assets and liabilities: see equations (7) and (20). In particular, Strongin (1995) and Bernanke and Mihov (1998), who identify the FED’s policy shock by constructing a model of the U.S. market for bank reserves, point out this problem. Strongin suggests that the policy-sector variables should be normalized by using the lag of total

variables, R is included in the policy sector. Therefore, in this identification scheme, we use the nine-variable VAR system composed of the five non-policy variables (IIP, CPI, PCOM, M2+CD, EX) and the four monetary variables in the policy sector (GD, CU, R, MD). [14] Unlike the PI scheme, this identification scheme allows us to fully identify the entire system of the CR model, or to attempt impulse response analysis for evaluation of the CR hypothesis, because it can directly generates the four VAR innovations of the policy sector via the OLS estimation of the nine-variable VAR system. We call this identification scheme the "Full Identification (FI)", and call the CR model estimated under the FI scheme the "Fully Identified CR (FI-CR) model". Compared with the PI-CR model, the FI-CR model is less suitable for a head to head comparison between the IC system (7)-(12) and the CR system (20)-(24) because of the non-nested structure attributed to different number of variables within the VAR systems of the IC and FI-CR models. Nonethless, the FI-CR model, including the new variable MD, accords more with the assumption of the CR hypothesis for monetary transmission mechanism, mentioned in subsection 4.2, that the quantity of high-powered money is important, whereas measures of supplying high-powered money is not, than the PI-CR model does. [15] Further, the FI-CR model comforms with the received way of VAR analysis, in which, one uses esimated impulse response functions to evaluate models or hypotheses in question. In section 6, we make a comparison between the IC and CR hypotheses not only by using the estimation results from the IC and FI-CR models, but also by using the estimated impulse response functions from the two models.

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reserves. Bernanke and Mihov normalize the policy-sector variables by using a 36-month moving average of total reserves. Bernanke and Mihov's normalization appears arbitrary because no basis for using the "36-month" moving average is offered. Therefore, following Strongin, we normalize the policy-sector variables (seasonally adjusted) by using the lag of monetary base (seasonally adjusted). In addition, the author estimates the IC and CR models using the standardized variables with lagged reserves or currency. The method of standardizing with these variables does not materially affect the following results.

[14] The two equiribrium conditions, given by equations (7) and (20), require that one of the policy-sector variables, except for the call rate (R), be redundant. Therefore, in the IC model, we exclude borrowed reserves (BR) following Bernanke-Mihov (1998), while in the CR model estimated under the identification scheme, we exclude reserves (RE).

[15] For the contemporaneous relationships between policy-sector variables described by the CR system (20)-(24), the PI-CR model retains the non-dependency of monetary transmission mechanism on measures of supplying high-powered money, an implication of the CR hypothesis, whereas for the dynamics of macroeconomy described by the VAR system (3)-(4), it does not. On the other hand, The FI-CR model retains the non-dependency assumption both for the contemporaneous relationships between policy-sector variables and for the dynamics of macroeconomy, and thereby we can derive estimated impulse response functions from the model.

To determine the number of lags in the VAR systems, we apply the Akaike Information Criterion (AIC). This criterion leads to the use of four lags in the ten-variable VAR system of the IC model and five lags in the nine-variable VAR system of the FI-CR model. [16] All the data are obtained from the Nikkei NEEDS, and the sample period is January 1975 to June 1995.

5.2 Comparison of the IC and CR Systems

In the following subsections, we mainly focus on estimation results from the IC and the Partially Identified CR (PI-CR) models, the first-step OLS estimation of which is based on the use of the same VAR system, to attempt a head to head comparison between the IC system (7)-(12) and the CR system (20)-(24). Through the comparison, we explore the best policy indicator of the BOJ and examine the BOJ's operating procedures to June 1995.

Estimates of the IC model are given in Table 3, and estimates of the PI-CR model is given in the upper panel of Table 4. Each table reports parameter estimates, with standard errors in parentheses. The final two columns of Tables 3 and 4 show, for all of the overidentified models suggested in Sections 3 and 4: (1) a p-value corresponding to the test of the overidentifying restrictions (OIR); and (2) a p-value for the parameter restrictions of the models nested within the IC and CR systems such as the CL, HP, and MIX models (JOINT). Any p-values greater than 0.05 are shown in bold type, and indicate that the particular model cannot be rejected at the five percent level of significance.

Firstly, we report the parameter estimates of the demand functions in the IC and PI-CR models. The slope coefficients of the currency demand function, α, is significant and correctly signed in the IC and PI-CR models. The slope coefficient of the reserves demand function, β, is of the correct sign, but is insignificant in both the IC and PI-CR models. The slope coefficient of the borrowing function in the IC model, γ, is of the correct sign, but is insignificant.

Next, we report the parameter estimates of the BOJ behavior functions in the IC and PI-CR models. In the IC model, for the BOJ behavior function corresponding to open-market operations, θ^{gd}, θ^{d}, and θ^{b} are significantly different from zero, but θ^{cu} is not. In the PI-CR model, for the BOJ behav-

[16] In addition to using the number of lags selected by AIC, the author estimates the VAR systems with three, four, five, six, and seven lags. The order of the VARs does not materially affect the results. The results reported are those obtained by using the number of lags selected by AIC.

ior function corresponding to both open-market operations and discount-window lending, all the parameter estimates are significantly different from zero. Of particular interest in the PI-CR model is the finding that the parameter estimates of the BOJ behavior function are close to unity, implying that the BOJ fully offsets demand shocks in the market for bank reserves and aims to stabilize the call rate.

Tests of the overidentifying restrictions show the following. The IC model is rejected at the five percent level of significance. The PI-CR model is not rejected at the five percent levels of significance, but is rejected at the ten percent levels of significance. Judging solely by the p-values, the CR system (20)-(24) appears to be superior to the IC system (7)-(12).

5.3 Estimates of the BOJ's Operating Procedures

Here, we report the estimates of the three overidentified models that are generated from the IC and PI-CR models.

Firstly, we report the estimates of the CL model. In the flamework of the IC model, the CL model is strongly rejected at the five percent level of significance. Further, the parameter estimates for the currency, reserves, and borrowed reserves demand functions are of the incorrect sign. In contrast, in the flamework of the PI-CR model, the CL model is not rejected. Further, the parameter estimates of the currency and reserves demand functions are of the correct sign and precisely estimated. This result is consistent with the finding that in the PI-CR model, the parameter estimates of the BOJ behavior function are close to unity.

Next, we report the estimates of the HP model within the PI-CR model. The slope coefficients of the demand functions appear reasonable. Indeed, the slope coefficient of the currency demand function are of the correct sign. In addition, the slope of the reserves demand function is of the correct sign and significantly different from zero. As the p-values of the OIR and JOINT tests show, the HP model is strongly rejected. However, this result is consistent with the finding that in the PI-CR model, the CL model, which assumes that the BOJ targets only the call rate, is easily accepted.

We report the estimates of the MIX model. In the flamework of the IC model, the MIX model is easily rejected (as was the CL model), although all of the parameter estimates are of the correct sign. In contrast, in the flamework of the PI-CR model, the MIX model is easily accepted and the parameter estimates appear reasonable. Indeed, the slope coefficients of the currency and reserves demand functions are of the correct sign and are significant. In addition, for the parameter estimates of the BOJ behavior function, $\phi^{cu} = \phi^{d}$ is close to unity, and the restriction that $\phi^{gd} = 1.0$ and $\phi^{cu} = \phi^{d}$ is not rejected at the five percent level of significance. These results imply the BOJ fully accommodates the three demand shocks (v^{gd}, v^{cu}, v^{d}), both via open-market operations and via discount-window lending.

The estimation results can be summarized as follows. In the flamework of the IC model, not only the IC model itself but also the two nested models are rejected at the five percent level of significance. By contrast, in the flamework of the PI-CR model, both the CL and MIX models as well as the the CR model itself are easily accepted, although the HP model is not. Further, all the slope coefficients of the two demand functions are of the correct sign. In addition, compared with the IC model, the PI-CR model provides a more consistent interpretation of the BOJ's operating procedures, in that the estimation results of the PI-CR model clearly implys that the BOJ targeted only the call rate. Therefore, judging by the estimation results from the IC and PI-CR models, the CR system (20)-(24) statistically outperforms the IC system (7)-(12). [17]

A review of the estimation results follows.

1. The PI-CR model outperforms the IC model and gives more consistent estimates. This implies that the BOJ did not passively accommodate the demand for discount window borrowing by private banks, but actively controlled the level of discount-window lending and rationed lending to private banks. Therefore, for the BOJ's operating procedures up to June 1995, we infer that the BOJ affected the short-run money market both via open-market operations and via discount-window lending. [18]

2. It is conceivable that unanticipated changes in the call rate represent unanticipated changes in the BOJ's policy stance. Therefore, we infer that the BOJ targeted only the call rate, and that the call rate is the best policy indicator of the BOJ.

6 Impulse Response Analysis

For the BOJ's operating procedures, the estimation results of the IC and the Partially Identified CR (PI-CR) models suggested the superiority of the

[17] As section 6 demonstrates, the estimation results of the Fully Identified CR (FI-CR) model are fairly similar to those of the PI-CR model.

[18] Ueda (1993) states, "Therefore, discount-window lending has been rationed in Japan. In addition, the level of lending has been changed by the BOJ, not by private banks" (p.12, lines 17-19).

CR hypothesis over the IC hypothesis. However, we do not wish to emphasize these estimates too much, because the partial identification do not strictly follow the traditional way of VAR analysis, in which, given identified monetary policy shocks, one uses esimated impulse response functions to evaluate models or hypotheses in question. In this section, we report estimation results of the Fully Identified CR (FI-CR) model and estemated impulse response functions from the model, focusing particularly on whether the CR hypothesis still have validity to explain the BOJ's operating procedures. In addition, we reexamine the plausibility of the IC hypothesis using estimated impulse response functions from the IC model.

6.1 Estimates of the Fully Identified CR model

Firstly, we report estimation results of the FI-CR model. Estimates of the FI-CR models are given in the lower panels of Table 4. The estimation results of this model are fairly similar to those of the PI-CR model. All the slope coefficients of the two demand functions are of the correct sign. Further, the parameter estimates of the BOJ behavior function in the FI-CR model are close to unity. In addition, the CL and MIX models as well as the FI-CR model itsefl are easily accepted. As with the esimation results of the PI-CR model, those of the FI-CR model clearly imply that the BOJ targeted only the call rate.

Table 5 shows the contributions of four structural shocks to the variances of government deposits (GD), currency (CU), the call rate (R), and the BOJ's assets held via open-market operations and discount-window lending (MD) in the framework of the FI-CR model. The table shows that the monetary policy shock, v^{md}, explains much of the variation in the call rate. Moreover, the variation in MD reflects changes in the demand conditions within the market, v^{gd}, v^{cu}, and v^{d}. These results also imply that the BOJ fully offsets the three demand shocks to stabilize the call rate.

As with the estimaton results of the PI-CR model, those of the FI-CR model also suggest that the CR hypothesis have varidity to explain the BOJ's operating procedures. The important point on comparison of the FI-CR and PI-CR models, both of which are based on the CR hypothesis, is that the two CR models have the same structure for the structural VAR system (6), but have different structure for the VAR system (3)-(4). The non-nested structure attributed to different number of variables within the VAR systems of the FI-CR and PI-CR models does not allow us to statisitically compare the performacne of the CR models without the use of the p-values of the OIR and JOINT statistics. However, as long as both of the CR models are not rejected significantly, and provide the same interpretation on the BOJ's operating procedures, we should not determine relative merit of the two CR models using only the p-values. We therefore confine our concern with the estimation results of the FI-CR model to confirming varidity of the CR hypothesis. [19]

6.2 Impulse Response Functions from the IC Model

Here, we report the esimated impulse response functions from the IC model. Figure 2 shows the impulse response functions of the IC model. The left column shows the estimated responses of the non-policy sector variables. The right column shows the estimated responses of the policy-sector variables. For ease of interpretation, we consider an expansionary shock with an impact effect on the call rate of -100 basis points. Solid lines indicate point estimates of impulse responses up to the 48th month. Dashed lines represent one standard error band, computed by using a Monte Carlo integration with 1000 replications.

As shown in Figure 2, the responses of the price indicator, CPI, is subject to the "Price Puzzle" because CPI responds to an expansionary policy shock by going down. Further, the response of M2+CD is subject to the "Liquidity Puzzle", because M2+CD goes down in response to an expansionary policy shock. Given these puzzles and the inconsistency of the estimation results discussed in the previous section, the IC model is implausible.

6.3 Impulse Response Functions from the FI-CR Model

Figure 3 shows the estimated impulse response functions from the FI-CR model. It should be noted that the price and liquidity puzzles that are observed in the IC model are not observed in the FI-CR model. Thus,

[19] Unlike the PI-CR model, the FI-CR model retains the non-dependency of monetary transmission mechanism on measures of supplying high-powered money, an implication of the CR hypothesis, both for the contemporaneous relationships between policy-sector variables described by the CR system (20)-(24) and for the dynamics of macroeconomy described by the VAR system (3)-(4). As long as section 5 demonstrates that the PI-CR model, which do not retain the non-dependency for the dynamics of macroeconomy, is not rejected, we can not necessarily suggest, judging by the estimatin results of the FI-CR model and the following estimated impulse response functions from the model, that the non-dependency is applicable not only to the contemporaneous relationships between policy-sector variables, also to the dynamics of macroeconomy. Hence, our suggetion obtaiend from the estimation results of the FI-CR model is restricted to confirmation that the CR hypothesis have varidity to explain the BOJ's operating procedures, even if we use two different CR models.

we can examine the estimated impulse response functions from the FI-CR model in detail.

Firstly, we report the estimated responses of the non-policy sector variables. The effect of the expansionary policy shock to output (IIP) builds gradually and reaches its peak after about one year, before declining back to zero. The effect of the CPI exhibits the "Nominal Rigidity", which means that the responses of the price indicators are zero for about a year following a policy shock. [20] PCOM, which is an indicator of future inflation, reaches its peak after about one year. This PCOM response is interesting in that it emerges before the CPI. M2+CD immediately responds to the policy shock, as expected. The response of M2+CD indicates the "Liquidity Effect" and reaches its peak after about one year. In particular, the timing of the M2+CD response is noteworthy because it corresponds to the estimated timing of the effect of the policy shock on output (IIP), and also to the emergence of the effect of the policy shock on the price indicator (CPI). This implies that monetary policy works through the conventional money demand mechanism. [21] The estimated response of the exchange rate (EX) is insignificant. However, according to the point estimate, the response of EX peaks after about 30 months and appears to be permanent.

Next, we report the estimated responses of the policy-sector variables. We do not assess the estimated response of government deposits (GD), about which we have no theoretical expectations. The estimated response of currency (CU) is erratic during the first year after the immediate positive response to the expansionary shock, but at about the one-year point, currency begins to decline, following the movement of the call rate (R). The estimated response of reserves (RE) is insignificant. However, according to the point estimate, the response of RE indicates a liquidity effect on the market for bank reserves lasting about one year, following the movement of the effects of the expansionary shock on the call rate. [22] From the movement of R, it is conceivable that the BOJ commits itself to expansionary policy for

[20] In the VAR literature on U.S. monetary policy, Christiano et al. (1996) also find one-year nominal rigidity in the response of price indicators.

[21] The present study does not address the controversy between the opposing credit and money views of the monetary transmission mechanism. Ogawa (1999), Hatakeda (1997), and Ueda (1993) examine this issue in detail.

[22] The impulse response of reserves (RE) is calculated by using the relation $RE = MD - GD - CU$. Hayashi (2001) uses daily data and estimates structural-equation models to identify the liquidity effect of the BOJ's monetary policy on the Japanese interbank market. Beaudry and Saito (1998) apply several methods, including a structural VAR approach, in order to identify the liquidity effect of monetary policy, and make international comparisons.

about one year. For the BOJ's assets held via open-market operations and discount-window lending (MD), there is an erratic impulse for about six months after the policy shock. This implies that the BOJ fully offsets fluctuations in the demand for treasury funds, currency, and reserves in order to stabilize the call rate.

A review of the above results follows.

1. The IC model suffers from price and liquidity puzzles, whereas the FI-CR model does not suffer from these puzzles. Further, the estimates of the FI-CR model shows validity of the CR hypothesis, as those of the PI-CR model showed. Given these findings and the estimation results in the previous section, the CR hypothesis is more plausible to explain the BOJ's operating procedures than the IC hypothesis.

2. In the FI-CR model, after an expansionary shock, output peaks after about one year before declining back to zero. The timing of the estimated peak and decline of output corresponds to the estimated timing of the "policy tightening", which indicates that the call rate becomes positive about one year after the expansionary shock. The effect on price exhibits the nominal rigidity for about one year and reaches its peak in about 30 months. The response of reserves shows up the liquidity effect in the market for bank reserves for about one year, following the movement of the effects of the expansionary shock to the call rate.

7 Conclusions

This paper draws three main substantive conclusions.

Firstly, with regard to its operating procedures up to June 1995, the Bank of Japan (BOJ) fully offset demand shocks in the market for bank reserves and aimed to stabilize the call rate by using both open-market operations and discount-window lending.

Secondly, the BOJ's policy shock up to June 1995 emerges as unanticipated changes in the call rate. Therefore, we suggest that the call rate should be identified as the best policy indicator of the BOJ up to June 1995. This suggestion is especially noteworthy because Shioji, and Kasa and Popper point out that no single operating procedure can explain the behavior of the BOJ.

Thirdly, with regard to the effects of the BOJ's monetary policy shock to the macroeconomy, the response of output reaches its peak after about one year before declining back to zero after about three years. The response of price exhibits the nominal rigidity for about one year and reaches its peak after about 30 months. The response of reserves exhibits the liquidity effect in the market for bank reserves for about one year following the shock to the call rate.

These conclusions are obtained without splitting the sample from January 1975 to June 1995. However, the most attractive feature of the Bernanke-Mihov approach is that the approach can determine how central banks make decisions in response to the institutional and macroeconomic changes surrounding monetary policy in each period, and what combinations of monetary variables can explain the facts. Future refinement requires that Japanese monetary policy in each period be statistically conceptualized by splitting the sample according to the institutional and macroeconomic changes surrounding the BOJ.

Appendix A: Constructing MO and MD

- Construction of MO:
  First, we apply X12-ARIMA to foreign assets (net), claims on government, claims on deposit money banks, lending to deposit-money banks, and unclassified assets (net). Secondly, we subtract lending to deposit-money banks (SA) from the claims on deposit-money banks (SA). [23] The transformed data measure claims that the BOJ acquires via open-market operations on deposit-money banks. Then, we define the sum of the transformed data, foreign assets (SA), claims on government (SA), and the unclassified assets (SA) as MO: the BOJ's assets held via open-markets operations. All the data are obtained from Nikkei NEEDS (Monetary Survey, Accounts of Monetary Authority).

- Construction of MD:
  After applying X12-ARIMA to lending to deposit-money banks, we define the sum of the lending (SA) and MO as MD: the BOJ's assets held via open-market operations and discount-window lending.

[23] SA denotes seasonally adjusted data.

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Table 3: Estimation Results from the Implicit Cost (IC) Model (1975:1-1995:6)

Models	Demand Equations			BOJ Equations				OIR	JOINT
	α	β	γ	θ^{gd}	θ^{cu}	θ^{d}	θ^{b}		
IC	2.293	0.001	0.004	1.054	0.050	1.091	-0.741	8.958	–
	(0.462)	(0.001)	(0.077)	(0.044)	(0.267)	(0.133)	(0.058)	(0.029)	
CL	-0.064	-0.001	-0.011	1.000	1.000	1.000	-1.000	650.6	647.7
	(0.053)	(0.002)	(0.0012)					(0.000)	(0.000)
MIX	0.008	0.003	0.001	1.000	0.873	0.873	-1.000	136.0	352.3
	(0.004)	(0.004)	(0.002)		(0.124)	(0.124)		(0.000)	(0.000)

1. For the parameter estimates of the Demand Equations and BOJ Equations, standard errors are in parentheses.
2. OIR and Joint indicate overidentifying restrictions test statistics and joint test statistics, respectively. p-values are in parentheses.
3. A likelihood ratio test is used to test the overidentifying restrictions. The degrees of freedom are three for the IC model, seven for the CL model, and six for the MIX model.
4. For the CL model, likelihood ratio test statistics of the joint hypothesis that $\theta^{gd} = \theta^{cu} = \theta^{d} = 1.0,\ \theta^{b} = -1.0$ are calculated using four degrees of freedom.
5. For the MIX model, likelihood ratio test statistics of the joint hypothesis that $\theta^{gd} = 1.0,\ \theta^{cu} = \theta^{d},\ \theta^{b} = -1.0$ are calculated using three degrees of freedom.

Table 4: Estimation Results from the Credit Rationing (CR) Model (1975:1-1995:6)

Methods	Models	Demand Equations α	Demand Equations β	BOJ Equations ψ^{gd}	BOJ Equations ψ^{cu}	BOJ Equations ψ^{d}	OIR	JOINT
PI	CR	0.003 (0.002)	0.020 (0.030)	0.994 (0.021)	0.926 (0.047)	0.932 (0.082)	2.768 (**0.096**)	–
	CL	0.003 (0.001)	0.002 (0.001)	1.000	1.000	1.000	4.465 (**0.346**)	1.516 (**0.678**)
	HP	0.004 (0.003)	0.063 (0.042)	1.000	0.000	0.000	156.7 (0.000)	153.7 (0.000)
	MIX	0.007 (0.005)	0.003 (0.002)	1.000	0.899 (0.114)	0.899 (0.114)	3.409 (**0.332**)	1.055 (**0.304**)
FI	CR	0.008 (0.010)	0.004 (0.004)	1.026 (0.018)	0.954 (0.350)	0.888 (0.089)	0.644 (**0.422**)	–
	CL	0.008 (0.002)	0.001 (0.001)	1.000	1.000	1.000	1.297 (**0.861**)	0.593 (**0.897**)
	HP	0.546 (0.820)	0.006 (0.001)	1.000	0.000	0.000	99.27 (0.000)	98.57 (0.000)
	MIX	0.008 (0.005)	0.002 (0.002)	1.000	0.905 (0.119)	0.905 (0.119)	0.769 (**0.856**)	0.528 (**0.467**)

1. PI and FI indicate partial identification and full identification, respectively.
2. For the parameter estimates of the Demand Equations and BOJ Equations, standard errors are in parentheses.
3. OIR and Joint indicate overidentifying restrictions test statistics and joint test statistics, respectively. p-values are in parentheses.
4. A likelihood ratio test is used to test the overidentifying restrictions. The degrees of freedom are one for the CR model, four for the HP model, and three for the MIX model.
5. For the CL model, likelihood ratio test statistics of the joint hypothesis that $\psi^{gd} = \psi^{cu} = \psi^{d} = 1.0$ are calculated with three degrees of freedom.
6. For the HP model, likelihood ratio test statistics of the joint hypothesis that $\psi^{gd} = 1.0$, $\psi^{cu} = \psi^{d} = 0.0$ are calculated with three degrees of freedom.
7. For the MIX model, likelihood ratio test statistics of the joint hypothesis that $\psi^{gd} = 1.0$, $\psi^{cu} = \psi^{d}$ are calculated with two degrees of freedom.

Table 5: Variance Decomposition from the FI-CR Model(%)

	GD	CU	R	MD
v^{gd}	100.0	2.732	1.122	**60.12**
v^{cu}	0.000	87.32	6.204	**25.34**
v^{d}	0.000	1.321	2.194	**14.32**
v^{boj}	0.000	8.267	**90.48**	0.219

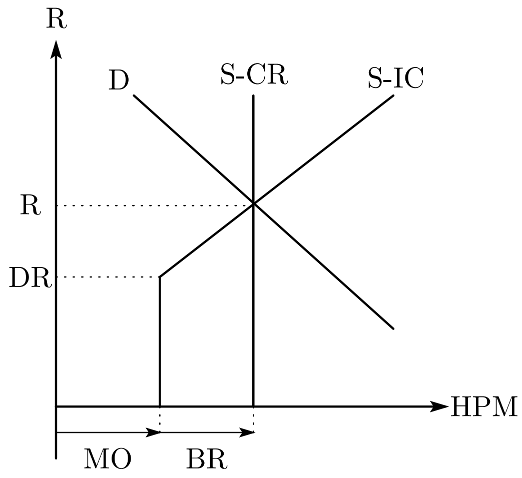
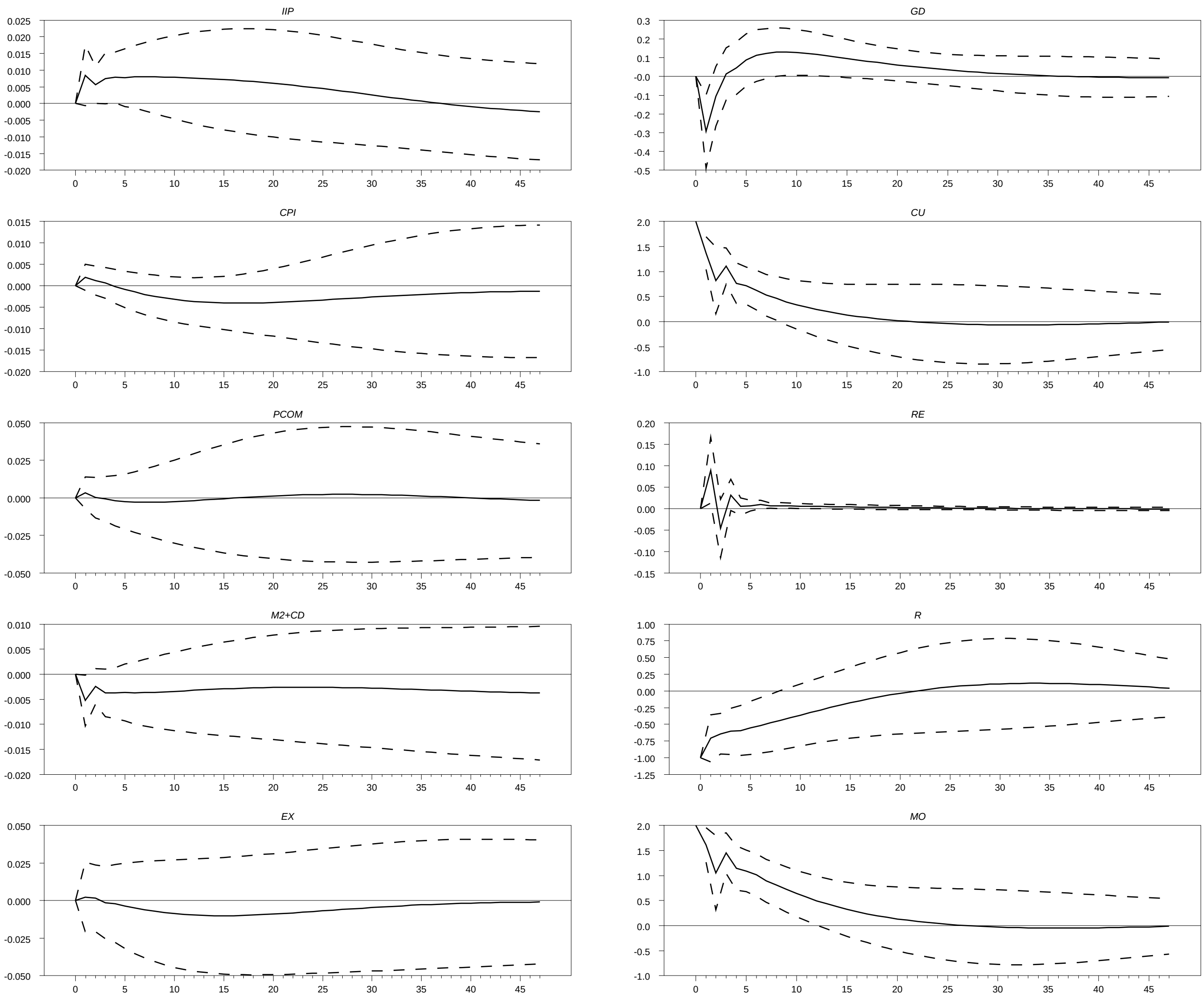


Figure 1: The Reserve Market up to June 1995.

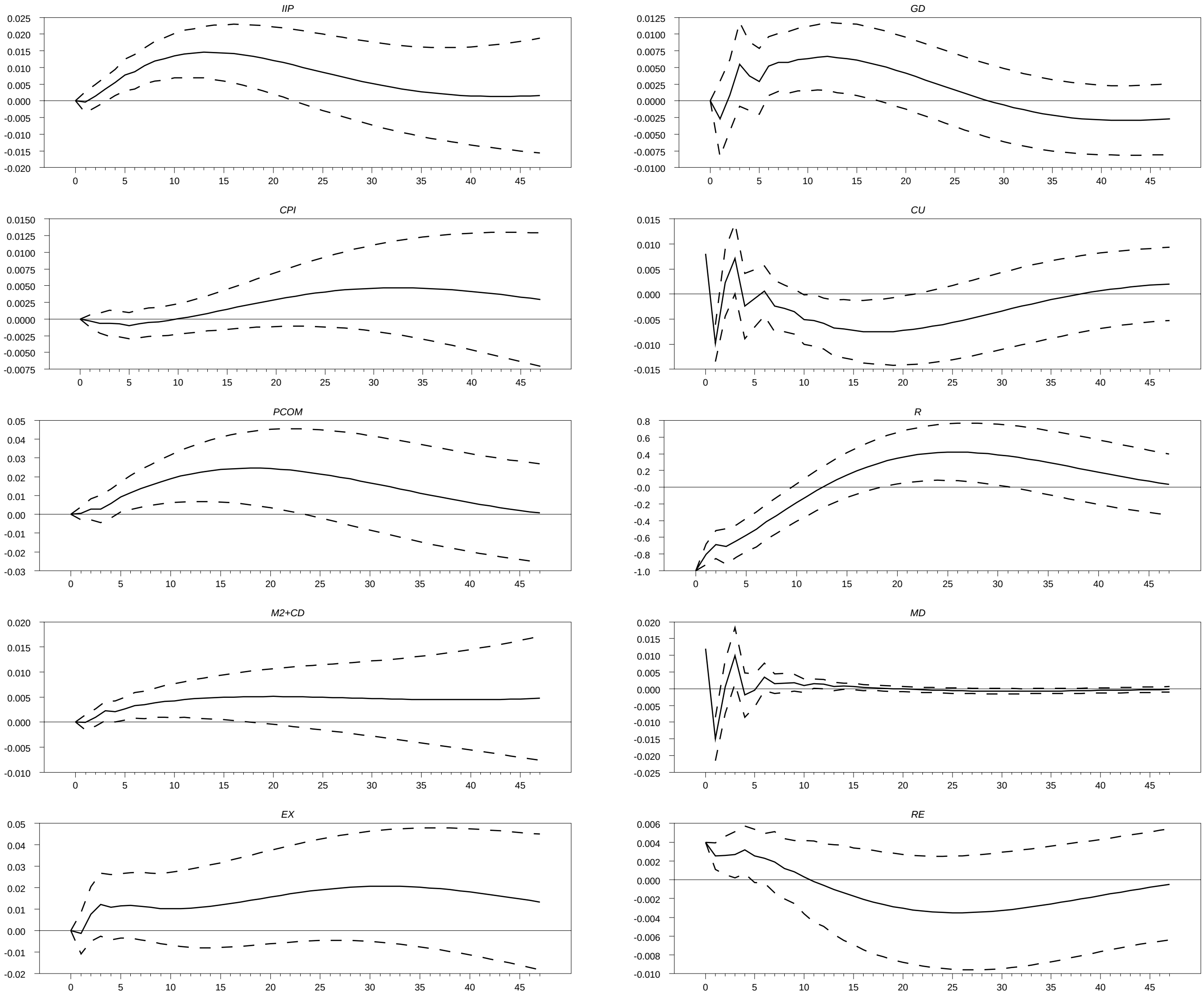
Figure 2: Impulse Responses of the Monetary Policy Shock for the IC Model (1975:1-1995:6)



1. The monetary policy shock is normalized so that it produces a 100-basis point decline in the call rate on impact.

2. The solid line and the dashed line represent point estimates and standard errors of the estimated impulse responses, respectively.

Figure 3: Impulse Responses of the Monetary Policy Shock for the FI-CR Model (1975:1-1995:6)



1. The monetary policy shock is normalized so that it produces a 100-basis point decline in the call rate on impact.

2. The solid line and the dashed line represent point estimates and standard errors of the estimated impulse responses, respectively.

3. Impulse response for RE (reserves) are calculated from RE=MD-GD-CU.