CARF Working Paper

CARF-F-323

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July 2013

CARF is presently supported by Bank of Tokyo-Mitsubishi UFJ, Ltd., Dai-ichi Mutual Life Insurance Company, Meiji Yasuda Life Insurance Company, Nomura Holdings, Inc. and Sumitomo Mitsui Banking Corporation (in alphabetical order). This financial support enables us to issue CARF Working Papers.

Banks' regulation, asset portfolio choice of banks, and macroeconomic dynamics*

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July 6, 2013

Abstract

Since the middle of 1990s, the Japanese banks have continuously tilted their asset portfolio towards the government bonds, reducing their lending to firms. In this paper, we investigate the causes and consequences of such changes in the banks' behaviors, by introducing the banks' asset portfolio decision into an otherwise standard New Keynesian model. The banks in our model construct their portfolio under the value at risk constraint, that requires banks repay their debt regardless of the realization of the asset returns. Under the constraint, an increase in down-side risks, tightening of capital requirement rules or deterioration of the banks' net worth reduce the banks' risk taking capacity, and incurs a shrinkage of the banks' balance sheet and asset rebalancing towards government bond. The changes in banks' investment decisions dampen output and inflation. Empirical studies suggest that our theoretical predictions are consistent with behavior of the Japanese banks.

Keywords: Value at Risk Constraint; Banks' Asset Allocation; Capital Requirements.

1 Introduction

It has been commented by many policy makers and academics that the level of Japan's government debt outstanding is historically high. Figure 1 displays the time path of the

*The authors would like to thank Takatoshi Ito, Toshiki Jinushi, Munehisa Kasuya, Koichiro Kamada, Yong Min Kim, Takeshi Kimura, Takashi Kozu, Eiji Maeda, Koji Nakamura, Kenji Nishizaki, Masashi Saito, Takatoshi Sekine, Yosuke Takeda, Tsutomu Watanabe, participants at the fourth University of Tokyo – Bank of Japan conference in 2011, CIGS conference in 2012, Research and Task Force Workshop in 2013, and the staff of the Bank of Japan, for their useful comments. The views expressed in this paper are those of the authors and do not necessarily reflect the official views of the Bank of Japan.

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government bonds outstanding relative to GDP and aggregate capital stock[1]. Clearly, the government bond accumulation has grown more quickly than the GDP, and the aggregate asset portfolio is tilted towards the government bond[2]. This acceleration of government debt accumulation is closely related to the banks' adjustments of their balance sheet and asset portfolio composition. Figure 2 displays changes in the banks' asset allocation between the government bond holdings and the investment to other assets that includes loan claim to firms and equity and private bond holdings. Clearly, the banks' purchase of the government bonds has risen since the mid 1990s, while the banks' loan claim and other asset have kept declining. Consequently, as Figure 3 indicates, a bulk of the government bonds issued during this period has been absorbed by the banking sector. However this is not necessarily because rate of return of loans to firms became disproportionately lower. Figure 4 shows the rates of return of capital and government bonds. Even though the rate of return of real investment, including loam claim as well as equity and private bond purchase, declined in this period, the spread between the two rates of return have risen, not fallen.

The purpose of this paper is to investigate the causes and consequence of the changes in banks' asset portfolio decisions. We examine both theoretically and empirically an hypothesis that a friction or a regulation in the banking sector (to be specified subsequently) is key to understand banks asset portfolio decisions and their macroeconomic consequences. We first develop a model that incorporates banks and government bonds into an otherwise standard New Keynesian model. Banks in our model economy collect deposits from the households, and invest the deposit and their own net worth into loan claims to firms and the government bonds whose real rates of return are stochastic. They decide their balance sheet size and asset portfolio allocation between the two kinds of assets, so as not to violate the value-at-risk constraint (hereafter VaR constraint). In our model, the VaR constraint requires banks construct asset portfolio in such a way that they repay all of their liabilities to the households regardless of realizations of ex-post returns of those two assets. In other words, the banks construct their asset portfolio so that they do not go under even when the maximum losses are realized for both assets. Our VaR constraint is similar to the constraint analyzed by Adrian and Shin (2011). In their study, the banks invest external funds and net worth only on capital goods, and the VaR constraint in their model works as a source of the banks' balance sheet fluctuations. By contrast, in our model, there are two kinds of assets to invest, and the VaR constraint affects banks' asset portfolio allocation as well as their balance sheet size.

The VaR constraint in our model affects the banks' risk taking capacity[3]. When the

[1]The government bond includes treasury discount bills, central government securities and FILP bonds, local government securities, and public corporation securities unless otherwise noted.

[2]There is a growing literature about the accumulation of government bond in Japanese economy from the perspective of government debt sustainability, including Doi et al. (2011) and Imrohologlu and Sudo (2011). See Enomoto and Iwamoto (2008) for the welfare implication of fiscal policy undertaken during the lost decade.

[3]In the current paper, we focus on the economy where banks risk taking capacity is limited, because

VaR constraint is absent from the economy, the banks' optimal asset portfolio decision requires that the expected returns from the two assets be equalized in equilibrium. When it is present the banks' asset portfolio depends not only on the expected returns of the two assets, but also on the maximum loss of each type of assets and the banks' net worth. For instance, when the maximum loss of holding loan claims increases, the banks rearrange their balance sheet size and the composition of asset portfolios so as to avert the bankruptcy. They try to maintain their solvency under the worst scenario by reducing the balance sheet size and by investing more to the asset whose maximum loss is smaller. We furthermore show that changes in institutional environment, such as reinforcement of banks' capital requirement can be analyzed within the same framework. What we have in mind here is the full-dress enforcement of Basel Committee agreement that took place in Japan as shown in Table 2. Such institutional initiatives encourage the rearrangement of the banks' balance sheet and asset portfolio by directly controlling the banks' risk taking capacity. The banks' net worth also plays a significant role in the banks' asset portfolio decision. When the net worth deteriorates, the banks' repayment capacity in a worst state becomes smaller than otherwise. In such a case, the banks avert bankruptcy by reducing the balance sheet as is shown by Adrian and Shin (2011), and by shifting the asset portfolio from the asset with a large maximum loss to that with a smaller maximum loss.

Next, we analyze implications of the banks' investment decisions under the VaR constraint to the dynamics of output and inflation. It is shown that an increase in the maximum loss of loan claim holding (or, increased enforcement of banks' capital requirement,) reduces investment to the loan claims, as banks rearrange the size of their balance sheet and the composition of their asset portfolio allocation. Consequently, output and inflation decline. This initial effect brings about the second-round effect on the macroeconomy, through the endogenous development of the banks' net worth. When the initial effect decreases the banks' net worth, it further dampens output and inflation, through the changes in the risk taking capacity originating from the shortage of the banks' net worth.

Our model's implication is consistent with Japan's experience since 1990. There is vast literature on the long-lasting stagnation in the Japanese economy since the beginning of the 1990s, the so-called lost decades. A pioneering work by Hayashi and Prescott (2002) show that, based on a simple growth model, an exogenous decline in the total factor productivity growth can account for the economic stagnation during this period. By contrast, studies such as Bayoumi (2001), Hoshi and Kashyap (2004, 2010), Caballero, Hoshi, and Kashyap (2008), and Hirose and Kurozumi (2010), emphasize a channel

of the VaR constraint. Consequently, the capital investment made by the banks is too small in the economy, compared with the economy where such constraint is absent. By contrast, recent studies, including Korinek (2011) and Kato and Tsuruga (2011), investigate the economy where the fire-sale externality of assets leads to an ex-ante excessive investment by an individual bank.

through which the malfunction of banking sector dampens the economic activity[4][5]. Japan witnessed the enforcement of Basel capital requirements, the accumulation of bad loans triggered by the burst of bubbles in the early 1990s and the subsequent deterioration of the banks' balance sheet. All of these events may induce the shrinkage of the banks' balance sheet and credit crunch. Our work is related to this second strand of literature, but our focus is more on banks portfolio allocation decisions rather than their balance sheet size. We show that those same events make banks invest more on government bonds rather than loans, generating downward pressure on the economic activity and inflation.

We then investigate empirically if the banks' net worth and/or tightening of regulation does play a role in determining the banks' portfolio allocation through the VaR constraint. To do this, we make use of a panel series of Japanese banks as well as the time series of macroeconomic variables. First, we conduct the cross-sectional analysis of banks' portfolio allocation and show that a reduction of a banks' net worth is followed by the increase of the government bond holding compared with the other assets. We also find that on average banks started to tilt their asset towards the government bond a few years before the enforcement of Basel III, indicating the importance of institutional arrangements in banks' asset portfolios. Second, we formulate a vector autoregression to explore the consequence of the banks' net worth disruption and a tightening of the regulation which we capture by a positive innovation to the ratio of government bond to the productive capital that permanently affects the ratio and the capital return. We find that estimated results are consistent with the theoretical implication of our model.

It is important to note that the analysis of the supply side about the background against the observed government bond accumulation is outside of the scope of this paper because the increased supply of the government bond is attributed to the government policy and not to the government's endogenous response to the changes of demand for the government bonds. Instead, the paper discusses the demand structure of the government bond that emerges as a consequence of the banks' optimal choice of portfolio allocation. Taking the government bond supply as given, we explore how the government bond demand is reflected in the banks' balance sheet size, their asset allocation, as well as the spread between the return to the two assets and the amount of resources invested to productive capitals in the economy.

The rest of the paper is organized as follows. Section 2 presents our model with banks that endogenously choose the asset portfolio under the VaR constraint. In addition, we explore the qualitative property of our model using a simplified setting. Section 3

[4]For example, Bayoumi (2001) uses a VAR to argue that that the disruption of the financial intermediation due to the deterioration of the banks' balance sheet or the enforcement of the capital requirement, played a dominant role in bringing down the economy.

[5]Hayakawa and Maeda (1997) and Sudo (2011) argue that the banking crisis aggravates the financial intermediation activity, encourages the households' precautionary saving, and lowers velocity of circulation of money and price level.

provides some empirical evidence. Section 4 concludes the analysis and discuss the future extension of our analysis.

2 The Model Economy

This section describes the structure of our model. The economy consists of seven types of agents: household, banks, intermediate goods producers, wholesale goods producers, final goods producers, government and central bank. See Figure 4 for model's brief outline.

The representative household supplies labor inputs to the intermediate goods producers, receives wages, makes deposit to the banks. She has no access to the financial market and cannot own the financial assets but bank deposits. Banks invest their own net worth and deposits to the two assets: the loan claim to the capital goods used by the intermediate goods producers, and the government bond. They construct their asset portfolio allocation, so as not to violate the VaR constraint. The intermediate goods producers hire labor and capital to produce intermediate goods. The wholesale goods producers produce differentiated wholesale goods from intermediate goods. They are monopolistic supplier of each type of wholesale goods, and set their prices are sticky. The final goods producers convert differentiated wholesale goods to final goods. The government collects lump-sum tax from the household and issues the government bond to finance interest payment and the government expenditure. The central bank controls the nominal interest rate according to a Tayor rule.

2.1 Household

The infinitely-lived representative household makes decision for consumption and deposit holdings. She has no access to financial markets, so all financial transactions are intermediated by banks.

The household's preference is given by as described in the expected utility function

$$\mathrm{E}_0 \sum_{t=0}^{\infty} \beta^t U(c\left(s^t\right), l\left(s^t\right)) = \mathrm{E}_0 \sum_{t=0}^{\infty} \beta^t \left(\log c\left(s^t\right) + \eta \log\left(1 - l\left(s^t\right)\right)\right), \tag{1}$$

where s^t is a state at period t, $c\left(s^t\right)$ is consumption goods, $l\left(s^t\right)$ is work effort, $\beta \in (0,1)$ is the discount factor and η is the weight assigned to leisure.

The budget constraint of the household is given by

$$c\left(s^t\right) + d\left(s^t\right) = r_d\left(s^{t-1}\right) d\left(s^{t-1}\right) + \frac{W\left(s^t\right)}{P\left(s^t\right)} l\left(s^t\right) + \Pi\left(s^t\right) - \tau\left(s^t\right) \tag{2}$$

where $d\left(s^t\right)$ is the household's deposit, $r_d\left(s^{t-1}\right)$ is the real deposit rate repaid by the banks for the deposit made in period $t-1$, $W\left(h, s^t\right)$ is the nominal wage rate, $P\left(s^t\right)$ is the price index, $\Pi\left(s^t\right)$ is the sum of the real profits of the intermediate goods producers and the banks that are returned to the household as dividends. $\tau\left(s^t\right)$ is the lump-sum real tax collected by the government. We assume that the deposit is risk-free asset, and the real deposit rate is the real risk-free rate.

The first-order conditions associated with the household's intertemporal decision is given by

$$U_c(c\left(s^t\right), l\left(s^t\right)) = \beta r_d\left(s^t\right) \mathrm{E}_t U_c(c\left(s^{t+1}\right), l\left(s^{t+1}\right)),$$

where $U_c(c\left(s^t\right), l\left(s^t\right))$ denotes the marginal utility with respect to the consumption at period t. Because the household's only financial asset is banks' deposit, her consumption growth is dependent on the risk-free rate.

Since the labor market is competitive, arranging the first order conditions associated with the household's intra-temporal decision is given by

$$\frac{U_l(c\left(s^t\right), l\left(s^t\right))}{U_c(c\left(s^t\right), l\left(s^t\right))} = \frac{W\left(s^t\right)}{P\left(s^t\right)},$$

where $U_l(c\left(s^t\right), l\left(s^t\right))$ denotes the marginal utility with respect to the leisure at period t.

2.2 Banks

The outline of banks' choice

There is a continuum of risk-neutral banks, indexed by $i \in (0,1)$. Each bank i collects deposit $d\left(i, s^t\right)$ from the households, and purchases the loan claim, namely capital stock, $k\left(i, s^t\right)$, and the real government bond $b\left(i, s^t\right) \equiv \frac{B\left(i, s^t\right)}{P\left(s^t\right)}$, from the final goods producers and the government, respectively. The expenses are financed by the deposit $d\left(i, s^t\right)$ and the bank i's own real net worth $n\left(i, s^t\right)$. The bank i's balance sheet each period is therefore given by

$$k\left(i, s^t\right) + \frac{B\left(i, s^t\right)}{P\left(s^t\right)} = n\left(i, s^t\right) + d\left(i, s^t\right). \tag{3}$$

The bank i receives returns from the two assets invested in the previous period, repays the deposit to the households, and retains the rest of the earnings as the own net worth. Consequently, the bank's net worth evolves according to the following law of motion

$$n\left(i, s^{t+1}\right) = r_k\left(s^{t+1}\right) k\left(i, s^t\right) + r_b\left(s^{t+1}\right) b\left(i, s^t\right) - r_d\left(s^t\right) d_t\left(i, s^t\right), \tag{4}$$

where $r_k\left(s^{t+1}\right)$ and $r_b\left(s^{t+1}\right)$ are the ex-post real return to the loan claim and the government bond, respectively. Note that the real return to the government bond is given by the policy rate $R_B\left(s^t\right)$ set by the central bank, divided by the inflation rate $\pi\left(s^{t+1}\right)$ through the relationship below.

$$r_b\left(s^{t+1}\right)=\frac{R_B\left(s^t\right)}{\pi\left(s^{t+1}\right)}.$$

The bank i keeps the net worth accumulation up to the period when it exits from the economy.[6] We assume that the bank's exiting probability each period is exogenously given by $1-\gamma\left(s^t\right)$. The continuation value of the bank i is then given by

$$V\left(n\left(i,s^t\right)\right)=\beta \mathrm{E}_t\Lambda_{t,t+1}\left[\gamma\left(s^t\right)V\left(n\left(i,s^{t+1}\right)\right)+\left(1-\gamma\left(s^t\right)\right)n\left(i,s^{t+1}\right)\right], \tag{5}$$

where $n\left(i,s^t\right)$ is the net worth held by the bank i, and $\Lambda_{t,t+1}$ denotes the households' stochastic discount factor from the period t to the period $t+1$.

In choosing the asset portfolio allocation between the two assets, the bank i considers the VaR constraint similar to the one discussed in Adrian and Shin (2011), together with the expected average returns of the two assets. Namely, the bank i adjusts its balance sheet in period t, so that it is able to repay all of its debt to the household, even if the two assets yield the maximum loss in period $t+1$. Denoting the maximum loss from holding the two assets by $\mathrm{E}_t\left[\underline{r}_k\left(s^{t+1}\right)\right]$ and $\mathrm{E}_t\left[\underline{r}_b\left(s^{t+1}\right)\right]$, respectively, the value at risk constraint is expressed by

$$\mathrm{E}_t\left[\underline{r}_k\left(s^{t+1}\right)\right]k\left(i,s^t\right)+\mathrm{E}_t\left[\underline{r}_b\left(s^{t+1}\right)\right]b\left(i,s^t\right)-r_d\left(s^t\right)d\left(i,s^t\right)\geq 0. \tag{6}$$

Here, we assume that loans are riskier than the government bond, so that $\mathrm{E}_t\left[\underline{r}_k\left(s^{t+1}\right)\right]<\mathrm{E}_t\left[\underline{r}_b\left(s^{t+1}\right)\right]$[7].Constraint (6) represents a constraint on bank net worth. To see this, substitute (4) into (6) to obtain

$$n\left(i,s^t\right)\geq\omega_k\left(s^t\right)k\left(i,s^t\right)+\omega_b\left(s^t\right)b\left(i,s^t\right). \tag{7}$$

We can thus interpret equation (7) as representing an institutional regulation such as the Basel capital requirement. Each coefficient $\omega_k\left(s^t\right)\equiv\frac{r_d\left(s^t\right)-\mathrm{E}_t\left[\underline{r}_k\left(s^{t+1}\right)\right]}{r_d\left(s^t\right)}$ and $\omega_d\left(s^t\right)\equiv\frac{r_d\left(s^t\right)-\mathrm{E}_t\left[\underline{r}_b\left(s^{t+1}\right)\right]}{r_d\left(s^t\right)}$ can be interpreted as representing regulatory risk-weight parameters attached to each type of assets. Along this line of interpretation, decreases in $\mathrm{E}_t\left[\underline{r}_k\left(s^{t+1}\right)\right]$ and $\mathrm{E}_t\left[\underline{r}_b\left(s^{t+1}\right)\right]$ are equivalent to tightening of the regulatory capital requirements

[6] Following Gertler and Karadi (2011), we assume that the bank transfers all of the accumulated net worth to the household when it exits from the economy.

[7] In the current paper, we concentrate our analysis on the equilibrium where the banks hold both of the two risky assets, and the worst returns of the two risky assets are smaller than the risk-free rate, so that the two equations below hold.

$$\begin{aligned}\mathrm{E}_t\underline{r}_k\left(s^{t+1}\right)-r_d\left(s^t\right) &< 0,\\ \mathrm{E}_t\underline{r}_b\left(s^{t+1}\right)-r_d\left(s^t\right) &< 0.\end{aligned}$$

through the increase of the risk-weights. In practice, under the current Basel framework, government bonds issued by Japanese government attract zero risk-weight because government bonds are considered as perfectly safe. This corresponds to our limiting case in which $\omega_d\left(s^t\right) = 0$. However in subsequent sections we analyze a general case in which $\omega_d\left(s^t\right) \geq 0$.

The banks' maximization problem

In Adrian and Shin (2011) where there is only one type of asset, the VaR constraint matters only to the size of bank's leverage. By contrast, in our model where there are two assets in the economy, the VaR constraint influences the asset portfolio allocation as well as the size of the leverage. The bank i's optimization problem is formulated as the maximization of the value (5) , (3) ,(4), and the VaR constraint (6). Because the banks are risk-neutral, we first guess that the value function of the bank i is given by

$$V\left(n\left(i,s^t\right)\right) = \phi\left(s^t\right) n\left(i,s^t\right),$$

then the equation (5) is reduced to

$$\begin{aligned}\max V\left(n\left(i,s^t\right)\right) = \beta \mathrm{E}_t[\Lambda_{t,t+1}\Bigg[\gamma\left(s^t\right)\phi\left(s^{t+1}\right)&\begin{pmatrix} q_k\left(s^{t+1}\right)k\left(i,s^t\right) \\ +q_b\left(s^{t+1}\right)b\left(i,s^t\right) \\ +r_d\left(s^{t+1}\right)n\left(i,s^t\right)\end{pmatrix} \\ +\left(1-\gamma\left(s^t\right)\right)\left(q_k\left(s^{t+1}\right)k\left(i,s^t\right) + q_b\left(s^{t+1}\right)b\left(i,s^t\right) + r_d\left(s^t\right)n\left(i,s^t\right)\right)&]\Bigg].\end{aligned}$$

The corresponding first order condition gives

$$\mathrm{E}_t\left[\frac{\left(\gamma\phi\left(s^{t+1}\right)+1-\gamma\left(s^t\right)\right)\Lambda_{t,t+1}q_k\left(s^{t+1}\right)}{\underline{q}_k\left(s^{t+1}\right)}\right] = \mathrm{E}_t\left[\frac{\left(\gamma\phi\left(s^{t+1}\right)+1-\gamma\left(s^t\right)\right)\Lambda_{t,t+1}q_b\left(s^{t+1}\right)}{\underline{q}_b\left(s^{t+1}\right)}\right]. \tag{8}$$

Here $q_k\left(s^{t+1}\right) \equiv r_k\left(s^{t+1}\right) - r_d\left(s^t\right)$ and $q_b\left(s^{t+1}\right) \equiv r_b\left(s^{t+1}\right) - r_d\left(s^t\right)$ denote the excess return to the loam claim holding and that to the government bond holding relative to the deposit, respectively. Similarly, $\underline{q}_k\left(s^{t+1}\right) \equiv \underline{r}_k\left(s^{t+1}\right) - r_d\left(s^t\right)$ and $\underline{q}_b\left(s^{t+1}\right) \equiv \underline{r}_b\left(s^{t+1}\right) - r_d\left(s^t\right)$ denote the excess return to the two risky assets when the worst return to the assets realize.

The equation (8) provides the bank's fundamental principle in allocating their assets into the loan claim and the government bond. When the VaR constraint is effective, there is no need that expected excess returns of the two assets are not equalized at the equilibrium. Instead, banks' asset portfolio is constructed so that the expected excess returns weighted by the maximum loss of each asset are equalized. Under the premise that the loan claim is riskier than the government bond, so that $\mathrm{E}_t\left[\underline{r}_k\left(s^{t+1}\right)\right] <$

$\mathrm{E}_t\left[\underline{r}_b\left(s^{t+1}\right)\right]$, the expected excess return of the loan claim needs to exceed that of the government bond, $\mathrm{E}_t\left[r_k\left(s^{t+1}\right)\right] > \mathrm{E}_t\left[r_b\left(s^{t+1}\right)\right]$, for compensation.

From equations (6) and (8), we obtain the expression for $\phi\left(s^t\right)$.

$$\phi\left(s^t\right) = \beta \mathrm{E}_t\left[\Lambda_{t,t+1}\left\{\gamma\left(s^t\right)\phi\left(s^{t+1}\right) + \left(1-\gamma\left(s^t\right)\right)\right\} r_d\left(s^t\right)\left(1 - q_k\left(s^{t+1}\right)/\underline{q}_k\left(s^{t+1}\right)\right)\right]. \tag{9}$$

Aggregation

The banks exit from the economy with probability $1-\gamma\left(s^t\right)$ each period, and the aggregate banks' net worth evolves according to the following law of motion;

$$n\left(s^t\right) = \gamma\left(s^t\right)\left[r_k\left(s^t\right)k\left(s^{t-1}\right) + r_b\left(s^t\right)b\left(s^{t-1}\right) - r_d\left(s^{t-1}\right)d\left(s^{t-1}\right)\right],$$

where $n\left(s^t\right)$ is the aggregate banks' net worth. An increase in the exiting probability reduces the bank's net worth. As shown in the equation (6), the reduced net worth helps tighten the banks' VaR constraint, affecting the size of the banks' balance sheet and the composition of the asset portfolio in the subsequent period[8][9].

2.3 Intermediate Goods Producers

The intermediate goods producers produce intermediate goods $y\left(s^t\right)$, selling them to the wholesale goods producers with the price $P_y\left(s^t\right)$. They hire labor inputs $l\left(s^t\right)$ from the household and borrow the capital $K\left(s^{t-1}\right)$ from the banks. Both the input and output market of the intermediate goods producers are competitive. The maximization problem of the intermediate goods producer is given by

$$\max_{y(s^t),\, k(s^{t-1}),\, l(s^t)} \frac{P_y\left(s^t\right)y\left(s^t\right)}{P\left(s^t\right)} - r\left(s^t\right)k\left(s^{t-1}\right) - W\left(s^t\right)l\left(s^t\right),$$

subject to

$$y\left(s^t\right) = \left(k\left(s^{t-1}\right)\right)^{\alpha}\left(Z\left(s^t\right)l\left(s^t\right)\right)^{1-\alpha}, \tag{10}$$

[8] Based on the financial accelerator model developed by Bernanke, Gertler, and Gilchrist (1999), Gilchrist and Leahy (2002) and Nolan and Thoenissen (2009) study the consequence of the exogenous deterioration of the entrepreneurial net worth to the economy. There the exogenous net worth change is considered as an irrational innovation the entrepreneurial net worth or shock to the technology associated with the efficacy of the financial intermediation.

[9] There are alternative ways to incorporate the shocks to the banks' net worth into the model. In Gertler and Karadi (2011), the existing capital stock becomes out of date, deteriorating the value of the banks' loan claim and net worth. In Aoki and Nikolov (2011) where the banks' investment on the bubble is analyzed, the collapse of the bubble leads to a deterioration of the banks' net worth.

where $k\left(s^{t-1}\right)$ is the capital stock, $r\left(s^t\right)$ is the real return to the use of capital, $Z\left(s^t\right)$ is the technology level, and $\alpha \in [0,1]$ is the capital share. The first order conditions of the intermediate goods producers yield the following equality.

$$
\begin{aligned}
r\left(s^t\right) &= \alpha \frac{P_y\left(s^t\right)}{P\left(s^t\right)} \left(k\left(s^{t-1}\right)\right)^{\alpha-1} \left(Z\left(s^t\right) l\left(s^t\right)\right)^{1-\alpha}, \\
\frac{W\left(s^t\right)}{P\left(s^t\right)} &= (1-\alpha) \frac{P_y\left(s^t\right)}{P\left(s^t\right)} \left(k\left(s^{t-1}\right)\right)^{\alpha} \left(Z\left(s^t\right)\right)^{1-\alpha} \left(l\left(s^t\right)\right)^{-\alpha}.
\end{aligned}
$$

Consequently, the banks' net return to the investment on the productive capital $r_k\left(s^t\right)$ is given by

$$
r_k\left(s^t\right) k\left(s^{t-1}\right) = r\left(s^t\right) k\left(s^{t-1}\right) + (1-\delta) k\left(s^{t-1}\right),
$$

where $\delta \in [0,1]$ is the depreciation rate of the capital stock. Similarly, the real wage paid to the household is expressed by

$$
\frac{W\left(s^t\right)}{P\left(s^t\right)} = s\left(s^t\right)(1-\alpha)\left(k\left(s^{t-1}\right)\right)^{\alpha} \left(Z\left(s^t\right)\right)^{1-\alpha} \left(l\left(s^t\right)\right)^{-\alpha}.
$$

2.4 Wholesale and Final Goods Producers

Optimization problem of wholesale and final goods producers

The wholesale goods sector contains a continuum of firms, each producing differentiated products, as indexed by $z \in [0,1]$, from the intermediate goods by the linear production technology

$$
x(z, s^t) = y(z, s^t).
$$

Here, $x(z, s^t)$ denotes the differentiated wholesale goods made by the wholesale goods producer z and $y(z, s^t)$ is the intermediate goods used as inputs by the producer z.

The final goods producer purchases these differentiated goods in a competitive market, producing the final goods from wholesale goods by the following CES aggregate technology

$$
x\left(s^t\right) = \left[\int_0^1 x(s^t, z)^{\frac{\varepsilon-1}{\varepsilon}} dz\right]^{\frac{\varepsilon}{1-\varepsilon}}, \quad \varepsilon > 1
$$

where $\varepsilon \in (1, \infty)$ denotes the time-varying elasticity of substitution between the wholesale differentiated goods. Given this CES technology of the final goods, the demand for each differentiated wholesale goods $x\left(z, s^t\right)$ is given by a function of the price of its product $p(z, s^t)$, the aggregate price index $P\left(s^t\right)$, and the aggregate demand for the final goods $x\left(s^t\right)$, as below

$$x(z,s^t)=\left(\frac{p(z,s^t)}{P\left(s^t\right)}\right)^{-\varepsilon}x\left(s^t\right).$$

Each wholesale goods producer z maximizes its profit by choosing the product price optimally. The maximization problem of each wholesale good producer is given by

$$\max_{p(z,s^{t+j})}\mathrm{E}_t\sum_{j=0}^{\infty}\beta^j\Lambda_{j-1,j}\left[\begin{array}{l}\left(\frac{p(z,s^{t+j})}{P(s^{t+j})}\right)^{1-\varepsilon}x\left(s^{t+j}\right)\\ -\left(\frac{P_y(s^{t+j})}{P(s^{t+j})}\right)\left(\frac{p(z,s^{t+j})}{P(s^{t+j})}\right)^{\varepsilon}x\left(s^{t+j}\right)\\ -\frac{\kappa}{2}\left(\frac{p(z,s^{t+j})}{p(z,s^{t+j-1})}-\frac{p\left(s^{t+j-1}\right)}{p(s^{t+j-2})}\right)^2\left(\frac{p(z,s^{t+j})}{P(s^{t+j})}\right)^{-\varepsilon}x\left(s^{t+j}\right)\end{array}\right],$$

where the third term denotes an adjustment cost that wholesale goods producer pays in changing its product price $p(z,s^t)$, and κ is the parameter that governs the size of adjustment cost.

Because all of the differentiated goods prices $p(z,s^t)$ set by the wholesale goods producers are identical at the symmetric equilibrium, we obtain the following Phillips curve of the economy from the first order condition of the firm's maximization problem.

$$\begin{aligned}-\varepsilon\left(1-\frac{P_y\left(s^t\right)}{P\left(s^t\right)}-0.5\left(\pi\left(s^t\right)-1\right)^2\right)+1-\kappa\left(\pi\left(s^t\right)-1\right)\pi\left(s^t\right)\\ +\beta\kappa\left(\pi\left(s^{t+1}\right)-1\right)\pi\left(s^{t+1}\right)\frac{x\left(s^{t+1}\right)}{x\left(s^t\right)}=0. \quad (11)\end{aligned}$$

The market clearing condition

The market clearing condition of the intermediate goods and the wholesale goods are given by

$$\begin{aligned}\int_0^1 x\left(s^t,z\right)dz &= y\left(s^t\right),\\ x\left(s^t\right) &= \int_0^1 x\left(s^t,z\right)dz\end{aligned}$$

The final goods serves as the household's consumption, investment to productive capital, and the government expenditure. The market clearing condition of the final goods is given by

$$c\left(s^t\right)+k\left(s^t\right)-(1-\delta)k\left(s^{t-1}\right)+G\left(s^t\right)=x\left(s^t\right)-\frac{\kappa}{2}\left(\pi\left(s^t\right)-1\right)^2x\left(s^t\right)$$

2.5 Government and Central Bank

The government collects a lump-sum tax $P(s^t)\tau(s^t)$ from the household and issues a government bond $B(s^t)$ to finance the repayment $R_B(s^{t-1})B(s^{t-1})$ to the banks and government expenditure $P(s^t)G(s^t)$. We assume that a balanced budget is maintained in each period t as follows:

$$R_B\left(s^{t-1}\right)B\left(s^{t-1}\right)+P\left(s^t\right)G\left(s^t\right)=P\left(s^t\right)\tau\left(s^t\right)+B\left(s^t\right). \tag{12}$$

The government tax policy is an increasing function of the outstanding government bond that is specified by the following equation:

$$\tau\left(s^t\right)=b\left(s^{t-1}\right)\left(\frac{b\left(s^{t-1}\right)}{x\left(s^t\right)}\right)^{\psi}T, \tag{13}$$

where $\psi\in[0,\infty]$ is an elasticity of lump-sum tax with respect to the government debt status, indicating that an increase in bond leads to an increase in tax, and T is a constant parameter.

The central bank sets the nominal interest rate according to a simple Taylor rule given by

$$\ln R_B\left(s^t\right)=(1-\rho_M)\ln R+\rho_M\ln R_B\left(s^{t-1}\right)+(1-\rho_M)\phi\ln\pi\left(s^t\right)+\epsilon_r\left(s^t\right), \tag{14}$$

where R is constant, $\rho_M\in[0,1]$ is the autoregressive coefficient of the polity rate, and $\phi>1$ is the policy weight attached to the inflation rate and $\epsilon_r(s^t)$ is an i.i.d. shock to the monetary policy rule[10].

2.6 Shock Process

The exogenous shocks in our economy, the shock to the bank's net worth $\gamma(s^t)$, the maximum loss of the capital asset $\underline{r}_k(s^t)$, the maximum loss of the government bond $\underline{r}_b(s^t)$, the technology growth $Z(s^t)$, and government expenditure $G(s^t)$, evolve according to

[10] Our parameterization of the policy parameters that is attached to government bond $\psi+1$ and ϕ are both greater than unity implies that our economy is in the Ricardian regime for both fiscal and monetary policy. Relatedly, in the current paper, we do not consider the case of the government's default. In Non-Ricardian regime with government defaults, inflation rate is only uniquely pinned down when the central bank responds to inflation aggressively. See, for example, Kocherlakota (2012).

the equations below:

$$\begin{aligned}
\ln \gamma\left(s^t\right) &= (1-\rho_\gamma)\ln \gamma + \rho_\gamma \ln \gamma\left(s^{t-1}\right) + \epsilon_\gamma\left(s^t\right), \\
\ln \underline{r}_k\left(s^t\right) &= (1-\rho_{\underline{r}_k})\ln \underline{r}_k + \rho_{\underline{r}_k} \ln \underline{r}_k\left(s^{t-1}\right) + \epsilon_{\underline{r}_k}\left(s^t\right), \qquad (15)\\
\ln \underline{r}_b\left(s^t\right) &= (1-\rho_{\underline{r}_b})\ln \underline{r}_b + \rho_{\underline{r}_b} \ln \underline{r}_b\left(s^{t-1}\right) + \epsilon_{\underline{r}_b}\left(s^t\right), \qquad (16)\\
\ln Z\left(s^t\right) &= \ln Z\left(s^{t-1}\right) + u_Z\left(s^t\right), \qquad (17)\\
u_Z\left(s^t\right) &= (1-\rho_Z)u_Z\left(s^{t-1}\right) + \epsilon_Z\left(s^t\right), \qquad (18)\\
\ln G\left(s^t\right) &= (1-\rho_G)\ln G + \rho_G \ln G\left(s^{t-1}\right) + \epsilon_G\left(s^t\right), \qquad (19)
\end{aligned}$$

where ρ_γ, $\rho_{\underline{r}_k}$, $\rho_{\underline{r}_b}$, ρ_Z, and $\rho_G \in (0,1)$ are the autoregressive root of the corresponding shocks, and $\epsilon_\gamma\left(s^t\right)$, $\epsilon_{\underline{r}_k}\left(s^t\right)$, $\epsilon_{\underline{r}_b}\left(s^t\right)$, $\epsilon_Z\left(s^t\right)$ and $\epsilon_G\left(s^t\right)$ are the exogenous i.i.d. shocks that are normally distributed with mean zero.

2.7 Equilibrium Condition

An equilibrium consists of a set of prices, $\{W\left(s^t\right), P\left(s^t\right), P_y\left(s^t\right), r_k\left(s^t\right), r\left(s^t\right), r_d\left(s^t\right), r_b\left(s^t\right), R_B\left(s^t\right)\}_{t=0}^{\infty}$, and the allocations $\{c\left(s^t\right), l\left(s^t\right), d\left(s^t\right), \Pi\left(s^t\right), k\left(s^t\right), x\left(s^t\right), y\left(s^t\right)\}_{t=0}^{\infty}$, for a given government policy $\{G\left(s^t\right),\ \tau\left(s^t\right)\}_{t=0}^{\infty}$, realization of exogenous variables $\{\epsilon_\gamma\left(s^t\right), \epsilon_{\underline{r}_k}\left(s^t\right), \epsilon_{\underline{r}_b}\left(s^t\right), \epsilon_Z\left(s^t\right), \epsilon_G\left(s^t\right), \epsilon_r\left(s^t\right)\}_{t=0}^{\infty}$, the expected worst returns $\{\underline{r}_k\left(s^t\right), \underline{r}_b\left(s^t\right)\}_{t=0}^{\infty}$, and initial conditions $\{B_{-1}\}$, $\{d_{-1}\}$, $\{k_{-1}\}$ such that for all t, i, and z :

(i) the household maximizes her utility given the prices;
(ii) the bank i maximizes its profits given the prices and the expected worst returns;
(iii) the intermediate goods producer maximizes its profits given the prices;
(iv) the wholesale goods producer z maximizes its profits given the prices;
(v) the final goods producer maximizes its profits given the prices;
(vi) the government budget constraint holds;
(vii) the central bank sets a policy rate following the Taylor rule; and
($viii$) markets clear.

2.8 VaR and Bank Portfolio at Steady state

Before investigating the model's dynamics, we analytically explore some determinants of the banks' balance sheet and asset portfolio allocation at the steady state with zero inflation rate. In particular, we focus on how the expected returns from holding the two risky assets, which we denote by r_b and r_k, are affected by the banks' VaR constraint, and how the banks' portfolio decision between the government bond b and the loan claim k is made[11]. For illustrative purpose, we assume in this subsection that the households

[11] The definition of the steady state in our economy needs to be carefully stated. Suppose that we define the steady state as the economy where all of the exogenous shocks are absent and every endogenous variables grow at the constant rate. The banks' asset allocation then becomes indeterminate because

supply labor inelastically, $l = 1$, and that government expenditure is zero $G = 0$. In this case, since r_k equals to the return to the capital stock in the economy, we have

$$r_k = \alpha Z k^{\alpha-1} + (1-\delta). \tag{20}$$

Assuming that $G = 0$ from equations (12) and (13) we obtain

$$r_b b = T\left(\frac{b}{x}\right)^{\psi} + b, \tag{21}$$

Evaluating the portfolio choice equation (8) , the VaR constraint equation (6) , and the law of motion of the bank's net worth (4) at the steady state values,

$$\frac{r_k - r_d}{r_d - \underline{r}_k} = \frac{r_b - r_d}{r_d - \underline{r}_b}, \tag{22}$$

$$\left(\underline{r}_k - r_d\right)k + \left(\underline{r}_b - r_d\right)b = -r_d n, \tag{23}$$

$$n = \frac{\gamma}{1-\gamma r_d}\left[\left(r_k - r_d\right)k + \left(r_b - r_d\right)b\right]. \tag{24}$$

Notice that the household's Euler equation at the steady state implies that

$$r_d = \frac{1}{\beta}.$$

From equations (20) to (24), the excess return from holding the two risky assets and the spread of the two risky assets;

$$r_b - r_d = \frac{1-\gamma r_d}{\gamma}\omega_b, \tag{25}$$

$$r_k - r_d = \frac{1-\gamma r_d}{\gamma}\omega_k. \tag{26}$$

$$r_k - r_b = \frac{1-\gamma r_d}{\gamma}\left(\omega_k - \omega_d\right). \tag{27}$$

where $\omega_k \equiv \frac{(r_d - \underline{r}_k)}{r_d}$ and $\omega_b \equiv \frac{(r_d - \underline{r}_b)}{r_d}$ which are the risk weights on capital and government bond respectively. Capital and bonds are then given by

$$k = \left[\frac{r_k - (1-\delta)}{\alpha Z}\right]^{\frac{1}{\alpha-1}}. \tag{28}$$

the their portfolio choice is dependent on the riskiness of the assets. In the current paper, we define the steady state following the Devereux and Sutherland (2010, 2011) where the banks take the possibility that worst scenario of the asset return realize into the consideration. Consequently, the risks of holding the assets affect the banks' portfolio at the steady state.

and

$$b = \left[\frac{r_b - 1}{T}\right]^{\frac{1}{\psi}} x = \left[\frac{r_b - 1}{T}\right]^{\frac{1}{\psi}} Z k^{\alpha}. \tag{29}$$

According the equation (25), (26), and (27) , the excess return from holding the two risky assets and the spread between the two assets are affected by the risk weights (ω_k and ω_b) and the banks' survival probability γ.

When the maximum loss of holding the loan claim $\underline{r}_k$ rises, which implies a rise in risk weight of capital ω_k, the banks' VaR constraint becomes tighter, reducing the banks' risk taking capacity. If the banks maintain the same amount of the loan claim holding, those facing higher ω_k require a higher expected return to the loan claim than otherwise. A similar mechanism works when $\underline{r}_b$ falls. The asset portfolio allocation between the two assets is influenced by the relative size of ω_k and ω_b. As the risk weight of loans becomes larger, the banks tilt their portfolio toward the government bond even when the expected return to the government bond is substantially lower than that to the loan claims.

A reduction in the survival probability γ lead to a rise in the two excess returns. As indicated by the equation (24) , a smaller survival probability prevents banks from accumulating their net worth. Because the scarcity of their net worth tightens the VaR constraint by increasing the risk of default, banks shrink their balance sheet. Since they reduce their demand for both of the two assets, their excess returns need to rise to clear the asset markets. As is shown by equation (27) , the net worth shortage dampens the banks' loan holdings more than their government bond holdings. This is because holding loans is more costly in order to satisfy the VaR constraint. Consequently, banks with deteriorated net worth reduce their loan claim by a disproportionately large amount.

Next, we discuss how the banks choose the size of loan claim k and the government bond b given prices. Since $\alpha - 1 < 0$ equation (28) implies that a higher return to the loan claim implies a smaller size of a loan claim and thus a smaller aggregate investment in the economy. Combining this with the discussions above, a decline in $\underline{r}_k$ or a decline in γ reduces the loan claim to firms.

Equation (29) implies that, for $\psi > 1$, banks tilt toward holding of the government bond, as the corresponding return increases. In this case, similarly to the case of k, a decline in $\underline{r}_b$ or γ lead to an increase in the bank's government bond holding b, through a rise in the government bond yield. The government tax policy parameters, ψ and T, affect the government bond supply and therefore affect the size of banks' bond holding at the equilibrium. With a smaller value for ψ or T, the government finances its expenditure more by tax than issuance of government bond, resulting in a larger government bond stock in the economy.

Lastly, we discuss how the bank allocates its asset between the government bond holding and the loan claim to the firms. From the equations (28) and (29) , the government bond holding relative to the loan claim is given by

$$\frac{b}{k} = \left[\frac{r_b - 1}{T}\right]^{\frac{1}{\psi}} \left[\frac{r_k - (1-\delta)}{\alpha}\right].$$

According to the above equation, any changes in the economic environments that enhance the return to the two risky assets r_b and r_k, including the $\underline{r}_k$, $\underline{r}_b$, and γ cause the bank to purchase more of the government bond, compared with the loan claim to firms.

2.9 Quantitative Analysis

In this section we investigate some quantitative implications of our model economy. Using the calibrated model, we compute dynamic responses of macroeconomic variables and banks' asset portfolio to changes in economic shocks bank's net worth $\epsilon_\gamma(s^t)$ and the maximum loss of loan claim $\epsilon_{\underline{r}_k}(s^t)$. In order to investigate the role of the VaR constraint, we compare the results with those of our model without the VaR constraint.

Parameter calibration

We calibrate the model economy to Japanese data. As for the banking sector, we calibrate the steady state values of $\underline{r}_k(s^t)$ and $\underline{r}_b(s^t)$ and $\gamma(s^t)$ so that the implied expected return to the two assets $\mathrm{E}_t[r_k(s^{t+1})]$ and $\mathrm{E}_t[r_b(s^{t+1})]$ at the steady state are equal to the historical average of the ex-post realized returns from the 1980s to the 2000s. Regarding the government sector, we calibrate T in equation (13) so that implied government bond over GDP is unity at the steady state. Other parameters are set so as to be consistent with existing studies. The parameter values used in the simulation are shown in Table 1.

Impulse responses

Here we report some impulse responses. Figure 5 shows the responses of the model economy to a permanent downward shift in the technology. In Figure 5, "bond over capital" stands for $b(s^t)/k(s^t)$ and captures the banks' portfolio allocation and "asset of bank" stands for $b(s^t)+k(s^t)$ and captures the banks' asset size. "Spread of capital," "Spread for bond," and "Expected return spread" stand for $\mathrm{E}_t[q_k(s^{t+1})]$, $\mathrm{E}_t[q_b(s^{t+1})]$, and $\mathrm{E}_t[r_k(s^{t+1}) - r_b(s^{t+1})]$, respectively and capture the asset return structure of the economy. Finally, "Risk-free Rate" stands for the deposit rate. In order to highlight the effects of the VaR constraint we report the responses of the model without VaR. The responses with the VaR is labeled as "benchmark" and is shown by black line with black circles. Those without the VaR constraint is labeled as "No VaR" and is shown by red line with white circles. Compared with the no VaR economy, the technology shock under the benchmark economy generates quantitatively larger recessionary effects in some of the macroeconomic variables due to the endogenous development of the banks' net worth and subsequent changes in banks' portfolio choice. As the technology slow down reduces the banks' profit from the investments and hampers their net worth accumulation, the banks shrink their balance sheets and tilt their asset portfolio toward the government purchase. Consequently, less capital is accumulated in the economy, increasing recessionary pressure to the economy.

Figure 6 shows the responses to a positive shock to the government expenditure. In both models the government expenditure crowds out capital but output increases due to the negative wealth effect of the government expenditure on labor supply, as in standard RBC models. A positive government expenditure shock increases the deposit rate (labeled "Risk-free rate " in the Figure) due to intertemporal substitution of consumption demand by the household. This higher deposit rate decreases bank net worth because the banks' repayment to the household sector increases. Then, with the VaR constraint, the net worth deterioration enhances the banks' demand toward the government bond through the same mechanism discussed so far. Therefore the decline in capital is large on impact.[12]

Figure 7 displays the responses to a negative shock to bank net worth. Note that in the economy where the VaR constraint is absent, the banks' net worth cannot be a source of the economic fluctuations, as the banks' investment decisions are unaffected by the net worth. With the VaR constraint, the net worth deterioration makes banks' asset portfolio tilted towards the government bond purchase, widens the expected return spread between the two assets, and brings about recession and deflation to the economy. The disruption influences the banks' investment decisions through two channels. The first channel is associated with the size of the banks' balance sheets. As pointed out by Adrian and Shin (2011), banks with deteriorated net worth shrink the size of their investments, leading to a fall in both the loan claim and the government bond purchase. Consequently, the output dampens. If otherwise, the banks are more likely to violate the VaR constraint in case that the maximum loss realizes. The second channel is associated with the asset allocation. The banks tilt their asset allocation toward relatively safer asset, which is the government bond, so as not to violate the VaR constraint, increasing the government bond purchase relative to the loan claims. As the banks substitute away from the loan claims and reduce capital supply to firms, the second channel amplifies the recessionary effects stemming from the first channel. At the impact period, the second effect dominates the first effect and the government bond purchase increases in response to the shock. As the strength of banks' demand toward the government bond is maintained, the expected return spread widens throughout the simulation period.

Figure 8 displays the responses to a permanent increase in the maximum loss in holding the loan claim to firms, which is a permanent decline in $\mathrm{E}_t \underline{r}_k \left(s^{t+1}\right)$. Our preferred interpretation of the permanent decline in the parameter is a permanent tightening of the capital requirement, such as introduction of Basel II or III. Since the loan claim

[12] Output and inflation respond by more in a model with the VaR constraint. This is because a further decline in capital (due to the VaR constraint) generates a larger negative wealth effect which increases labour supply by more. As a result output increases by more. Inflation increases by more because the decrease in capital increases real marginal cost.

becomes riskier than before, the banks tilt their asset portfolio toward the government bond purchase. Consequently, the supply of the productive capital to the economy falls, leading to output decline and deflation. Reflecting the banks' strong demand toward the government bond purchase, the expected return spread between the assets widens. It is also notable that the permanent tightening affects the return structure permanently, altering the long-run ratio of government bond to capital as well as the level of output.

3 Empirical Analysis

In this section, we ask if the model's implications are consistent with the data. First, we conduct a cross-sectional analysis focusing on the relationship between the banks' net worth and their asset portfolio choice across banks. Second, we conduct a time-series analysis and explore dynamic relationship between the aggregate bank variables and some macroeconomic variables.

Cross-sectional analysis

Our analysis is based on the annual security report of individual bank covering the period from 1990 to 2012. Using the data contains 174 banks in total including all of city banks and regional banks located in Japan, we explore how developments of net worth of each individual bank affect its asset allocation. Our model predicts that, when the VaR constraint binds, a disruption of the net worth increases the government bond purchase relative to loan claims. The purpose of this subsection is to investigate if such a relationship is empirically confirmed.

Figure 9 displays the share of the government bonds in the banks' portfolio, the banks' net worth, and the contemporaneous correlation coefficient between the share of the government bond and the level of the banks' net worth across Japanese banks.[13] We depict the time path of each variable for internationally active banks and domestic banks separately since the VaR constraint binds differently across the two types of bank groups.[14] While both the share of the government bond and the banks' net worth increase over the sample period, the growth rates of the two variables accelerate in 2000 and beyond particularly for internationally active banks. A possible reason behind such observation is expected introduction of Basel II and III. During this period, several lager banks responded to the tightening of the capital requirement by issuing equity and accumulating their net worth, as discussed in BOJ (2010). Consequently, net worth accumulates and portfolio is tilted toward government bond holding at the same time, yielding the positive correlation between the two variables. By contrast, during the 1990s, banks respond to the deterioration of the banks' balance sheet brought about by

[13] The share of the government bond in banks' portfolio corresponds to $b\left(i,s^t\right)/\left(k\left(i,s^t\right)+b\left(i,s^t\right)\right)$ in our model.

[14] Here we classify 12 banks that are international active banks in 2009 into international banks and classify the rest into domestic banks.

the bubble burst and/or the banking crisis by increasing the government bond purchase, yielding the negative correlation between the two variables.

To see the statistical relationship between the banks' net worth and portfolio, we run the following cross-sectional regression. We pool the relative size of the government bond holding and net worth for each bank during the sample period and regress the former variable on the latter variable using the following equation:

$$\left(\frac{b\left(i,s^{t}\right)}{k\left(i,s^{t}\right)+b\left(i,s^{t}\right)}-\frac{b\left(i,s^{t-1}\right)}{k\left(i,s^{t-1}\right)+b\left(i,s^{t-1}\right)}\right)=\mu_{t}+\alpha\times\log\left(\frac{n\left(i,s^{t-1}\right)}{n\left(i,s^{t-2}\right)}\right)+\epsilon\left(i,s^{t}\right),$$

where $\epsilon\left(i,s^{t}\right)$ is an error term that is specific to bank i at time t. We employ yearly differenced series so as to control for the fixed effect stemming from bank's idiosyncratic characteristics and take one year lag for bank's net worth so as to avoid simultaneity bias.

We conduct the estimation exercise using three different settings for μ_t to isolate the government bond accumulation stemming from the banks' endogenous portfolio choice and that stemming from the government's bond supply policy. In the first setting, μ_t is constant and the coefficient α explains variations across the banks' portfolio in different years as well as across different banks. In the second setting, μ_t is growth rate of aggregate government bond outstanding and the coefficient α captures the partial effect of the banks' net worth conditional on the government's bond supply policy. In the third setting, μ_t is time dummy and the coefficient α captures the cross-sectional banks' portfolio difference within the same year.

Table 3 reports our results in the three different settings. As shown in the upper table, the estimated coefficient α-s under the first setting are all negative at the statistically significant level of 5%, indicating that a negative growth of a bank's net worth a year before leads to an increase in the portfolio share of the government bonds. The results are similar under the second and the third setting for domestic banks, indicating the net worth is negatively related to the variations in banks' portfolio even when influence from macroeconomic environments including government's bond supply policy is isolated. For international banks, such relationship is nonsignificant under the third setting, suggesting that offsetting effect from the tightening of the capital requirement may be larger than the domestic banks.

Time-series analysis

Next we investigate how aggregate banks' net worth and asset portfolio interact with other macroeconomic variables. To this end, we formulate a vector autoregression (VAR) that is similar to the one developed in Altig et al. (2011). Our VAR involves 10 variables: first difference of the logarithm of the ratio of the aggregate government bond stock to the aggregate capital stock, first difference of the logarithm of the labor productivity, first difference of the logarithm of the GDP deflator, first difference of the logarithm of the aggregate bank real net worth, the logarithm of the per capita working hours, ex-ante return spread between the prime loan rate and ten-year government bond rate, which is a proxy of the ex-ante return spread of the two assets in the model, the logarithm of the consumption ratio over GDP, the logarithm of the investment ratio over GDP, treasury bill rate, and the logarithm of the velocity of money circulation. To construct the government bond-capital ratio, we divide the quarterly series of the beginning-of-period net debt of the general government provided in Doi et al. (2011) by the quarterly series of the beginning-of-period capital stock which we construct from the interpolation of annual capital stock series of National Accounts based on the quarterly real investment series. We construct the real bank net worth series from the net wort of domestically licensed banks reported in Flow of Funds Account. Since this series is reported in book value in 1997Q3 and the precedent periods, we backwardly extend the series using the stock price of financial sector in Tokyo Stock Exchange. We make use of GDP deflator to convert nominal variables to real variables. All of the series except the treasury bill rate series are seasonally adjusted. Our VAR includes 5 lags for each variable and is estimated over the period from 1990Q1 to 2010Q1.

Figure 10 and 11 plot the impulse response of the macroeconomic variables to a negative innovation to the aggregate banks' net worth and to a positive innovation to the ratio of the aggregate government bond stock to capital stock, respectively[15]. In identifying the former shocks, we assume that the shock affects all of the macroeconomic variables in the VAR contemporaneously except the government bond-capital ratio and labor productivity and affects the two variables with a lag. In identifying the latter shock, we assume that the shock permanently affects the ratio itself and labor productivity, applying the long-run restrictions similar to the way used to extract investment specific shock in Altig et al. (2011). Estimated response of the macroeconomic variables to the two shocks are in large consistent with the prediction of our model with VaR constraint. In response to the negative net worth shock, the ratio of government bond to capital increases and the spread between the two assets widens significantly, indicating that the exogenous disruption in banks' net worth increases the banks' demand for the government bond, hampering aggregate capital investment relative to the government bonds purchase. As the model suggests, such a decline in investment lowers production level, causing output decline and deflation. In response to the positive shock to the ratio of government bond to capital stock, because banks refrain from capital accumulation, macroeconomic variables, such as investment and output, develop negatively at significant level.

[15] The size of the innovation is one standard deviation.

4 Conclusion

The Japanese banks' asset allocation has significantly shifted from the lending to the private firms to the government bond holding, particularly from the middle of the 1990s. Consequently, a sizable amount of government bond is now held by the banks. In order to draw some macroeconomic implications of the banks' government bond holding, we developed a New Keynesian model that incorporates the banks' endogenous decision about their asset allocation subject to the VaR constraint. The VaR constraint affects bank asset portfolio by limiting their risk taking capacity. We have shown that bank regulation can explain why Japanese banks tilted their asset portfolio towards the government bonds. We also show that this shift in asset portfolio can depress output. Out theoretical predictions are in line with data. Using the cross sectional Japanese bank data, we have found that banks with smaller net worth invest more heavily on the government bonds. In addition, the VAR analysis shows that a decrease in aggregate bank net worth increases aggregate government bond to capital ratio, which is consistent with the prediction of the model.

In our model, bank regulation such as enforcement of the Basel capital requirement works in a similar way to an increase in riskiness of bank assets. There is growing literature that focuses on the role of risks on business cycle fluctuations. See, for example, Fernandez-Villaverde et al. (2011). Our model can be applied to analyze this issue but we leave it for future research.

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Table 1: Baseline parameters

Parameter	Value	Description
β	.99	Quarterly subjective discount rate
α	.35	Capital share in production function
η	2	Utility weight on leisure
ε	21	Elasticity of substitution across goods
δ	.025	Quarterly depreciation rate of capital stock
κ	20	Cost associated with price adjustment
γ	.95	Surviving probability of banks
r_k	.65	The worst quarterly return to loan claim at the steady state
r_b	.9	The worst quarterly return to loan claim at the steady state
g_y	.18	Government expenditure over GDP at the steady state
ψ	.5	Parameter of government policy rule
T	.195	Parameter of government policy rule
ϕ	1.2	Policy weight attached to inflation in monetary policy rule
ρ_M	.9	Autoregressive parameter in monetary policy rule

Table 2: Major Episodes related to Basel Accord and Banking Crisis in Japan

Date	Description of Episode	
Jan. 1991	Bubble burst in Japan	$\gamma \Downarrow$
Mar. 1993	Full-dress Basel I requirements became effective in Japan.	$\underline{r_k} \Downarrow$
Nov. 1997	Sanyo Securities declared bankruptcy (banking crisis).	$\gamma \Downarrow$
Oct. 1998	The Financial Revitalization Act was enacted.	$\underline{r_k} \Downarrow$
Mar. 2007	Basel II capital requirements became effective in Japan.	$\underline{r_k} \Downarrow$
Feb. 2008	Start of recession in Japan following the global financial crisis.	
Mar. 2013	Basel III capital requirements became effective in Japan.	$\underline{r_k} \Downarrow$

Table 3: Results of Cross-sectional Analysis of Japanese Banks

Estimation Setting with Constant (Pooled Regression)

Explanatory Variables	Estimated Coefficient	P-value
All Banks	-0.006342	0.0004
International Active Banks	-0.015816	0.0278
Domestic Banks	-0.005652	0.0021

Estimation Setting conditional on Government's Bond Supply Policy

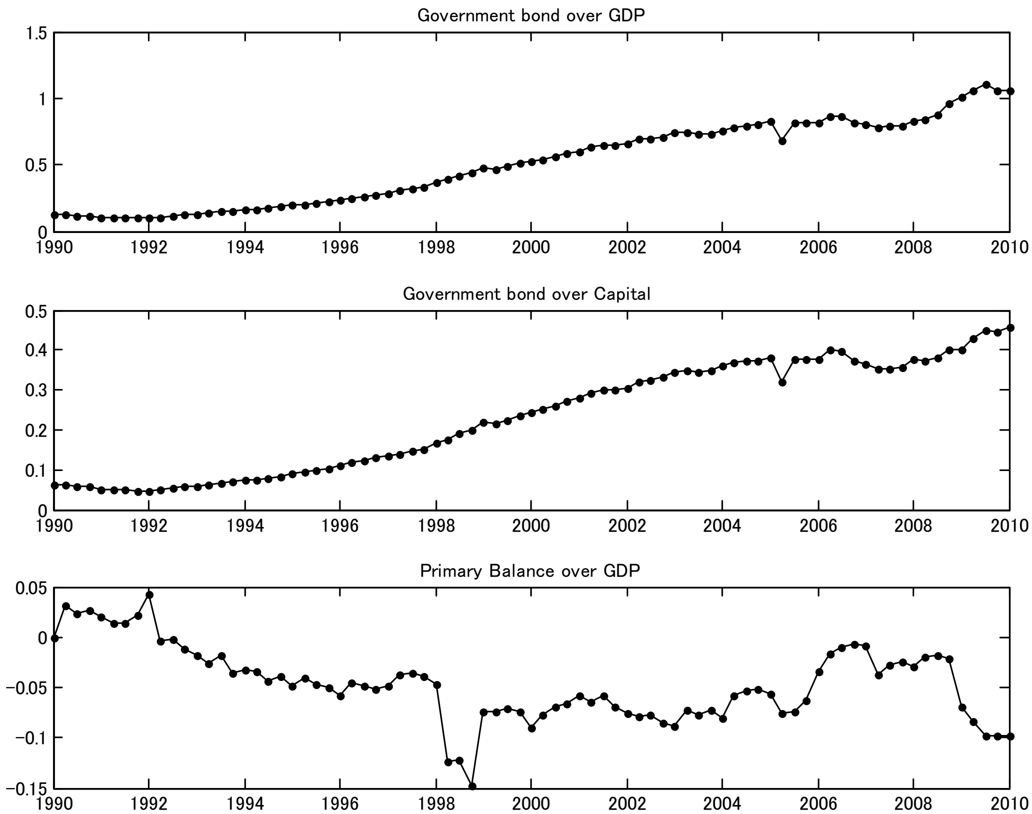
Explanatory Variables	Estimated Coefficient	P-value
All Banks	-0.004676	0.0099
International Active Banks	-0.012354	0.0906
Domestic Banks	-0.004698	0.0115

Estimation Setting with Time Dummies

Explanatory Variables	Estimated Coefficient	P-value
All Banks	-0.005711	0.0024
International Active Banks	0.005887	0.62
Domestic Banks	-0.005365	0.0055

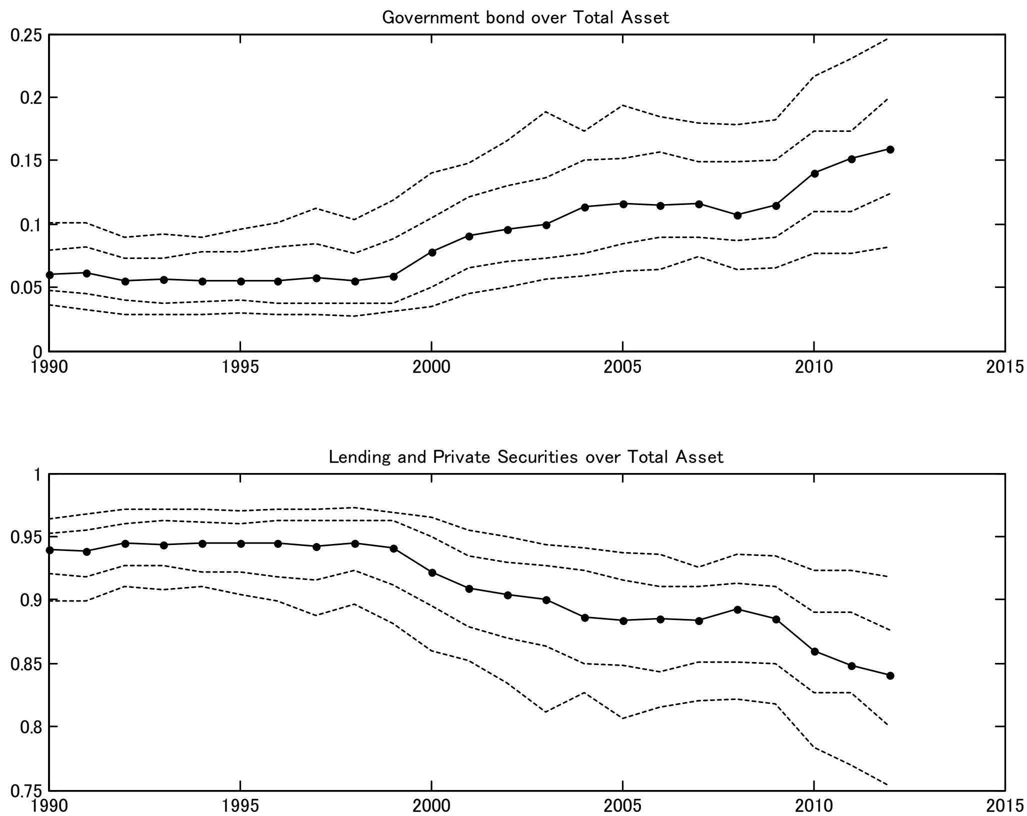
Note: The three tables display the estimation results of the different estimation settings for μ_t.

Figure 1: Size of Government Bond relative to Macroeconomic Variables



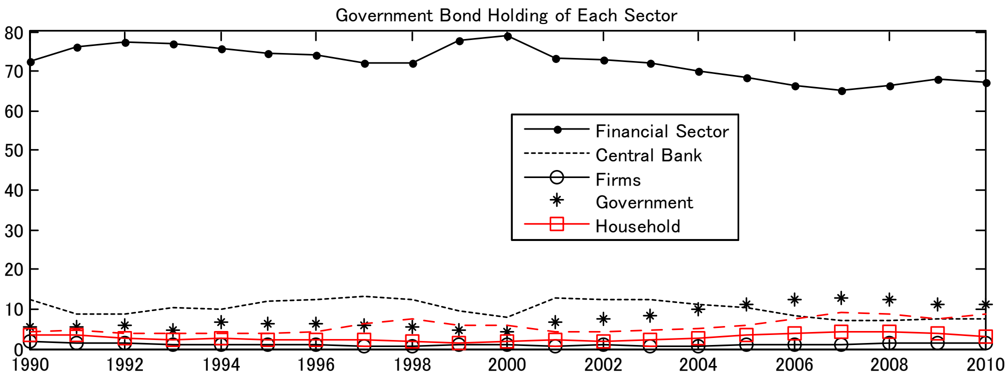
Note: The data are borrowed from Doi et al. (2011).

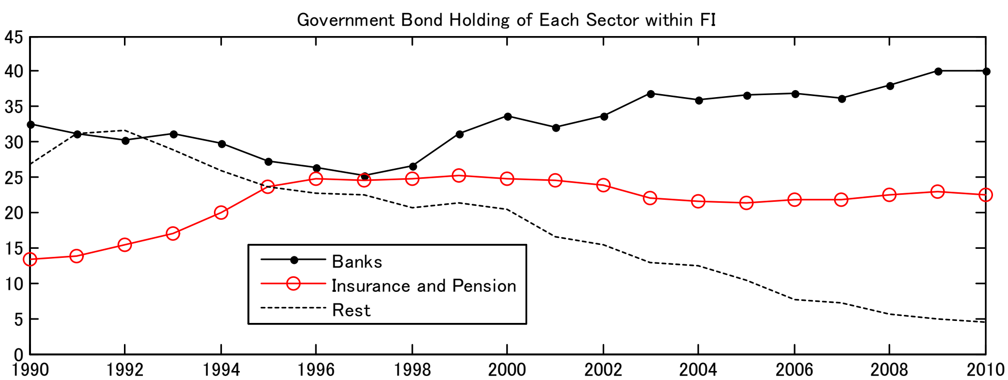
Figure 2: Banks' Asset Allocation



Note: Upper panel displays the government bond holding relative to the total amount of asset and the lower panel displays the asset other than government bond holding relative to the total amount of asset for Japanese banks. The series are constructed from the annual security report of all of the city banks and regional banks in Japan that exist in each year. The solid with black circle denotes the median and dotted lines are 90th, 75th, 25th, and 10th of the cross-bank figures.

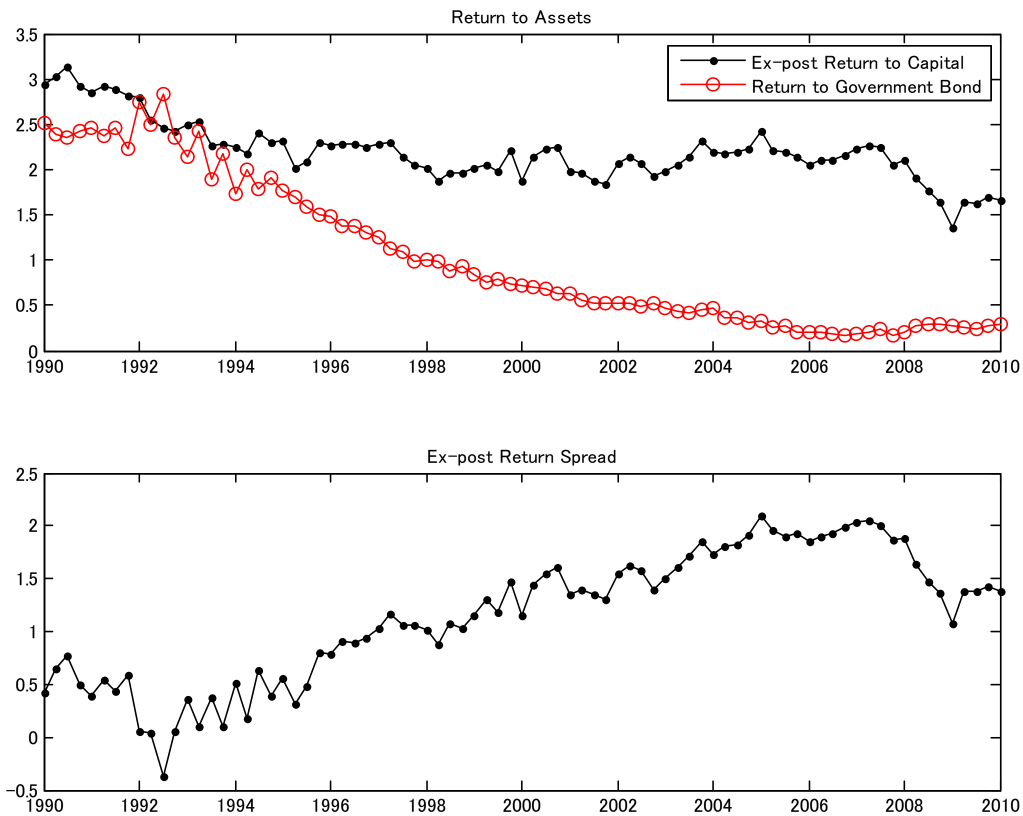
Figure 3: Government Bond Holding by Sector





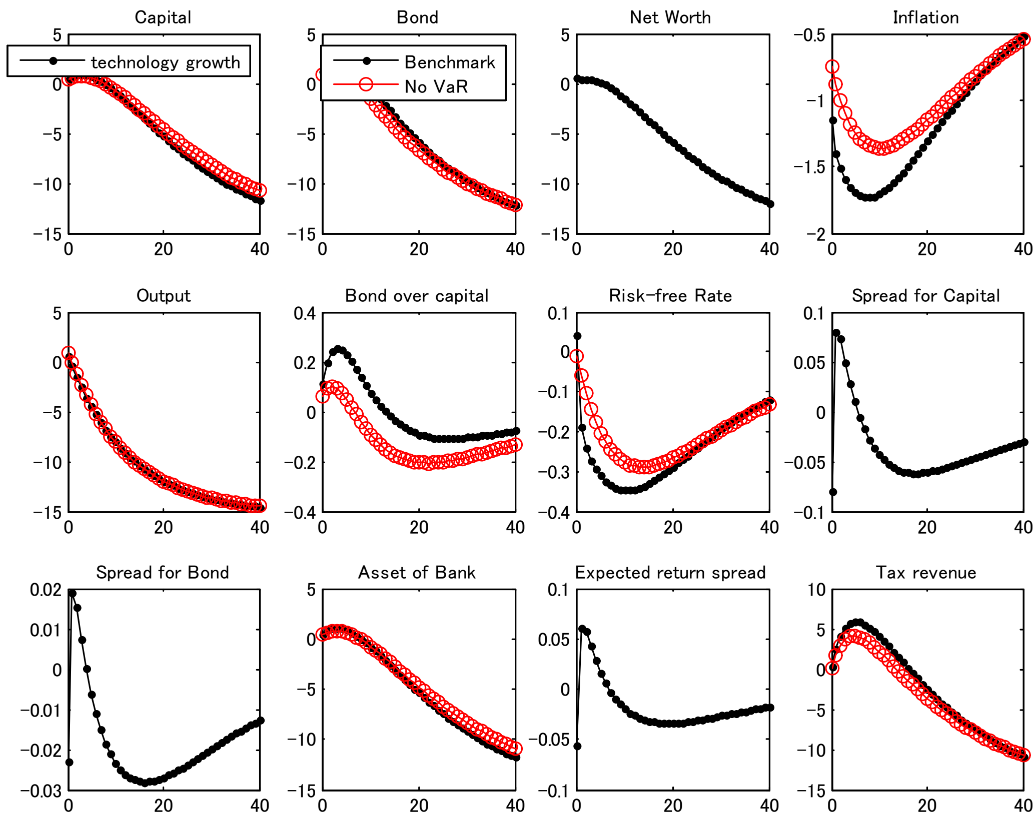
Note: All series are taken from Japan's Flow of Funds Accounts released from the Bank of Japan. In this figure, the banks include all of depository corporations that consists of banks, postal savings, and collectively managed trusts. The rest in the lower panel corresponds to other financial institutions that includes securities investment trusts, nonbanks, public financial institutions, and financial dealers and brokers, as well as financial auxiliaries.

Figure 4: Ex-post Return to Capital Investment and Government Bond Purchase



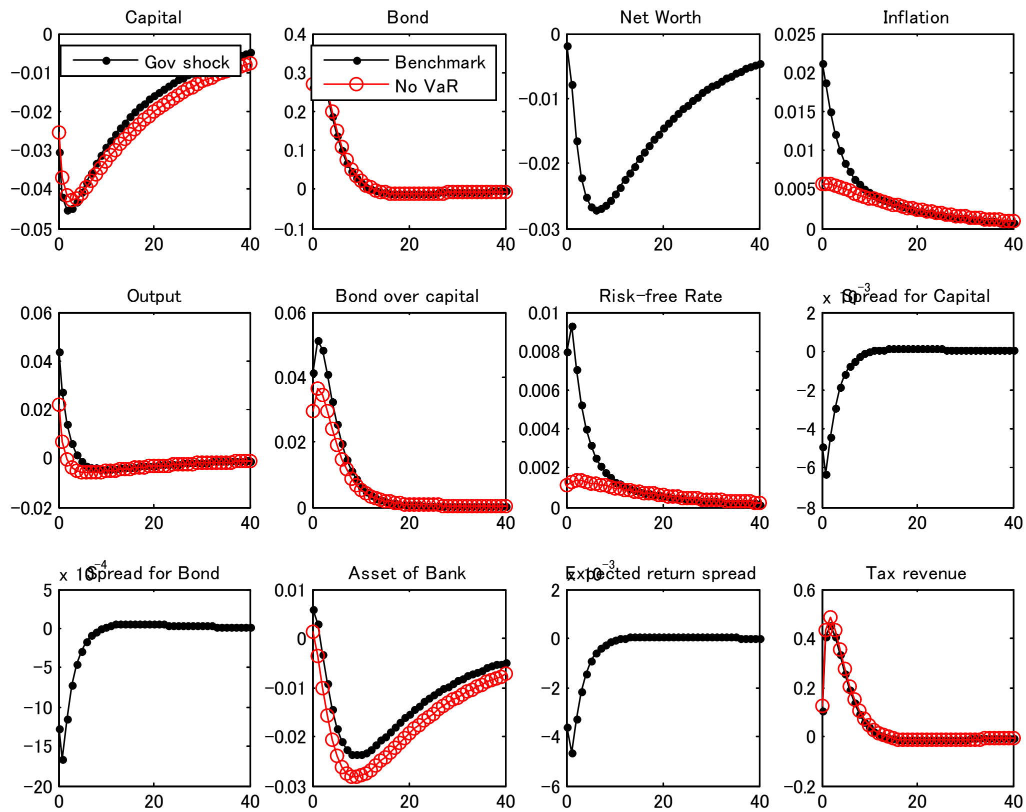
Note: Ex-post return to capital investment is computed from the capital income, which is constructed following the methodology proposed by Hayashi and Prescott (2002), divided by the capital stock. Both capital income and capital stock series are based on the National Accounts of Japan. Ex-post return to government bond purchase is computed from the net interest payment divided by the government bond outstanding. The corresponding data are borrowed from Doi et al. (2011).

Figure 5: Economic Response to a Permanent Negative Shock to Technology



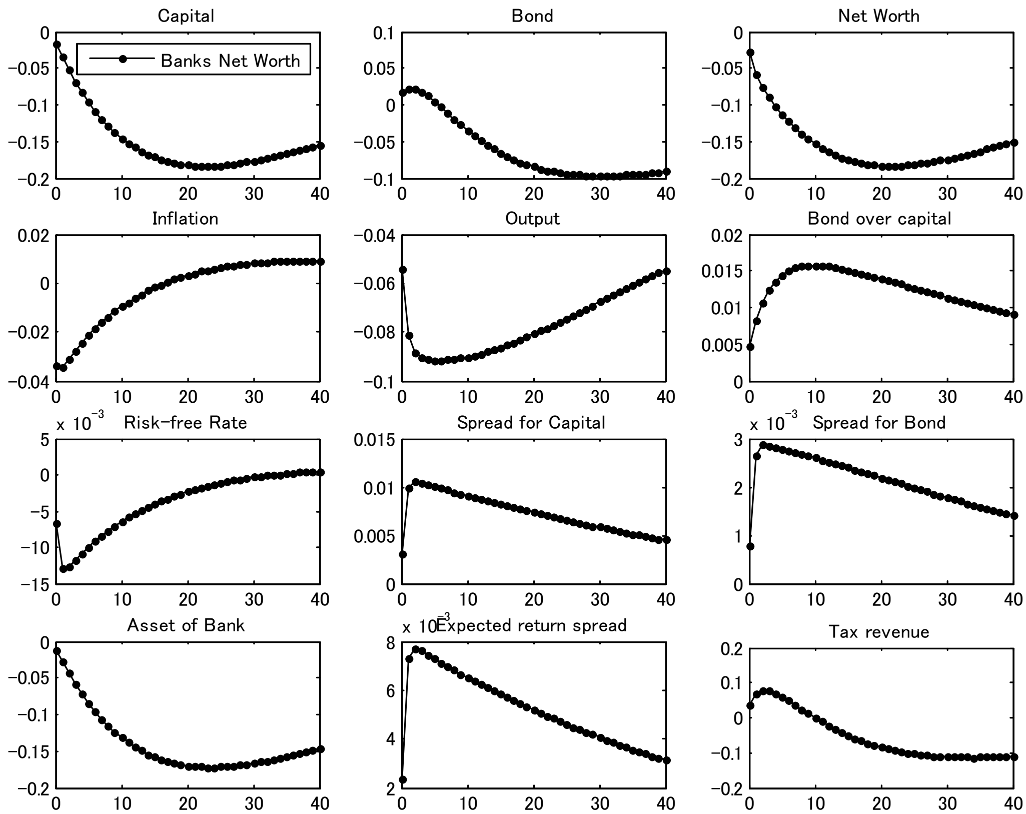
Note: The permanent negative shock to technology is defined as an unexpected decline in technology growth u_Z.

Figure 6: Economic Response to a Positive Shock to Government Expenditure



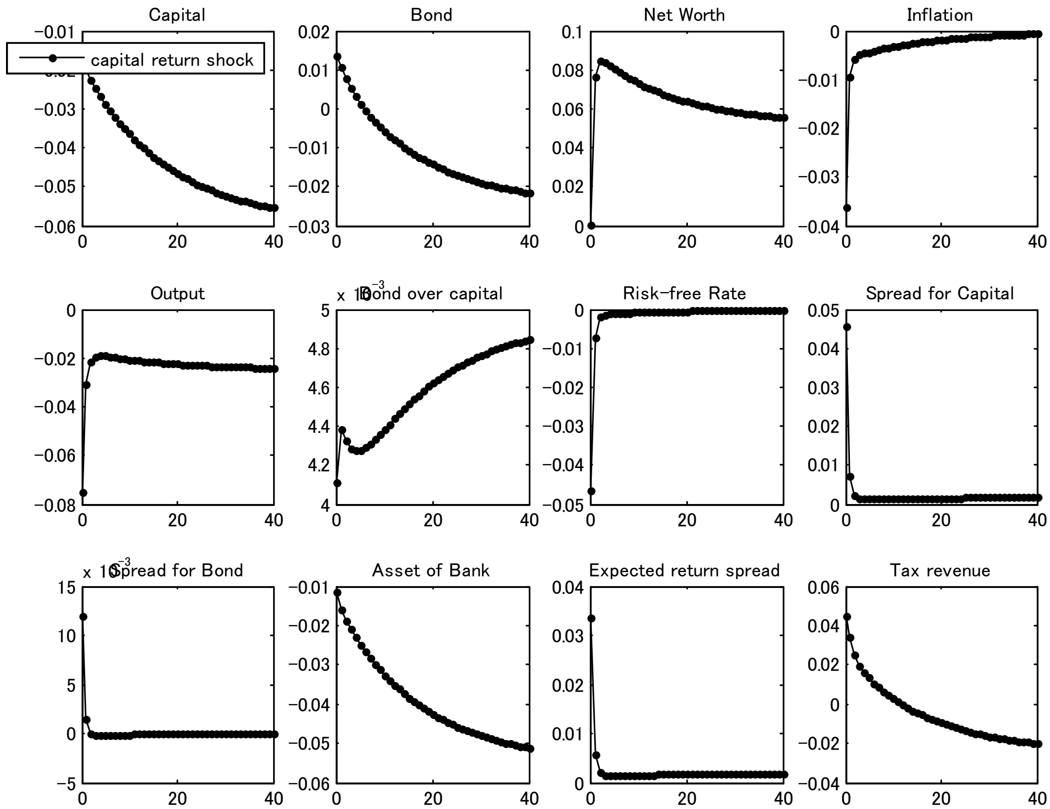
Note: The positive shock to government expenditure is defined as an unexpected increase in government expenditure G.

Figure 7: Economic Response to a Negative Shock to Banks' Net Worth



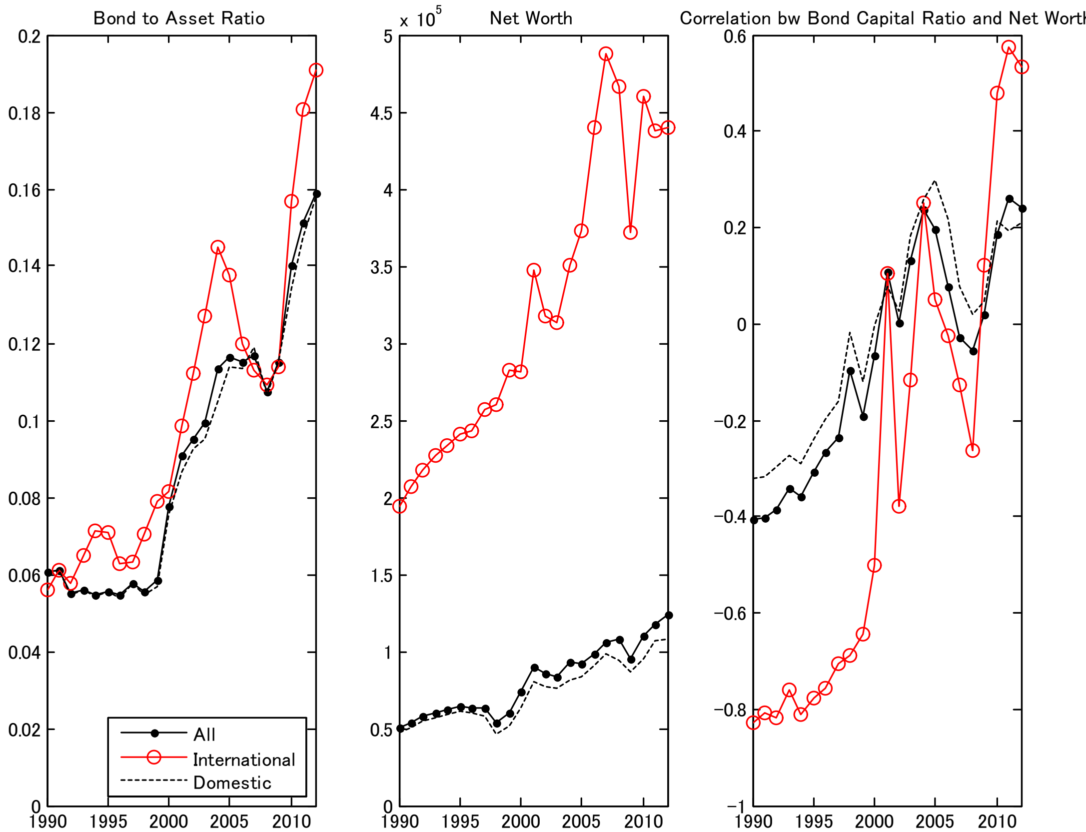
Note: The negative shock to banks' net worth is defined as an unexpected disruption in bank's surviving probability γ.

Figure 8: Economic Response to a Negative Shock to VaR Constraint



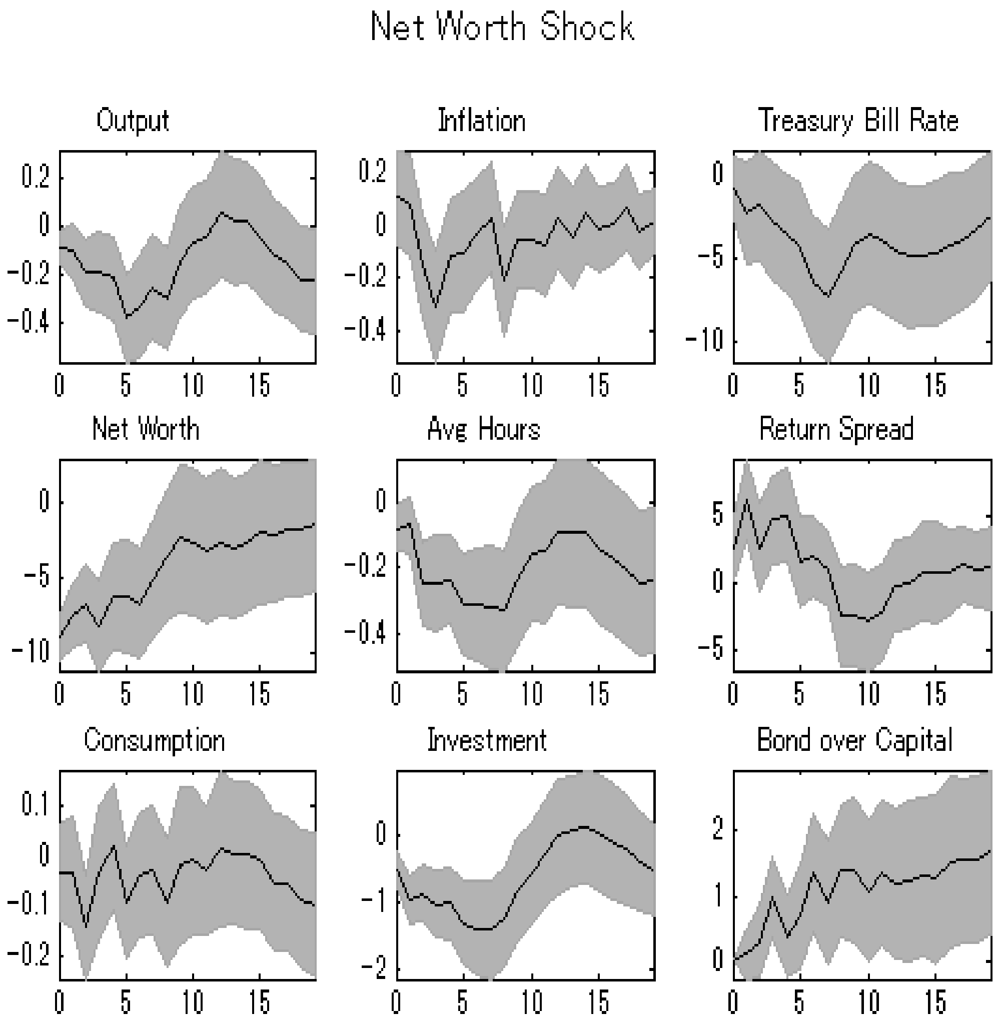
Note: The negative shock to VaR constraint is defined as an unexpected decrease in the maximum loss of capital investment $\underline{r}_k$.

Figure 9: Correlation between Government Bond Ratio and Net Worth



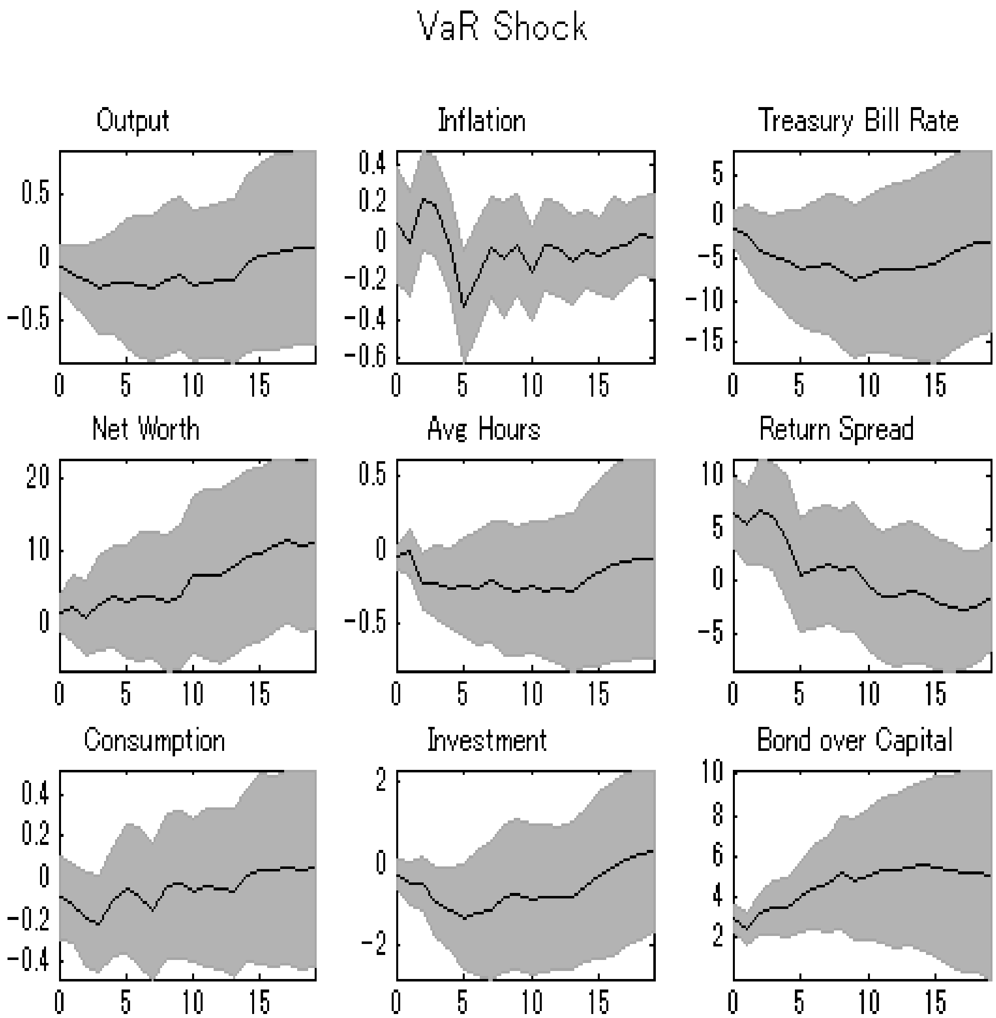
Note: The time path of government bond to asset ratio and net worth depicted in the left and middle panel respectively are the median of the banks that belong to each of the three groups. The series of correlation depicted in the right panel is the contemporanous correlation coefficient of the government bond to asset ratio and net worth level acoss banks for each year.

Figure 10: Macroeconomic Response to a Negative Shock to Banks' Net Worth



Note: Economic response to negative innovation in the banks' net worth. Each colored band has a width of two standard deviation. The X-axis records number of quarters elapsed after the shock.

Figure 11: Macroeconomic Response to a Negative Shock to Bond-Capital Ratio



Note: Economic response to a positive innovation in the ratio of government bond stock to the capital stock. Each colored band has a width of two standard deviation. The X-axis records number of quarters elapsed after the shock.