Bank of Japan Working Paper Series

Financial Markets, Monetary Policy and Reference Rates: Assessments in DSGE Framework

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No.12-E-12
December 2012

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December 28, 2012

Abstract

In this paper, we explore the roles played by reference rates in business cycle fluctuations using a medium-scale full-fledged dynamic stochastic general equilibrium (DSGE) model. Our model is an extended model of chained-credit-contract model developed by Hirakata, Sudo, and Ueda (2011b) estimated by the Japanese data. In our economy, there are interbank as well as lending markets. Credit spreads determined in the markets are affected by the borrowers' creditworthiness and degree of informational friction in the credit markets. Focusing on the role of reference rates that affects economic decisions through the delivery of information about the nature of economy, we evaluate channels through which the reference rates affects credit spreads and macroeconomic activities. We find that (i) reference rates may mitigate informational friction in the credit markets, leading to a higher investment, output, and inflation, (ii) reference rates may contribute to economic stabilization by providing accurate economic forecast, and (iii) reference rates may bring about unintended consequence of monetary policy implementation by adding a noise to the credit spreads. Our results indicate the importance of reliable reference rates, particularly under the environment where uncertainty prevails, from the perspective of resource allocation, stabilization, and policy implementation.

Keywords: Reference Rates; Credit Spreads; Informational Friction, Signal Extraction, Monetary Policy

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1 Introduction

Since the financial crisis starting in 2007, a growing attention has been paid to the role played by the reference rates in financial transactions among both policy makers and scholars. Although there is a strong agreement about the usefulness of the reference rate in guiding pricing of financial products, some recent studies emphasize a negative side of a coin. For instance, Abrantez-Mtez et. al (2012), investigating empirically if manipulations have been in place particularly during the financial crisis, suggest that Libor rates may have suffered, though not materially, from manipulation problem.[1]

In this paper, we ask roles of reference rates in business cycle fluctuations.[2] To this end, we make use of a medium-scale full-fledged dynamic stochastic general equilibrium (DSGE) model developed by Muto, Sudo, and Yoneyama (2012, hereafter MSY)[3] and discuss how reference rate affects economic behavior of agents, credit spreads in financial transaction, and macroeconomic performance. Our model is built upon a chained-credit-contract model developed by Hirakata, Sudo, and Ueda (2009, 2011a, b, hereafter HSU) and is estimated using Japanese data from the 1980s to 2000s. In our economy, there are credit constrained financial intermediaries (hereafter FIs) as well as credit constrained goods producing firms and those borrowing sectors raise external funds from the interbank market and lending market, respectively. Similarly to Bernanke, Gertler, and Gilchrist (1999), there is informational friction between lenders and borrowers. That is, while borrowers' output are diverse, lenders cannot observe realization of each borrower's output unless monitoring is conducted. When lenders recognize that either borrowers' riskiness or expense associated with monitoring goes up, then lenders charge higher spread on their lending rates. While credit spreads are primarily affected by the borrowers' creditworthiness measured by size of net worth, degree of informational friction in credit markets also plays the important role in determining the spreads.

We study three distinct channels through which reference rate affects macroeconomy. The first channel stresses influence of reference rate on informational friction in the credit markets. We consider a case where a reliable reference rate reduces cost of monitoring activities associated with financial intermediation and a case where it reduces borrowers' diversity regarding perceived idiosyncratic productivity from lenders' perspective. When monitoring cost is less costly, expected default cost falls and credit spread tightens, facilitating financial intermediation and boosting the economy. Similarly, when lenders perceive that idiosyncratic productivity converges across borrowers, because expected portion of defaulting borrowers falls, credit spreads shrink, giving way to economic expansion.

The second channel stresses influence of reference rates on agents' forecast and its implication for macroeconomic stability. We consider a case where agents today receive news about future economic events. While agents decide the current economic activities taking the information contained in the news into their consideration, the news is contaminated with noises and agents' expectation of the future events conditional on the news may depart from what will actually materialize. The discrepancy between the today's forecast and realization of the future events yields an additional source of business cycle fluctuations. When reference rates deliver accurate information about the future economic events, the discrepancy shrinks, achieving economic stability.

[1] By contrast, Kuo, Skeie, and Vickery (2012) discuss that Libor rates generally comove with other measures of borrowing rates although they find that Libor quotes sometimes lie below these measures and less disperse compared to them. See also Snider and Youle (2010) for related discussion.

[2] In contrast to our study that focuses on the role of reference rates in the macroeonomic activity, Muto (2012) studies the role in the interbank interest rates.

[3] See also Kawata et al. (2012) for the evaluation of role of reference rates in the macroeconomic fluctuations using a financial macro-econometric model.

The third channel stresses influence of reference rates through a monetary policy implementation. We consider a case where a monetary authority cannot observe a noise in the credit spreads separately from the fundamental variations. While the noise itself is a non-fundamental innovation, when a policy rate systematically responds to credit spreads that contains the noise, the noise causes an unintended consequence from the central bank's perspective. From the private agents' perspective, the response of the policy rate acts as a shock to the monetary policy rule, adversely affecting macroeconomic stability.

This paper is organized into six sections. Section 2 briefly describes our model. The model consists of two categories of financial markets, interbank market and lending markets, and three types of market participants, investors, FIs, and entrepreneurs. Credit spreads in the model are determined by two factors: creditworthiness of borrowers and degree of informational friction between borrowers and lenders. Here, reference rate affects both two factors. In section 3, 4, and 5, we propose three channels through which reference rate affects credit spreads and macroeconomic activities by providing agents information regarding the nature of the economy. Section 3 discusses the role of reference rate in reducing degree of informational friction in credit markets. When the friction is mitigated, credit spreads shrink and aggregate investment becomes less costly. Section 4 discusses the role of reference rate in helping agents' expectation formation about future economic events and stabilizing business cycle fluctuations. Section 5 explores the case when reference rate contains non-fundamental noises and affects monetary policy implementation. Section 6 draws a conclusion.

2 The economy

This section describes our model structure. The model is borrowed from MSY (2012) and the model outline is shown in Figure 1. The economy consists of five sectors: the household sector, the financial intermediary (FI) sector, the non-durables sector, the durables sector, and the government sector. The household sector consists of two agents, the representative household and the investors. The representative household supplies labor inputs to the goods-producing sectors, earns wage, makes a deposit to the investors, and receives repayment in return. The investors collect deposits from the household and lend them to the FI sector by making credit contracts called IF contracts with the FIs. The FIs raise the external funds from the investor through the IF contracts and lend them to the goods-producing sectors by making credit contracts with each of the sectors. We call each of the contracts, the FEC and the FED contract, respectively. Each goods-producing sector consists of three agents, the entrepreneurs, the capital goods producers, and the goods producers. The entrepreneurs raise external funds from the FIs, purchase capital goods from the capital goods producers using the funds, and provide the capital goods to the goods producers. They then earn the rental price of the capital goods in return, accumulating the earnings as the net worth. The capital goods producers purchase investment goods from the durables sector and produce the capital goods. The goods producers produce goods from labor input, capital goods, and intermediate goods. Government sector consists of the government and the central bank. The government collects tax from the household sector and spends the tax revenue for the government purchase. The central bank adjusts the nominal interest rate so as to stabilize the inflation rate.

2.1 Credit Contracts

2.1.1 FEC and FED Contracts

Basic Setting

The FEC and FED contract are made between a FI and a continuum of the entrepreneurs in the two goods-producing sectors. In period t, each type i FI offers a loan contract to an infinite number of group j_{i_ξ} entrepreneurs in sector ξ. An entrepreneur in group j_{i_ξ} owns net worth $N_{\xi,j_{i_\xi}}(s^t)$ and purchases capital of $Q_\xi(s^t)K_{j_{i_\xi}}(s^t)$, where s^t is the whole history of states until period t, $Q_\xi(s^t)$ is the price paid per unit of capital and $K_{j_{i_\xi}}(s^t)$ is the quantity of capital purchased by the group j_{i_ξ} entrepreneur in sector ξ. Since the net worth $N_{\xi,j_{i_\xi}}(s^t)$ of the entrepreneur is smaller than the amount of the capital purchase $Q_\xi(s^t)K_{j_{i_\xi}}(s^t)$, the entrepreneur raises the rest of the funds $Q_\xi(s^t)K_{j_{i_\xi}}(s^t) - N_{\xi,j_{i_\xi}}(s^t)$ from the type i FI.

The net return to a capital of a group j_{i_ξ} entrepreneur is a product of the two elements: an aggregate return to capital $R_\xi(s^{t+1})$ in sector ξ and an idiosyncratic productivity shock $\omega_{\xi,j_{i_\xi}}(s^{t+1})$, that is specific to the group j_{i_ξ} entrepreneur.[4] There is informational asymmetry between lenders and borrowers and the FI cannot observe the realization of the idiosyncratic shock $\omega_{\xi,j_{i_\xi}}(s^{t+1})$ without paying the monitoring cost μ_ξ. Under this informational friction, the FEC and FED contracts specify:

- amount of debt that the group j_{i_ξ} entrepreneur borrows from a type i FI, $Q_\xi(s^t)K_{j_{i_\xi}}(s^t) - N_{\xi,j_{i_\xi}}(s^t)$, and
- cut-off value of idiosyncratic productivity shock $\omega_{\xi,j_{i_\xi}}(s^{t+1})$, which we denote by $\overline{\omega}_{\xi,j_{i_\xi}}(s^{t+1})$, such that the group j_{i_ξ} entrepreneur repays its debt if $\omega_{\xi,j_{i_\xi}}(s^{t+1}) \geq \overline{\omega}_{\xi,j_{i_\xi}}(s^{t+1})$ and declares the default if otherwise.

Entrepreneurs' participation constraint

A group j_{i_ξ} entrepreneur joins the FEC or FED contract only when the return from the credit contract is at least equal to the opportunity cost. Based on the FEC or FED contract, a portion of the entrepreneurs $\int_{\overline{\omega}_{\xi,j_{i_\xi}}(s^{t+1})}^{\infty} dF_\xi(\omega_\xi)$ does not default and the rest of them default. If they do not default, *ex post,* they receive the net return to its capital holdings:

$$\left(\omega_{\xi,j_{i_\xi}}\left(s^{t+1}\right) - \overline{\omega}_{\xi,j_{i_\xi}}\left(s^{t+1}\right)\right) R_\xi\left(s^{t+1}\right) Q_\xi\left(s^t\right) K_{j_{i_\xi}}\left(s^t\right).$$

The entrepreneurial loan rate in sector ξ is therefore given by

$$r_{\xi,j_{i_\xi}}\left(s^{t+1}\right) \equiv \frac{\overline{\omega}_{\xi,j_{i_\xi}}\left(s^{t+1}\right) R_\xi\left(s^{t+1}\right) Q_\xi\left(s^t\right) K_{j_{i_\xi}}\left(s^t\right)}{Q_\xi\left(s^t\right) K_{j_{i_\xi}}\left(s^t\right) - N_{\xi,j_{i_\xi}}\left(s^t\right)}. \tag{1}$$

[4] Here, $\omega_{\xi,j_{i_\xi}}(s^t)$ is a unit mean, lognormal random variable distributed independently over time and across entrepreneurs in sector ξ. We express its density function by $f_\xi\left(\omega_{\xi,j_{i_\xi}}\right)$, and its cumulative distribution function by $F_\xi\left(\omega_{\xi,j_{i_\xi}}\right)$.

Instead of participating in the FEC or FED contract, a group j_{i_ξ} entrepreneur can purchase capital goods using only its own net worth $N_{\xi,j_{i_\xi}}(s^t)$. In this case, *ex ante,* the entrepreneur expects to receive the earning $R_\xi(s^{t+1})N_{\xi,j_{i_\xi}}(s^t)$, and *ex post* it receives the earning $\omega_{\xi,j_{i_\xi}}(s^{t+1})R_\xi(s^{t+1})N_{\xi,j_{i_\xi}}(s^t)$. Therefore, the FEC and FED contract between a type i FI and group j_{i_ξ} entrepreneur is agreed by the group j_{i_ξ} entrepreneur only when the following inequality is expected to hold:

$$R_\xi\left(s^{t+1}\right)Q_\xi\left(s^t\right)K_{j_{i_\xi}}\left(s^t\right)\left(\int_{\overline{\omega}_{\xi,j_{i_\xi}}(s^{t+1}|s^t)}^{\infty}\left(\omega_\xi-\overline{\omega}_{\xi,j_{i_\xi}}\left(s^{t+1}|s^t\right)\right)dF_\xi\left(\omega_\xi\right)\right)\geq R_\xi\left(s^{t+1}\right)N_{\xi,j_{i_\xi}}\left(s^t\right)\text{ for }\forall j_{i_\xi}. \tag{2}$$

FIs' profit from the credit contracts with the goods-producing sectors

Based on equation (2), the expected earnings of the type i bank from the FEC and FED contracts are given by

$$\sum_{\xi=c,x}\int_{j_{i_\xi}}\Phi_{\xi_i}\left(s^{t+1}|s^t\right)R_\xi\left(s^{t+1}|s^t\right)Q_\xi\left(s^t\right)K_{j_{i_\xi}}\left(s^t\right)dj_{i_\xi},$$

where

$$\Phi_{\xi_i}\left(s^{t+1}|s^t\right)\equiv\int_{\overline{\omega}_{\xi,j_{i_\xi}}(s^{t+1}|s^t)}^{\infty}\overline{\omega}_{\xi,j_{i_\xi}}\left(s^{t+1}|s^t\right)dF_\xi\left(\omega_\xi\right)-\mu_\xi\int_0^{\overline{\omega}_{\xi,j_{i_\xi}}}\omega_\xi dF_\xi\left(\omega_\xi\right),\text{ for }\xi=c,x. \tag{3}$$

Note that term associated with μ_ξ accounts for the *ex post* monitoring cost that a type i FI pays when a group j_{i_ξ} entrepreneur in the ξ sector declares the default.

The type i FI makes a contract with a infinite number of group j_{i_ξ} entrepreneurs in sector ξ, and as shown in HSU (2009), the cut-off value $\overline{\omega}_{\xi,j_{i_\xi}}$ that is chosen by the type i FI is identical across all entrepreneurs in sector ξ that make contract with the type i FI. Consequently, the FI's expected total return from both the FEC and FED contracts is given by

$$\sum_{\xi=c,x}\Phi_{\xi_i}\left(s^{t+1}|s^t\right)R_\xi\left(s^{t+1}|s^t\right)Q_\xi\left(s^t\right)K_{i_\xi}\left(s^t\right),$$

where

$$K_{i_\xi}\left(s^t\right)\equiv\int_{j_{i_\xi}}K_{j_{i_\xi}}\left(s^t\right)dj_{i_\xi},\text{ for }\xi=c,x.$$

For the convenience of analysis below, we define the total amount of net worth held by the group j_{i_ξ} entrepreneur in sector ξ.

$$N_{\xi,i}\left(s^t\right)\equiv\int_{j_{i_\xi}}N_{\xi,j_{i_\xi}}\left(s^t\right)dj_{i_\xi},\text{ for }\xi=c,x.$$

2.1.2 IF Contracts

Basic setting

The IF contract is made between an investor and a continuum of the FIs. In period t, each type i FI holds the net worth $N_{F,i}(s^t)$ and makes loans to group j_{i_ξ} entrepreneurs in the sector ξ at an amount of $Q_\xi(s^t) K_{\xi,i}(s^t) - N_{\xi,i}(s^t)$. Since the FI's net worth is smaller than its loans to the entrepreneurs in the two sectors, it borrows the rest $\sum_{\xi=c,x}[Q_\xi(s^t) K_{\xi,i}(s^t) - N_{\xi,i}(s^t)] - N_{F,i}(s^t)$ from the investor. Similarly to the FEC and FED contracts, there is informational asymmetry between the lender and the borrowers. Each type i FI faces an idiosyncratic productivity shock $\omega_{F,i}(s^{t+1})$. This shock $\omega_{F,i}(s^{t+1})$ represents technological differences across the FIs, for example, those associated with risk management, maturity mismatch control, and loan securitization[5]. Incorporating this idiosyncratic shock, the FI's receipt from the loans to the entrepreneurs is given by[6]

$$\omega_{F,i}(s^{t+1}) \left[\sum_{\xi=c,x} \Phi_{\xi_i}(s^{t+1}|s^t) R_\xi(s^{t+1}|s^t) Q_\xi(s^t) K_{i_\xi}(s^t) \right].$$

The investor can observe the realization of the shock only by paying the monitoring cost μ_F. Under this credit friction, the IF contract specifies:

- amount of debt that a type i FI borrows from the investor, $\sum_{\xi=c,x}[Q_\xi(s^t) K_{\xi,i}(s^t) - N_{\xi,i}(s^t)] - N_{F,i}(s^t)$, and
- cut-off value of idiosyncratic shock $\omega_{F,i}(s^{t+1})$, which we denote by $\overline{\omega}_{F,i}(s^{t+1}|s^t)$, such that the FI repays debt if $\omega_{F,i}(s^{t+1}) \geq \overline{\omega}_{F,i}(s^{t+1}|s^t)$ and declares the default if otherwise.

FIs' profit from the credit contracts

According to the IF contract, a portion of the FIs $\int_{\overline{\omega}_{F,i}(s^{t+1}|s^t)}^{\infty} dF_F(\omega_F)$ do not default while the rest of them default. The net profit of a non-default FI i equals its receipt from the FEC and the FED contract multiplied by the idiosyncratic shock $\omega_{F,i}(s^{t+1})$ minus repayment to the investor:

$$\left(\omega_{F,i}(s^{t+1}) - \overline{\omega}_{F,i}(s^{t+1}|s^t)\right) \left(\sum_{\xi=c,x} \Phi_{\xi_i}(s^{t+1}|s^t) R_\xi(s^{t+1}|s^t) Q_\xi(s^t) K_{i_\xi}(s^t) \right).$$

The FIs' loan rate is therefore given by

$$r_F(s^{t+1}|s^t) \equiv \frac{\overline{\omega}_{F,i}(s^{t+1}|s^t) \left(\sum_{\xi=c,x} \Phi_{\xi_i}(s^{t+1}|s^t) R_\xi(s^{t+1}|s^t) Q_\xi(s^t) K_{i_\xi}(s^t) \right)}{\sum_{\xi=c,x}[Q_\xi(s^t) K_{\xi,i}(s^t) - N_{\xi,i}(s^t)] - N_{F,i}(s^t)}.$$

Investors' participation constraint

There is a participation constraint for the investor in the IF contract. Given the risk-free rate of return in the economy $R(s^t)$, the investor's profit from the investment in the loans to the banks must at least equal to the opportunity cost of lending. That is

$$\Phi_{F,i}(s^{t+1}|s^t) \left[\sum_{\xi=c,x} \Phi_{\xi_i}(s^{t+1}|s^t) R_\xi(s^{t+1}|s^t) Q_\xi(s^t) K_{i_\xi}(s^t) \right]$$

[5] See HSU (2010) for the alternative interpretations for $\omega_{F,i}(s^t)$.

[6] Similarly to the entrepreneurial riskiness ω_{ξ,j_i}, the FIs' riskiness $\omega_{F,i}$ is a unit mean, lognormal random variable distributed independently over time and across FIs i. Its density function and its cumulative distribution function are given by $f_F(\omega_{F,i})$ and $F_F(\omega_{F,i})$, respectively.

$$\geq R\left(s^t\right)\left[\sum_{\xi=c,x}\left[Q_\xi\left(s^t\right)K_{\xi,i}\left(s^t\right)-N_{\xi,i}\left(s^t\right)\right]-N_{F,i}\left(s^t\right)\right] \text{ for } \forall i, s^{t+1}|s^t, \tag{4}$$

where

$$\Phi_{F,i}\left(s^{t+1}|s^t\right)\equiv\int_{\overline{\omega}_{F,i}\left(s^{t+1}|s^t\right)}^{\infty}\overline{\omega}_{F,i}\left(s^{t+1}|s^t\right)dF_F\left(\omega_F\right)-\mu_F\int_0^{\overline{\omega}_{F,i}\left(s^{t+1}|s^t\right)}\omega_F dF_F\left(\omega_F\right). \tag{5}$$

2.1.3 Optimal Credit Contract

Given the structure of the FEC, FED, and IF contract, a type i FI optimally chooses capital goods purchased from capital goods producing sectors, the cut-off value in the three classes of contracts, respectively. As shown in HSU (2009), since all FIs are identical in terms of Φ_{ξ_i},the expected profit of a type i FI is given by

$$\left[\int_{\overline{\omega}_F\left(s^{t+1}|s^t\right)}^{\infty}\left(\omega_F-\overline{\omega}_F\left(s^{t+1}|s^t\right)\right)dF_F\left(\omega_F\right)\right]\left[\sum_{\xi=c,x}\Phi_\xi\left(s^{t+1}|s^t\right)R_\xi\left(s^{t+1}|s^t\right)Q_\xi\left(s^t\right)K_{i_\xi}\left(s^t\right)\right]. \tag{6}$$

The FI then maximizes the term (6), subject to the investor's participation constraint (4) and entrepreneurial participation constraints (2).

2.1.4 Dynamic Behavior of Net Worth

The net worth of the FIs and the entrepreneurs in the two goods-producing sectors depend on their earnings from the credit contracts and their labor income. Both FIs and entrepreneurs inelastically supply a unit of labor to goods producers in the goods-producing sectors and receive labor income $W_{F_c}\left(s^t\right)$, $W_{E_c}\left(s^t\right)$, $W_{F_x}\left(s^t\right)$, and $W_{E_x}\left(s^t\right)$.[7] The aggregate net worths of the FIs and the entrepreneurs are given by

$$N_F\left(s^{t+1}\right)=\gamma_F V_F\left(s^t\right)+\varepsilon_{N_F}\left(s^t\right)+\sum_{\xi=c,x}\frac{W_{F_\xi}\left(s^t\right)}{P_{CPI}\left(s^t\right)}, \tag{7}$$

$$N_\xi\left(s^{t+1}\right)=\gamma_\xi V_\xi\left(s^t\right)+\frac{W_{E_\xi}\left(s^t\right)}{P_{CPI}\left(s^t\right)}+\varepsilon_{N_\xi} \text{ for } \xi=c,x, \tag{8}$$

with

$$\begin{aligned}
V_F\left(s^t\right) &\equiv \left(\int_{\overline{\omega}_F\left(s^{t+1}|s^t\right)}^{\infty}\left(\omega_F-\overline{\omega}_F\left(s^{t+1}|s^t\right)\right)dF_F\left(\omega_F\right)\right)\left[\sum_{\xi=c,x}\Phi_\xi\left(s^{t+1}|s^t\right)R_\xi\left(s^{t+1}\right)Q_\xi\left(s^t\right)K_\xi\left(s^t\right)\right],\\
V_\xi\left(s^t\right) &\equiv \left(\int_{\overline{\omega}_\xi\left(s^{t+1}|s^t\right)}^{\infty}\left(\omega_\xi-\overline{\omega}_\xi\left(s^{t+1}|s^t\right)\right)dF_\xi\left(\omega_\xi\right)\right)R_\xi\left(s^{t+1}\right)Q_\xi\left(s^t\right)K_\xi\left(s^t\right), \text{ for } \xi=c,x.
\end{aligned}$$

[7] See Bernanke, Gertler, and Gilchrist (1999), Christiano, Motto, Rostagno (2008) and HSU (2011a, b) for the technical background on introducing inelasitc labor supply from the FIs and the entrepreneurs.

Here, γ_ξ for $\xi = F$, c, and x are probabilities that each FIs or entrepreneurs survive to the next period. The FIs and the entrepreneurs who are in business in period t and fail to survive in period $t+1$ consume $\left(1-\gamma_\xi\right) V_\xi\left(s^t\right)$, respectively. The net worth accumulations in the three sectors are affected by exogenous shocks represented by $\varepsilon_{N_\xi}\left(s^t\right)$ that is orthogonal to the fundamental earnings from the credit contracts. We assume these shocks are i.i.d. They are financial shocks that capture an "asset bubble," "irrational exuberance," or an "innovation in the efficiency of credit contracts," hitting the FI sector or the goods-producing sectors.

2.2 Households

Set up

Household h is an infinitely-lived representative agent with preference over the non-durables consumption, $C\left(h, s^t\right)$, service from the stock of durables, $D\left(h, s^t\right)$, and work effort, $L_\xi\left(h, s^t\right)$ for $\xi = c, x$, as described in the expected utility function, (9)

$$U_0 \equiv E_0 \sum_{t=0}^{\infty} \beta^t \left[\log\left(C^{\psi_c}\left(h, s^t\right) D^{\psi_d}\left(h, s^t\right)\right) - \varphi \frac{\left(\sum_{\xi=c,x} L_\xi\left(h, s^t\right)\right)^{1+v}}{1+v}\right], \tag{9}$$

where $\beta \in (0,1)$ is the discount factor, $v > 0$ is the inverse of the Frisch labor-supply elasticity, and φ is the weighting assigned to leisure. The parameters $\psi_\xi \in (0,1)$ for $\xi = c, d$ represents relative weights on utility from consuming each goods. The budget constraint for household h is given by

$$\sum_{\xi=c,x} P_\xi\left(s^t\right) \xi\left(h, s^t\right) + S\left(i, s^t\right) \leq \left[\begin{array}{l} \sum_{\xi=c,x} W_\xi\left(h, s^t\right) L_\xi\left(h, s^t\right) \\ -\sum_{\xi=c,x} \frac{\kappa_{w_\xi}}{2}\left(\frac{W_\xi\left(h, s^t\right)}{W_\xi\left(h, s^{t-1}\right)} - 1\right)^2 W_\xi\left(s^t\right) L_\xi\left(s^t\right) \\ +R\left(s^{t-1}\right) S\left(h, s^{t-1}\right) + \Omega\left(h, s^t\right) + \tau\left(h, s^t\right) \end{array}\right], \tag{10}$$

where $P_\xi\left(s^t\right)$ denotes nominal prices of goods ξ, $S\left(h, s^{t-1}\right)$ is the saving, $R_s\left(s^t\right)$ is the nominal rate on deposit, $\Omega\left(h, s^t\right)$ is the nominal profit returned to the household, and $\tau\left(s^t\right)$ is the lump-sum nominal transfer from the government. $W_\xi\left(h, s^t\right)$ is the nominal wage and $W_\xi\left(s^t\right)$ is aggregate indices of the nominal wage in sector ξ. The second term in the right hand side of the equation stands for the nominal cost associated with adjusting nominal wage $W_\xi\left(h, s^t\right)$, and κ_{w_ξ} is parameter that governs the size of the cost.

Labor supply decision

Household h has the monopolistic power in its differentiated labor input $L_\xi\left(h, s^t\right)$ in sector ξ. The demand of the differentiated labor is given by

$$L_\xi\left(h, s^t\right) = \left(\frac{W_\xi\left(h, s^t\right)}{W_\xi\left(s^t\right)}\right)^{-\theta_{W_\xi}\left(s^t\right)} L_\xi\left(s^t\right) \text{ for } \xi = c, x, \tag{11}$$

where $L_\xi\left(s^t\right)$ is aggregate indices of labor input in sector ξ that is defined as

$$L_\xi\left(s^t\right) = \left[\int_0^1 L_{\xi,t}\left(h, s^t\right)^{\left(\theta_{W_\xi}\left(s^t\right)-1\right)/\theta_{W_\xi}\left(s^t\right)} dh\right]^{\theta_{W_\xi}\left(s^t\right)/\left(\theta_{W_\xi}\left(s^t\right)-1\right)} \text{ for } \xi = c, x,$$

where $\theta_{Wc}(s^t)$ and $\theta_{W_x}(s^t) \in (1,\infty)$ deliver time-varying elasticity of labor demand for differentiated labor input with respect to wages.

Durables accumulation

The law of motion for the stock of durables is given by

$$D(h,s^t) = (1-\delta_d) D_{t-1}(h,s^{t-1}) + \left(1 - \frac{\kappa_{dd}}{2}\left(\frac{X_t(h,s^t)}{X_{t-1}(h,s^{t-1})} - 1\right)^2\right) X_t(h,s^t), \tag{12}$$

where $\delta_d \in (0,1)$ is the depreciation rate of the durables stock, and κ_{dd} is the parameter associated with durable stock adjustment.

2.3 Goods Producers

Set up

The economy consists of two distinct sectors of production: the non-durables sector and the durables sector. We assume that both sectors contain a continuum of firms, each producing differentiated products, as indexed by $l \in [0,1]$ and $m \in [0,1]$, respectively. We use $C_g(s^t)$ to denote a gross output of composite of differentiated non-durables $\{C_g(l,s^t)\}_{l\in[0,1]}$, and $X_g(s^t)$ to denote a gross output of composite of differentiated durables $\{X_g(m,s^t)\}_{m\in[0,1]}$. The production functions of the two composites are

$$C_g(s^t) = \left[\int_0^1 C_g(l,s^t)^{(\theta_{P_c}(s^t)-1)/\theta_{P_c}(s^t)}\, dl\right]^{\theta_{P_c}(s^t)/(\theta_{P_c}(s^t)-1)},$$

$$X_g(s^t) = \left[\int_0^1 X_g(m,s^t)^{(\theta_{P_x}(s^t)-1)/\theta_{P_x}(s^t)}\, dm\right]^{\theta_{P_x}(s^t)/(\theta_{P_x}(s^t)-1)},$$

where $\theta_{Pc}(s^t)$ and $\theta_{P_x}(s^t) \in (1,\infty)$ denote the time-varying elasticity of substitution between products. The composite products are produced in an aggregation sector that faces perfect competition. The demand functions for the non-durables firm l and for the durables firm m are derived from the optimization behavior of the aggregation sector, represented by

$$C_g(l,s^t) = \left[\frac{P_c(l,s^t)}{P_c(s^t)}\right]^{-\theta_{P_c}(s^t)} C_g(s^t) \text{ and } X_g(m,s^t) = \left[\frac{P_x(m,s^t)}{P_x(s^t)}\right]^{-\theta_{P_x}(s^t)} X_g(s^t). \tag{13}$$

These prices are related to the prices of the non-durables $\{P_c(l,s^t)\}_{l\in[0,1]}$ and the durables $\{P_x(m,s^t)\}_{m\in[0,1]}$ by

$$P_c(s^t) = \left[\int_0^1 P_c(l,s^t)^{(1-\theta_{P_c}(s^t))}\, dl\right]^{1/(1-\theta_{P_c}(s^t))} \text{ and } P_x(s^t) = \left[\int_0^1 P_x(m,s^t)^{(1-\theta_{P_x}(s^t))}\, dm\right].$$

Resource constraint

The composites serve either as final goods and as intermediate production inputs. The allocation of the gross output of the non-durables is

$$\begin{aligned}
C_g\left(s^t\right) &= C\left(s^t\right) + \int_0^1 \Psi_c\left(l, s^t\right) dl + \int_0^1 \Psi_x\left(m, s^t\right) dm \\
&+ \sum_{\xi=c,x} \left(\mu_\xi \int_0^{\overline{\omega}_\xi} \omega_\xi dF_\xi\left(\omega_\xi\right)\right) R_\xi\left(s^t\right) Q_\xi\left(s^{t-1}\right) K_\xi\left(s^{t-1}\right) \\
&+ \mu_F \left(\mu_F \int_0^{\overline{\omega}_F} \omega_F dF_F\left(\omega_F\right)\right) \left\{\sum_{\xi=c,x} \Phi_\xi\left(\overline{\omega}_\xi\left(s^t\right)\right) R_\xi\left(s^t\right) Q_\xi\left(s^{t-1}\right) K_\xi\left(s^{t-1}\right)\right\} \\
&+ \sum_{\xi=c,x,F} \left(1-\gamma_\xi\right) V_\xi\left(s^t\right), \qquad (14)
\end{aligned}$$

where $\{\Psi_c(l, s^t)\}_{l\in[0,1]}$ are intermediate production inputs used by firm l in the non-durables sector, and $\{\Psi_x(m, s^t)\}_{m\in[0,1]}$ are intermediate production inputs used by firm m in the durables sector. Note also that lenders in credit contracts consume non-durables in monitoring defaulting borrowers. The similar equation holds for a composite of durables $X_g(s^t)$ and intermediate production inputs $\{\Gamma_c(l, s^t)\}_{l\in[0,1]}$, $\{\Gamma_x(m, s^t)\}_{m\in[0,1]}$:

$$X_t^g\left(s^t\right) = X\left(s^t\right) + \int_0^1 \Gamma_c\left(l, s^t\right) dl + \int_0^1 \Gamma_x\left(m, s^t\right) dm + \sum_{\xi=c,x} I_\xi\left(s^t\right) + G_x\left(s^t\right).$$

Production function

The inputs used in each sector are labor, capital and intermediate inputs. The production functions of the two goods-producing sectors are given by

$$C_g\left(l, s^t\right) = \begin{bmatrix} Z\left(s^t\right) A\left(s^t\right) \Psi_c\left(l, s^t\right)^{\gamma_{11}} \Gamma_c\left(l, s^t\right)^{\gamma_{21}} \\ \left[L_c\left(l, s^t\right)^{\alpha}\right]^{1-\gamma_{11}-\gamma_{21}} \\ \left[\left[K_c\left(l, s^t\right) U_c\left(l, s^t\right)\right]^{1-\alpha-\alpha_E-\alpha_{FI}}\right]^{1-\gamma_{11}-\gamma_{21}} - F_c \end{bmatrix}, \qquad (15)$$

$$X_g\left(m, s^t\right) = \begin{bmatrix} Z\left(s^t\right) Z_x\left(s^t\right) A\left(s^t\right) A_x\left(s^t\right) \Psi_x\left(m, s^t\right)^{\gamma_{12}} \Gamma_x\left(m, s^t\right)^{\gamma_{22}} \\ \left[L_x\left(m, s^t\right)^{\alpha}\right]^{1-\gamma_{12}-\gamma_{22}} \\ \left[\left[K_x\left(m, s^t\right) U_x\left(l, s^t\right)\right]^{1-\alpha-\alpha_E-\alpha_{FI}}\right]^{1-\gamma_{12}-\gamma_{22}} - F_x, \end{bmatrix}. \qquad (16)$$

Here, $Z(s^t)$ and $Z_x(s^t)$ are the non-stationary component of technology that is common to the goods-producing sectors and that is specific to the durables sector, respectively. Similarly, $A(s^t)$ and $A_x(s^t)$ are the stationary component of technology that is common to the goods producing sectors and that is specific to the durables sector, respectively. $U_\xi(s^t)$ and F_ξ are the capacity utilization rate of capital input and fixed cost in sector ξ. The parameters γ_{ab} for $a, b = 1, 2$ denotes the cost share of total expenditure on inputs in sector a due to the purchase of intermediate inputs from sector b.

Price setting

Firm l in the non-durables sector are monopolistic competitors in the products market where they set prices for their products $P_c(l, s^t)$ in reference to the demand given by (13). It can reset the prices solving the following problem:

$$\max_{\{C_g(l,s^t),\ P_c(l,s^t)\}} \mathrm{E}_t \sum_{q=0}^{\infty} \frac{\Lambda_{t+q}}{\Lambda_t} \frac{\Pi_c\left(l, s^{t+q}\right)}{P_c\left(s^{t+q}\right)}, \tag{17}$$

$$s.t.\ \Pi_c\left(l, s^{t+q}\right) = \begin{array}{l} P_c\left(l, s^{t+q}\right) C_g\left(l, s^{t+q}\right) - MC_c\left(l, s^{t+q}\right)\left(C_g\left(l, s^{t+q}\right) + F_c\right) \\ -\frac{\kappa_{p_c}}{2}\left(\frac{P_c\left(l, s^{t+q}\right)}{P_c\left(l, s^{t+q-1}\right)} - 1\right)^2 P_c\left(s^{t+q}\right) C_g\left(s^{t+q}\right) \end{array},$$

where Λ_{t+q} is the Lagrange multiplier associated with budget constraint (10), and κ_{p_c} is the parameter associated with non-durables price adjustment. The price setting of the durables sectors is conducted in the similar way.

2.4 Capital Goods Producer

Capital goods producers in sector ξ for $\xi = c, x$ convert investment goods $I_\xi\left(s^t\right)$ purchased from durables sector to capital goods $K_\xi\left(s^t\right)$, using technology $F_{I_\xi}\left(s^t\right)$, and sell it to the entrepreneurs in sector ξ with price $Q_\xi\left(s^t\right)$. The capital goods producers' problem is to maximize the profit function given below:

$$\begin{aligned} &\max_{I_\xi(s^t)} \sum_{q=0}^{\infty} \Pi\left(s^{t+q}|s^t\right) \Lambda_{t,t+q}(s^{t+q}) \\ &\cdot\left[Q_\xi\left(s^{t+q}\right) K_\xi\left(s^{t+q}\right) - (1-\delta) Q_\xi\left(s^{t+q}\right) K_\xi\left(s^{t+q-1}\right) - \frac{P_x\left(s^t\right)}{P_{CPI}\left(s^t\right)} I_\xi\left(s^{t+q}\right)\right], \end{aligned} \tag{18}$$

where F_{I_ξ} is defined as follows:

$$F_{I_\xi}\left(I_\xi\left(s^{t+q}\right), I_\xi\left(s^{t+q-1}\right), \kappa_{I_\xi}\left(s^{t+q}\right)\right) \equiv \frac{\kappa_{I_\xi}\left(s^{t+q}\right)}{2}\left(\frac{I_\xi\left(s^{t+q}\right)}{I_\xi\left(s^{t+q-1}\right)} - 1\right)^2.$$

Note that $\kappa_\xi\left(s^{t+q}\right)$ is a time-varying parameter that is associated with investment adjustment cost in sector ξ.[8] Because capital depreciates in each period, the evolvement of total capital used in sector ξ available in period t is given by

$$K_\xi\left(s^t\right) = \left(1 - F_{I_\xi}\left(I_\xi\left(s^t\right), I_\xi\left(s^{t-1}\right)\right)\right) I_\xi\left(s^t\right) + (1-\delta) K_\xi\left(s^{t-1}\right), \tag{19}$$

where $\delta \in (0,1)$ is the depreciation rate of the capital stock.

2.5 Aggregate Variables

Here, we define some macroeconomic variables. The real GDP $Y_t\left(s^t\right)$ is defined as the weighted average of value-added components:

$$Y\left(s^t\right) \equiv \left[C\left(s^t\right)\right]^{\zeta_{GDP_c}} \left[X\left(s^t\right) + I_c\left(s^t\right) + I_x\left(s^t\right) + G_x\left(s^t\right)\right]^{1-\zeta_{GDP_c}}, \tag{20}$$

where ζ_{GDP_c} is the steady-state expenditure share of the value-added produced by the non-durables sector. The GDP deflator inflation is given by

[8] See MSY (2012) for details of the capital goods producers' maximization problem.

$$\pi\left(s^t\right)=\left(P_c\left(s^t\right)/P_c\left(s^{t-1}\right)\right)^{\zeta_{GDP_c}}\left(P_x\left(s^t\right)/P_x\left(s^{t-1}\right)\right)^{1-\zeta_{GDP_c}}.$$

Using the inflation rate defined above, the real interest rate is given by the Fischer equation that connects the nominal interest rate $R_n\left(s^t\right)$ and the expected inflation:

$$R\left(s^t\right)=R_n\left(s^t\right)/\mathrm{E}_t\pi\left(s^{t+1}|s^t\right).$$

2.6 Government Sector

The government collects a lump-sum tax $\tau\left(s^t\right)$ from the household to finance and government purchase $P_x\left(s^t\right)G_x\left(s^t\right)$ whose amount is exogenously given. We assume that a balanced budget is maintained in each period t as follows:

$$P_x\left(s^t\right)G_x\left(s^t\right)=\tau\left(s^t\right)$$

The central bank adjusts policy rate according to the following Taylor rule:

$$\log R_n\left(s^t\right)=\rho R_n\left(s^{t-1}\right)+(1-\rho)\varphi\log\pi\left(s^t\right)+\epsilon_{R_n}\left(s^t\right). \tag{21}$$

Here, $\rho\in(0,1)$ is the persistency parameter of monetary policy, $\varphi>1$ is the policy weight attached to the inflation rate and $\epsilon_{R_n}\left(s^t\right)$ is an i.i.d. shock to the monetary policy rule.

2.7 Shock Process

The exogenous variables in our economy, the permanent technology in the two goods-producing sectors $Z\left(s^t\right)$, the permanent technology in the durables sector $Z_x\left(s^t\right)$, the exogenous component of the net worth in sector ξ, $\varepsilon_{N_\xi}\left(s^t\right)$, for $\xi=F,c,$ or x, the government spending $G_x\left(s^t\right)$, the capital stock adjustment cost in sector ξ, $\kappa_{I_\xi}\left(s^t\right)$, the price markup in sector ξ, $\theta_{P_\xi}\left(s^t\right)$, the wage markup in sector ξ, $\theta_{W_\xi}\left(s^t\right)$, and the technology of capacity utilization of capital inputs $Z_U\left(s^t\right)$ evolve according to the equation below:

$$\begin{aligned}
\ln Z\left(s^t\right) &= \ln Z\left(s^{t-1}\right)+u_Z\left(s^t\right),\ u_Z\left(s^t\right)=\rho_Z u_Z\left(s^{t-1}\right)+\epsilon_Z\left(s^t\right),\\
\ln Z_x\left(s^t\right) &= \ln Z_x\left(s^{t-1}\right)+u_{Z_x}\left(s^t\right),\ u_{Z_x}\left(s^t\right)=\rho_{Z_x}u_{Z_x}\left(s^{t-1}\right)+\epsilon_{Z_x}\left(s^t\right),\\
\varepsilon_{N_\xi}\left(s^t\right) &= \rho_{N_\xi}\varepsilon_{N_\xi}\left(s^{t-1}\right)+\epsilon_{N_\xi}\left(s^t\right),\ \text{for } \xi=F,c,x,\\
\ln G_x\left(s^t\right) &= (1-\rho_{G_x})\ln G_x+\rho_{G_x}\ln G_x\left(s^{t-1}\right)+\epsilon_{G_x}\left(s^t\right),\\
\ln\kappa_{I_\xi}\left(s^t\right) &= (1-\rho_{I_\xi})\ln\kappa_{I_c}+\rho_{I_\xi}\ln\kappa_{I_\xi}\left(s^{t-1}\right)+\epsilon_{I_\xi}\left(s^t\right),\ \text{for } \xi=c,x,\\
\ln\theta_{P_\xi}\left(s^t\right) &= (1-\rho_{P_\xi})\ln\theta_{P_\xi}+\rho_{P_\xi}\ln\theta_{P_\xi}\left(s^{t-1}\right)+\epsilon_{P_\xi}\left(s^t\right),\ \text{for } \xi=c,x,\\
\ln\theta_{W_\xi}\left(s^t\right) &= (1-\rho_{W_c})\ln\theta_{W_\xi}+\rho_{W_\xi}\ln\theta_{W_\xi}\left(s^{t-1}\right)+\epsilon_{W_\xi}\left(s^t\right),\ \text{for } \xi=c,x,\ \text{and}\\
\ln Z_U\left(s^t\right) &= (1-\rho_U)\ln Z_U+\rho_U\ln Z_U\left(s^{t-1}\right)+\epsilon_U\left(s^t\right),
\end{aligned}$$

where ρ_Z, ρ_{Z_x}, ρ_{N_F}, ρ_{N_c}, ρ_{N_x}, ρ_{G_x}, ρ_{I_c}, ρ_{I_x}, ρ_{P_c}, ρ_{P_x}, ρ_{W_x}, ρ_{W_c} and $\rho_U\in(0,1)$ are the autoregressive root of the corresponding shocks, and $\epsilon_Z\left(s^t\right)$, $\epsilon_{Z_x}\left(s^t\right)$, $\epsilon_{N_F}\left(s^t\right)$, $\epsilon_{N_c}\left(s^t\right)$, $\epsilon_{N_x}\left(s^t\right)$, $\epsilon_{G_x}\left(s^t\right)$, $\epsilon_{K_c}\left(s^t\right)$, $\epsilon_{K_x}\left(s^t\right)$, $\epsilon_{P_c}\left(s^t\right)$, $\epsilon_{P_x}\left(s^t\right)$, $\epsilon_{W_c}\left(s^t\right)$, $\epsilon_{W_x}\left(s^t\right)$, and $\epsilon_U\left(s^t\right)$, are the exogenous i.i.d. shocks that are normally distributed with mean zero.

2.8 Equilibrium

An equilibrium consists of a set of prices, $\{P_c(s^t), P_x(s^t), W_c(s^t), W_x(s^t), R_c(s^t), R_x(s^t), R(s^t), Q_c(s^t), Q_x(s^t)\}_{t=0}^{\infty}$, and the allocations $\{C(s^t),\ C_g(s^t),\ C_g(l,s^t),\ \Psi_c(l,s^t),\ \Psi_x(m,s^t),\ X(s^t), X_g(s^t), X_g(m,s^t), \Gamma_c(l,s^t), \Gamma_x(m,s^t), I_c(s^t), I_x(s^t), L_c(l,s^t), L_x(m,s^t), K_c(l,s^t), K_x(m,s^t), U_c(l,s^t), U_x(m,s^t)\}_{t=0}^{\infty}$, for all $l,m \in [0,1]$, for given government policy $\{G(s^t), \tau(s^t), R_n(s^t)\}_{t=0}^{\infty}$, realization of exogenous variables $\{\epsilon_Z(s^t),\ \epsilon_{Zx}(s^t),\ \epsilon_{R_n}(s^t),\ \epsilon_A(s^t),\ \epsilon_{A_c}(s^t),\ \epsilon_{N_F}(s^t),\ \epsilon_{N_c}(s^t), \epsilon_{N_x}(s^t), \epsilon_{G_x}(s^t), \epsilon_{K_c}(s^t), \epsilon_{K_x}(s^t), \epsilon_{P_c}(s^t), \epsilon_{P_x}(s^t), \epsilon_{W_c}(s^t), \epsilon_{W_x}(s^t), \epsilon_U(s^t)\}_{t=0}^{\infty}$, and initial conditions $\{N_F(s^{-1})\}$, $\{N_c(s^{-1})\}$, $\{N_x(s^{-1})\}$ such that for all t, the following conditions are satisfied.

(i) each household h maximizes his/her utility given the prices;

(ii) each FI i maximizes its profits given the prices and the net worths;

(iii) each entrepreneurs j_{i_c} and j_{i_x} maximizes its profits given the prices and the net worth;

(iv) goods producer l in the non-durables sector and goods producer m in the durables sector maximize their profits given the prices;

(v) capital goods producers in the two goods producing sectors maximize their profit given prices;

(vi) the government budget constraint holds;

(vii) the central bank sets a policy rate following the Taylor rule; and

($viii$) markets clear.

3 Reference rate and informational friction

In this section, we investigate the relationship between informational friction in the credit markets and the reference rates. To do this, we first discuss how credit spreads are determined. Assuming that goods producing sectors are identical for simplicity so that $R_c(s^{t+1}|s^t) = R_x(s^{t+1}|s^t) = R_E(s^{t+1}|s^t)$ holds, then equation (4) is arranged into the following form:[9]

$$\begin{aligned}\frac{R_E(s^{t+1}|s^t)}{R(s^t)} &= \frac{\sum_{\xi=c,x}\left[Q_\xi(s^t)K_\xi(s^t) - N_\xi(s^t)\right] - N_F(s^t)}{\Phi_F(s^{t+1}|s^t)\sum_{\xi=c,x}\Phi_\xi(s^{t+1}|s^t)Q_\xi(s^t)K_\xi(s^t)} \\ &= \frac{1 - \frac{\sum_{\xi=c,x}N_\xi(s^t)}{\sum_{\xi=c,x}Q_\xi(s^t)K_\xi(s^t)} - \frac{N_F(s^t)}{\sum_{\xi=c,x}Q_\xi(s^t)K_\xi(s^t)}}{\Phi_F(s^{t+1}|s^t)\Phi_E(s^{t+1}|s^t)},\ \forall s^{t+1}|s^t.\end{aligned}$$

$R_E(s^{t+1}|s^t)/R(s^t)$ captures credit spread between the rental cost of capital confronting goods producing sectors and risk-free rate, and this credit spread is determined by the creditworthiness of borrowers as well as degree of informational friction. To see this, we demonstrate in Figure 2 how the credit spread varies according to changes in the borrowers' net worth and the degree of informational friction in credit markets. n_F and n_E denoted in the x-axis stand for the net worth held by the FIs sector relative to total amount of investment and the net worth held by the goods-producing sector relative to total amount of investment, respectively:

$$n_F \equiv \frac{N_F(s^t)}{\sum_{\xi=c,x}Q_\xi(s^t)K_\xi(s^t)}, \text{and } n_E \equiv \frac{\sum_{\xi=c,x}N_\xi(s^t)}{\sum_{\xi=c,x}Q_\xi(s^t)K_\xi(s^t)}.$$

Clearly, the credit spread is negatively related to the creditworthiness of borrowers. Figure 3 displays the working mechanism behind the relationship. As the net worth becomes more scarce

[9] Assuming that the two goods sector identical implies that $\Phi_\xi(s^{t+1}|s^t) = \Phi_E(s^{t+1}|s^t)$ for $\xi = c, x$.

relative to the investment amount, the expected monitoring cost rises reflecting a higher leverage and defaulting probability of borrowers. Because the lenders charge the expected monitoring costs on their lending rates to the borrowers, the credit spreads widen.

Creditworthiness is not the only determinant of the credit spread in the model. To see this, we depict how the credit spread is altered when degree of informational friction is enhanced. We consider two cases: a deterioration of monitoring technology, caught by a higher μ_ξ, and an increase of borrowers' riskiness,[10] caught by a higher standard deviation of idiosyncratic productivity σ_ξ, in the borrowing sector ξ, for $\xi = c, x,$and F, respectively. Figure 2 and 3 demonstrate how different values of these parameters deliver different size of the credit spreads. For a given borrowers' default probability, a lower monitoring technology causes a higher monitoring cost, leading to a higher credit spread. Similarly, for a given cut-off value $\overline{\omega}_\xi$, a larger borrowers' riskiness implies that larger portion of borrowers fall below the cut-off value, causing higher defaulting probabilities and wider credit spreads. In the section below, we discuss channels through which a reliable reference rate affects the degree of information friction and credit spreads by changing the monitoring costs that lenders pay and the borrowers' riskiness.

3.1 Reference rates and monitoring technology

Set up

We first discuss the role of the reference rate by investigating the macroeconomic implications of monitoring technology μ_ξ in sector ξ that varies responding to a change in the economic environment. In our model, when a borrower j in sector ξ declares default, lenders must pin down realization of its idiosyncratic productivity ω_{ξ_j}. Without any information provided as to the value of ω_{ξ_j}, lenders consider that ω_{ξ_j} falls in the range between negative infinity and the cut-off value $\overline{\omega}_\xi$. Here, it is natural to assume that resources used for monitoring activities are reduced when lenders receive additional public signal that specifies the range of values ω_{ξ_j} can take. Suppose, for instance, that if a pair of numbers $\left\{\omega_{\xi_{j1}},\ \omega_{\xi_{j0}}\right\}$ such that $-\infty < \omega_{\xi_{j0}} \leq \omega_{\xi_j} \leq \omega_{\xi_{j1}} < \overline{\omega}_\xi$ is informed to the lenders, then μ_ξ should decline compared to the case of otherwise as lenders' monitoring activity becomes more efficient. In addition, μ_ξ should drop further as the discrepancy between the two numbers $|\omega_{\xi_{j1}} - \omega_{\xi_{j0}}|$ approaches zero.

Dynamic response of an improvement in monitoring technology

We consider a case when a reference rate is informative about a realization of ω_{ξ_j} and provides the range $|\omega_{\xi_{j1}} - \omega_{\xi_{j0}}|$ to the lenders. As lenders spend less resources for monitoring activities, μ_ξ falls. Borrowing parameter values estimated in MSY (2012),[11] we investigate both quantitative and qualitative consequence of such changes in credit contracts. Figure 4 displays the equilibrium response of our model to an improvement in monitoring technology in the IF and FEC contract brought about by a short-run decline in μ_F and μ_c. As indicated in Figure 3, defaulting probability of borrowers being unchanged, a smaller monitoring cost μ_F leads to a lower expected default costs confronting investors. Consequently, the credit spread in interbank $r_F\left(s^{t+1}|s^t\right) - R\left(s^t\right)$ shrinks.

[10] Following Christiano, Motto, and Rostagno (2009), we call this standard deviation of idiosyncratic productivity σ in the borrowing sectors "riskiness." See also Kobayashi (2012) where the reference rate is decomposed into risk-free rate, risk premium, liquidity premium, and "uncertainty" premium.

[11] MSY (2012) estimates the model used in this paper using the Japanese data from the 1980s to 2000s. The parameter values are reported in Table 1.

Because cost of external financing for capital goods purchase becomes cheaper to entrepreneurs, investment grows, leading to higher GDP and inflation.

There is the second-round effect stemming from endogenous developments of borrowers' net worths. As the demand for capital goods tightens in response to the shock to the monitoring cost, asset price $Q_{\xi}\left(s^{t}\right)$ for $\xi = c, x$ goes up. Higher asset prices together with expanding output production facilitate accumulation of net worth in the FIs and goods-producing sectors, N_{ξ}, for $\xi = F, c$, and x, through equations (7) and (8). The endogenous improvement of borrowers' creditworthiness reduces credit spreads in lending markets as well as in interbank market, facilitating investment further.

For the same size of decline in monitoring cost, a macroeconomic consequence of the cost decline in the IF contract is larger than that in the FEC contracts, although the decline in the two costs yield qualitatively similar macroeconomic impacts. One reason behind this outcome is that while a narrowing credit spread in the interbank market is easily transmitted to two credit spreads in the lending markets through the financial linkage, a narrowing credit spread in the lending market affects the credit spread in the interbank only indirectly through the endogenous movements of net worths.[12]

3.2 Reference rates and borrowers' perceived idiosyncratic productivity

Set up

We next discuss the channel through which reference rate affects perceived uncertainty regarding idiosyncratic productivity of borrowers, called riskiness, in the credit markets. Our analysis is closely related to studies including Lucas (1972), Morris and Shin (2003), and Ui (2003). Their economy consists of multiple agents where each of the agents receives two separate signals, private signal and public signal, about the state of nature. The two signals are contaminated with noise and agents form their expectations by solving signal extraction problem. Because all agents receive the same public signal, an improvement of the public signal precision causes a cross-sectional convergence of agents' expectation and their actions.

We introduce agents called operator into MSY (2012). There are three classes of operators and each class of operator is attached to each of the three sectors, providing a sector specific operational service. There is an infinite number of operators in each sector and an individual operator ι provides a service flow $h_{F,\iota}\left(s^{t}\right)$ to a randomly chosen FI, say type i FI. We assume that an idiosyncratic productivity of a type i FI $\omega_{F,i}\left(s^{t}\right)$ is affected by the operator's endogenous choice of operational service amount as well as an exogenous component:

$$\omega_{F,i}\left(s^{t}\right) \equiv \overbrace{\omega_{F_{exo},i}\left(s^{t}\right)}^{\text{exogenous component}} + \overbrace{h_{F,\iota}\left(s^{t}\right) - h_{F}\left(s^{t}\right)}^{\text{endogenous component}}.$$

Here, the exogenous component is normally distributed with zero mean and variances $\sigma^{2}_{F_{exo}}$ and $h_{F}\left(s^{t}\right)$ in the endogenous component is an average of operational service provided by operators attached to the FI sector. We assume the similar setting holds for operators attached to goods-producing sectors.

Individual operator ι determines its operational service $h_{F,\iota}\left(s^{t}\right)$ so as to meet the aggregate demand $\theta_{F}\left(s^{t}\right)$. The aggregate demand is not known to the operator and it infers the aggregate

[12] See Christiano, Motto, and Rostagno (2003, 2008, and 2010) for quantitative importance of shocks to riskiness in goods-producing sectors in the U.S. and euro area.

demand, using of two sources of information, a private signal $\upsilon_{F,\iota}(s^t)$ whose realization is specific to ι and public signal $\Omega_F(s^t)$ that is commonly delivered to all operators. While both the signals include the sum of the true value of aggregate demand $\theta_F(s^t)$ and noises $\upsilon_{F,\iota}(s^t)$ and $\varpi_F(s^t)$, the two components are not observable to the operators.

$$\begin{aligned} \upsilon_{F,\iota}(s^t) &= \theta_F(s^t) + \upsilon_{F,\iota}(s^t), \\ \Omega_F(s^t) &= \theta_F(s^t) + \varpi_F(s^t). \end{aligned}$$

Noises $\upsilon_{F,\iota}(s^t)$ and $\varpi_F(s^t)$ are normally distributed with zero mean and variance of $\sigma^2_{V_F}$ and $\sigma^2_{\varpi_F}$. Based on the statistical inference, operation service provided by the operator ι conditional on the realizations of the two signals, $\upsilon_{F,\iota}(s^t)$ and $\Omega_F(s^t)$, is then given by

$$h_{F,\iota}(s^t) = \mathrm{E}\left[\theta_F(s^t) \,|\upsilon_{F,\iota}(s^t), \Omega_F(s^t)\right] = \frac{\upsilon_{F,\iota}(s^t)\,\sigma^2_{\varpi_F} + \Omega_F(s^t)\,\sigma^2_{V_F}}{\sigma^2_{V_F} + \sigma^2_{\varpi_F}}.$$

While each operator is *ex-ante* identical, it provides a different amount of operational service from each other since it receives a different realization of private signals. Consequently, the signals generate a divergence of operational service $h_{F,\iota}(s^t)$ across agencies. Because $\upsilon_{F,\iota}(s^t)$ is normally distributed with variance of $\sigma^2_{V_F}$, cross-sectional variance of operators' operation service is given by

$$\int_0^1 \left[h_{F,\iota}(s^t) - h_F(s^t)\right]^2 d\iota = \frac{\sigma^2_{V_F}}{\left(\sigma^2_{V_F}/\sigma^2_{\varpi_F} + 1\right)^2}.$$

Clearly, the FIs' riskiness, the cross-sectional standard deviation of operational service, is increasing function of variance of the noise contained in public signal. The riskiness of the FI is therefore given by

$$\sigma^2_F(s^t) = \sigma^2_{F_{exo}}(s^t) + \frac{\sigma^2_{V_F}(s^t)}{\left(\sigma^2_{V_F}/\sigma^2_{\varpi_F} + 1\right)^2}. \tag{22}$$

When public signal increases its accuracy about aggregate demand for operational service, therefore, a cross-sectional variance of operational services becomes smaller, reducing the riskiness of the FI sector. The similar mechanism holds in the goods-producing sectors.

Economic response to an improvement in public signal

Figure 5 displays the equilibrium response of macroeconomic variables to a temporary decline of riskiness in the interbank market σ^2_F driven by an improvement of reference rate $\sigma^2_{\varpi_F}$. As it lowers an expected portion of defaulting borrowers in interbank market, the interbank spread $r_f(s^{t+1}|s^t) - R(s^t)$ narrows, making a external finance for capital goods purchase cheaper. Consequently, investment and output grow and inflation increases. The second round effect is also present. The endogenous developments of the net worths in the borrowers of the credit markets help further reduce credit spreads, boosting the economy. The figure also displays the equilibrium response of our model to a temporary decline of riskiness in the lending market σ^2_c. Similarly to the consequence of reduced monitoring costs μ_F and μ_c, changes in the two riskiness bring about qualitatively the same impacts on the economy, though macroeconomic impacts caused by the decline in σ^2_F is substantially larger compared to the one caused by the decline in σ^2_c.[13]

[13] In this paper, we investigate the economic response to a unexpected decline in monitoring cost and riskiness and display that such shocks boost the economy. Clearly, if the degree of informational friction increases because of the changes in these parameters in the opposite direction, then output is instead dampened. See Heider et al. (2009) for the discussion that relate informational friction and surge in the credit spread during the financial crisis.

4 Reference rates as a tool of expectation management

In this section, we discuss the role of reference rates in expectation formation and business cycle fluctuations. To do this, we extend the literature of "Pigou cycle," including Pigou (1926), Beaudry and Portier (2006), and Jaimovich and Rebelo (2009). These studies shed the light on the anticipated shock as a distinct source of business cycle fluctuations from unanticipated shocks that have been considered as the key determinants of the business cycle fluctuations. Agent in their models receives news regarding future events such as an exogenous rise in the goods production technology that will occur several quarters ahead. Since the agent's economic decision today is affected by his/her expectation, current economic variables are dependent upon the way that agent responds to the news. In particular, recent studies along this line estimate a DSGE model that incorporates anticipated shocks and document that such news shocks are quantitatively important drivers of the business cycle fluctuation in the U.S. and in Japan (Fujiwara, Hirose, and Shintani 2009; and Schimitt-Grohé and Uribe; 2012).

Similarly to the discussions in Section 3, we discuss the role of reference rate in expectation formation by introducing an additional setting to MSY (2012). We specifically consider news that informs agents that there will be an exogenous change in the FIs' net worth in the future. In contrast to standard treatment of news in the literature where quantity of the economic event, such as the size of productivity increase, is perfectly foreseen, news in our economy is contaminated with noises. As agents are only certain about the timing of the event but uncertain about the size of the event, they predict the size using a statistical inference. Consequently, agents' expectation regarding the net worth shock does not necessarily match with what materializes in the future. The discrepancy between the predicted size of net worth change and the materialized size acts as an additional source of business cycle fluctuations in the economy.

Set up

We assume that agents in the economy receive news in period t that informs them that there will be an exogenous change in FIs' net worth by Δn_F in the two years horizon, in period $t+8$. When the news arrives in period t, therefore, agents expect that a net worth in $t+8$ evolves according to

$$N_F\left(s^{t+8}\right)=\gamma_F V_F\left(s^{t+7}\right)+\varepsilon_{N_F}\left(s^{t+7}\right)+\frac{W_{F_c}\left(s^{t+7}\right)}{P_{CPI}\left(s^{t+7}\right)}+\frac{W_{F_x}\left(s^{t+7}\right)}{P_{CPI}\left(s^{t+7}\right)}+\mathrm{E}_t\left[\Delta n_F\left(s^{t+8}\right)\right].$$

Agents know that there is a change in the net worth, but they do not know its size with certainty. In addition to the news, agents receive two signals in period t, private signal and public signal, denoted by $\upsilon_F\left(s^t\right)$ and $\Omega_F\left(s^t\right)$, respectively. Both two signals are the sum of the true value of future net worth change $\Delta n_F\left(s^{t+8}\right)$ and disturbances $v_F\left(s^t\right)$ and $\varpi_F\left(s^t\right)$.

$$\begin{aligned}\upsilon_F\left(s^t\right) &= \Delta n_F\left(s^{t+8}\right)+v_F\left(s^t\right),\\ \Omega_F\left(s^t\right) &= \Delta n_F\left(s^{t+8}\right)+\varpi_F\left(s^t\right).\end{aligned}$$

Similarly to the setting in Section 3, these disturbances $v_{F,\iota}\left(s^t\right)$ and $\varpi_{F,\iota}\left(s^t\right)$ are normally distributed with zero mean and variance $\sigma^2_{V_F}$ and $\sigma^2_{\varpi_F}$, respectively, and these statistical properties of the disturbances are known to agents.

Agents only observe realization of the signals and do not observe each of the two components. Making use of the statistical properties of disturbances, they forecast the size of future exogenous net worth change $\Delta n_F\left(s^{t+8}\right)$ based on the statistical inference:

$$\mathrm{E}\left[\Delta n_F\left(s^{t+8}\right)|\upsilon_F\left(s^t\right),\Omega_F\left(s^t\right)\right]=\frac{\upsilon_F\left(s^t\right)\sigma^2_{\varpi_F}+\Omega_F\left(s^t\right)\sigma^2_{V_F}}{\sigma^2_{V_F}+\sigma^2_{\varpi_F}}.$$

The above equation indicates that an expected value of exogenous net worth change conditional on information available today is affected by the variance of public and private signals $\sigma^2_{V_F}$, $\sigma^2_{\varpi_F}$. It further indicates that, other things being equal, as variance of public signal $\sigma^2_{\varpi_F}$ is reduced, the discrepancy between expectation and realization regarding the net worth change diminishes. While such a discrepancy itself works as an innovation to the economy, the accuracy of expectation brought about by the reliable public signal help mitigate economic fluctuations stemming from the innovation.

Quantitative role played by a reliable public signal in stabilization economic fluctuations

We then quantitatively investigate the role of public signal in stabilizing macroeconomic fluctuation through its guidance of agents' expectation formation. We start from a simple example, comparing two cases; a case when an exogenous net worth change materializes exactly in the way that it was expected (case i) and a case when the net worth change does not materialize even though it was expected to occur (case ii). Mathematical formulations of those two cases are given by the following two equations:

$$\begin{aligned}\text{case i} \quad &: \quad \Delta n_F\left(s^{t+8}\right)=\mathrm{E}\left[\Delta n_F\left(s^{t+8}\right)|\upsilon_F\left(s^t\right),\Omega_F\left(s^t\right)\right]=-1,\\ \text{case ii} \quad &: \quad \Delta n_F\left(s^{t+8}\right)=0\neq\mathrm{E}\left[\Delta n_F\left(s^{t+8}\right)|\upsilon_F\left(s^t\right),\Omega_F\left(s^t\right)\right]=-1.\end{aligned}$$

Note that the two scenarios are identical in terms of agents' expectation formation about the size of exogenous net worth change and differ in the materialization of the net worth changes.

Figure 6 displays the equilibrium response of the economy to the news under the two scenarios. In both cases, at the arrival of the news, entrepreneurs expect that they are going to face a higher borrowing rate in the two years horizon as credit spread widens reflecting an exogenous disruption of FIs' net worth by $\Delta n_F\left(s^{t+8}\right)$. Because the expected borrowing rate rises, the expected investment demand falls, leading to a fall in current asset price $Q_c\left(s^t\right)$. The fall in current asset price reduces current net worth in both FI and goods-producing sectors through equations (7) and (8), widening current credit spreads and dampening current investment, output, and inflation. The equilibrium time paths under the two scenarios, the case i and the case ii, are identical up until period $t+8$ in the period when the news materializes. Under the case i, since the exogenous deterioration of net worth occurs in the way that it was expected, agents have already take the deterioration into consideration. Consequently, no surprise takes place in the economy. Although the net worth of FI displays a sharp decline in the period, macroeconomic variables evolve smoothly over the period of materialization and beyond. Under the case ii, exogenous deterioration of net worth does not materialize in period $t+8$, even though agents expect that such deterioration occurs. This is conceived as a positive surprise to the agents in the economy. Consequently, asset price $Q_c\left(s^{t+8}\right)$ upsurges, driving output and inflation upward, yielding a volatile economic fluctuations compared to the case ii. Clearly, what plays the part is the accuracy of expectation formation in stabilization of the economy.

Next, we discuss two other scenarios where materialized size of the net worth change is the same across scenarios while the expectations regarding the size of the changes are different. In the case iii, agents expect a unit decline in FIs' net worth and the materialized exogenous change in the FIs' net worth is half of its prediction. In case iv, agents accurately predict that size of exogenous net worth change in two years ahead. Again, formulations of the two cases are shown as below:

$$\begin{aligned} \text{case iii} &: \quad \Delta n_F\left(s^{t+8}\right) = -0.5 \neq \mathrm{E}\left[\Delta n_F\left(s^{t+8}\right) | \upsilon_F\left(s^t\right), \Omega_F\left(s^t\right)\right] = -1, \\ \text{case iv} &: \quad \Delta n_F\left(s^{t+8}\right) = -0.5 = \mathrm{E}\left[\Delta n_F\left(s^{t+8}\right) | \upsilon_F\left(s^t\right), \Omega_F\left(s^t\right)\right]. \end{aligned}$$

Figure 7 displays the equilibrium response of the economy to the news under the two scenarios. In contrast to the two scenarios displayed in Figure 6 where agents form the same expectation, the equilibrium time paths under case iii and iv are different throughout the simulation period. Since agents under case iv expect a smaller decline in the net worth than agents under case iii, adverse impacts of the news on the macroeconomic activity are moderate up to period $t+8$ in the former scenario. In period $t+8$, a net worth declines with the same size materializes in the two scenarios. In case iii, since the exogenous net worth decline turns out to be smaller than expected, the discrepancy between the expected change and materialized change is conceived as an expansionary shock to the agents in the materialized period. Consequently, output, inflation, and other macroeconomic variables suddenly jump up at the period.

The analysis above indicate that accuracy in agents' expectation regarding future shocks contributes to a stabilization of the macroeconomy. To see this in details, we gauge the variations of macroeconomic variable x conditional on the news arrival σ_x^2, by taking average of squared deviation from its steady state value Δx_t over five years horizon after the news arrival;

$$\sigma_x^2 = \sum_{t=0}^{20} \left(\Delta x_t\right)^2.$$

Table below documents a size of the variations σ_x^2 under four scenarios where agents' expectation conditional on the news is -2, -1, 0, and 1, respectively, and the net worth change that materializes 8th quarter after the news is all -0.5. For illustrative purpose, all variations are divided by the variations $\sigma_{y,iv}^2$ that is measured under the scenario iv where realization of the net worth change exactly matches with the agents' expectation. As the absolute value of discrepancy between the expected size and materialized size of the net worth change widens, the measured volatility monotonically increases for all four macroeconomic variables, output, inflation, labor input, and value-added produced from the durables sector (sum of consumer durable expenditure and investment), indicating that the improvement in economic outlook thanks to a reliable reference rate brings about the macroeconomic stabilization.

	$\sigma_y^2/\sigma_{y,iv}^2$	$\sigma_\pi^2/\sigma_{\pi,iv}^2$	$\sigma_l^2/\sigma_{l,iv}^2$	$\sigma_I^2/\sigma_{I,iv}^2$
$\mathrm{E}\left[\Delta n_F\left(s^{t+8}\right) \| \upsilon_F\left(s^t\right), \Omega_F\left(s^t\right)\right] = -2$	10.41	27.48	17.97	13.38
$\mathrm{E}\left[\Delta n_F\left(s^{t+8}\right) \| \upsilon_F\left(s^t\right), \Omega_F\left(s^t\right)\right] = -1$	2.46	5.06	2.90	2.95
$\mathrm{E}\left[\Delta n_F\left(s^{t+8}\right) \| \upsilon_F\left(s^t\right), \Omega_F\left(s^t\right)\right] = 0$	1.24	1.72	2.86	1.22
$\mathrm{E}\left[\Delta n_F\left(s^{t+8}\right) \| \upsilon_F\left(s^t\right), \Omega_F\left(s^t\right)\right] = 1$	6.77	17.50	17.84	8.20

5 Reference rates as a disturbance to monetary policy implementation

Set up

Finally, we explore a channel where reference rate acts as a disturbance to the economy through monetary policy implementation. As discussed in early study of Berkowitz (1998), reference rates may include noises that separate these interest rates from fundamentals, partly because in practice they often suffer from a small sample problem of interviewed banks and affected by inaccurate observations or manipulation even after trimmed-means treatment is applied.[14] We consider a set of economies where an observed credit spread is contaminated with a non-fundamental noise and a central bank adjusts its policy rate according to the movement of the observed credit spread that includes the noise. While such a noise itself plays no role in resource allocation and prices, it results in fluctuations in macroeconomic variables through the systematic response of the central bank to the noise. From the private agents' perspective, such movements in the policy rate is perceived as a shock to the monetary policy rule, adding an additional source of business cycle fluctuation.

Equilibrium response to a noise in the credit spread

First, we examine the implication of such noise using a framework of spread-adjusted Taylor rule. Following Cúrdia and Woodford (2010) and Hirakata, Sudo, and Ueda (2011b), we define a rule as a monetary policy rule that lowers the intercept of the standard Taylor rule by responding to an observed widening of interbank credit spread. Under this class of policy, a observed widening (shrinking) of the credit spread is systematically met by a cut (rise) in the interest rate, yielding an expansionary (contractionary) effect on the economy. Policy rule equation given by the equation (21) is now modified to

$$\log R_n\left(s^t\right) = \left\{ \begin{array}{c} \rho R_n\left(s^{t-1}\right) + (1-\rho)\,\varphi \log \pi\left(s^t\right) \\ -\,(1-\rho)\,\phi_{r_f} \log\left(\frac{\left(\mathrm{E}_t\left[r_f\left(s^{t+1}|s^t\right)\right] - R\left(s^t\right) + \varpi_F\left(s^t\right)\right)}{\mathrm{E}[r_F]-R}\right) \end{array} \right\}, \tag{23}$$

where $\mathrm{E}[r_F] - R$ is the steady-state values of interbank credit spread and nonnegative coefficient ϕ_{r_f} is a policy weight attached to the credit spread.[15] The term $\varpi_F\left(s^t\right)$ stands for an observational error in the observed credit spread that follows i.i.d. process. We assume that other economic environments remain the same.

Figure 8 displays the equilibrium response of the economy to an exogenous disruption in the FIs' net worth when the central bank pursues a spread-adjusted Taylor rule. The shortage of the FIs' net worth primarily causes a widening of credit spread in the interbank market and pronounced to the lending markets, leading to a higher external finance premium facing goods producing firms. Consequently, output falls and inflation lowers. According to the rule (23), the central bank cuts its policy rate so as to mitigate the widening of the credit spread as well as the deflationary pressure. In the presence of a positive (negative) noise in the observed credit spread, the central bank cuts its policy rate greater than (smaller than) the case without such noise. For private agents in the economy, these systematic response of policy rate from the central bank perspective is conceived as a positive (negative) monetary policy shock to the economy, giving an expansionary (contractionary) effect to the economy compared to the case of otherwise.

Second, we investigate a case when the central bank falls into the liquidity trap and no longer follows a standard Taylor rule that is specified in equation (21). Following closely Laseen and

[14] In addition to these problems, illiquidity of the markets may also adversely affect the function of reference rates. See Gynthelberg and Wooldridge (2008).

[15] While there are several credit spreads in our model, implications of the spread-adjusted Taylor rule to the macroeconomic activity and welfare differ depending on which credit spread is incorporated in the monetary policy rule. See Hirakata, Sudo, and Ueda (2011b) for the detailed discussion.

Svensson (2011) and Bodenstein, Guerrieri, and Gust (2010), we consider a version of Taylor rule expressed in the following equation.

$$\log R_n\left(s^t\right)=\max\left(\begin{array}{l}\rho R_n\left(s^{t-1}\right)+(1-\rho)\,\varphi\log\pi\left(s^t\right)\\ -(1-\rho)\,\phi_{r_f}\log\left(\frac{\left(\mathrm{E}_t\left[r_f\left(s^{t+1}|s^t\right)\right]-R\left(s^t\right)+\varpi_F\left(s^t\right)\right)}{\mathrm{E}\left[r_F\right]-R}\right)\end{array},0\right). \tag{24}$$

Under this rule, in the wake of adverse deflationary shock, the central bank cuts its policy rate to zero for a period that such shock persists. As the adverse impact fades away, it then gradually raises its policy rate to a positive value. When there is a nonzero realization of the noise $\varpi_F\left(s^t\right)$, then the monetary policy implementation leads to unintended outcome by forwarding or delaying the timing of the exit policy compared to the ideal timing targeted by the central bank.

Figure 9 displays the equilibrium response of the economy to a large disruption in the FIs' net worth. Because the size of the shock is substantially large, the policy rate following equation (24) continuously hits its floor for several quarters after the shock. When no observational error occurs in the interbank market, the central bank starts to set a positive interest rate 9th quarter after the adverse shock. In case that a positive noise prevails in the credit market and the observed credit spread from central bank's perspective is higher than the actual credit spread, the central bank delays timing of raising its policy rate according to the policy weight attached to the credit spread. In this example, the central bank raises interest rate in period $t=13$ because of the noise. Macroeconomic consequence of the delaying in policy action is clear. Because an expansionary monetary policy is maintained longer than a case otherwise, economy experiences a higher output and inflation.

6 Conclusive Remark

In recent years, particularly after the financial crisis, a growing attention has been paid to the role played by reference rate in the economy. In contrast to existing studies that concentrate primarily on its role in transactions in the financial market, in this paper, we explore what the reference rate does to the macroeconomic activity using a medium-scale dynamic general equilibrium model developed by Muto, Sudo, and Yoneyama (2012). We show that a reliable reference rate may give rise to a favorable economic outcome either through a moderation of the degree of informational friction in the credit markets or through an improvement of economic forecast. We also demonstrate, however, that reference rate may lead to an unintended consequence of monetary policy if it contains a non-fundamental noise that affects decision making of the central bank. Our results illustrate the importance of reliable reference rates in the economy particularly under the environment with economic uncertainty from the perspective of resource allocation in credit markets, macroeconomic stabilization, and policy implementation.

In the current paper, we concentrate our analysis on issues about reference rate as information tool and do not address other aspects of the reference rate. We believe, however, that there are two more issues regarding reference rate worth further investigation. The first issue is about its international spillover effect. When considered in open economy framework, reference rate emerges as transmitter of a country-specific shock in one country, say country A, to the rest of the globe. For instance, spreads in countries other than A may widen in response to a domestic noise in country A, which is independent from creditworthiness and degree of informational friction in these countries, and such widening of spreads lead to output fluctuations. When there is trade relationship between these countries, effects of the original shock may even be pronounced. The second issue is about its distributional effect. As pointed out by Abrantes-Metz et al. (2012), under- and overestimates of reference rates may generate net worth transfer between borrowers and lenders both within and across sectors. For instance, whenever an adverse effect of a unit decline in net worth in one sector is not equivalent to a favorable effect of a unit increase in net worth in the other sector, the transfer results in aggregate fluctuations.[16] Exploring the role of the reference rates in details through those two dimensions is left for future research.

[16] HSU (2011a, b) demonstrates that a disruption in the banks' net worth causes a disproportionately large impact on the economy compared to the same size of disruption in the goods producing sector, indicating that the net worth transfer across the two sectors is accompanied by the aggregate impact.

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Estimated Parameters

(1) Values of Estimated Parameters (Prior and Posterior Distributions)

	Prior Distribution			Posterior Distribution		
	Distribution	Mean	S.D.	Mean	5th Percentiles	95th Percentiles
Capital Stock Adjustment Cost (Non-durable)	beta	0.5	0.05	0.55	0.54	0.57
Capital Stock Adjustment Cost (Durable)	beta	0.5	0.05	0.53	0.49	0.57
Durable Stock Adjustment Cost	norm	8	3	0.85	0.79	0.91
Price Adjustment Cost (Non-durable)	norm	16	6	50.96	47.80	54.17
Price Adjustment Cost (Durable)	norm	16	6	52.98	51.46	54.17
Nominal Wage Adjustment Cost (Non-durable)	norm	16	6	26.74	19.99	34.37
Nominal Wage Adjustment Cost (Durable)	norm	16	6	17.71	9.44	25.44
Policy Weight on Inflation in Taylor Rule	norm	1.8	0.05	1.92	1.84	2.00
Parameter for Capital Utilization Rate	norm	5	1	7.85	6.66	9.08
Permanent Technology Shock (Durable) AR	norm	0.5	0.15	0.35	0.33	0.36
Permanent Technology Shock (Common) AR	norm	0.5	0.15	0.32	0.31	0.34
Net Worth Shock (FI) AR	beta	0.85	0.1	0.30	0.29	0.31
Net Worth Shock (Non-durable) AR	beta	0.85	0.1	0.53	0.51	0.55
Net Worth Shock (Durable) AR	beta	0.85	0.1	0.55	0.52	0.58
Demand Shock AR	beta	0.5	0.15	0.77	0.74	0.80
Investment Adjustment Shock (Non-durable) AR	beta	0.7	0.15	0.96	0.93	0.98
Investment Adjustment Shock (Durable) AR	beta	0.7	0.15	0.94	0.91	0.99
Price Markup Shock (Non-durable) AR	beta	0.5	0.15	0.46	0.42	0.48
Price Markup Shock (Durable) AR	beta	0.5	0.15	0.48	0.45	0.51
Nominal Wage Markup Shock (Non-durable) AR	beta	0.5	0.15	0.46	0.45	0.48
Nominal Wage Markup Shock (Durable) AR	beta	0.5	0.15	0.47	0.45	0.50
Capacity Utilization Rate Shock AR	beta	0.5	0.15	0.63	0.54	0.72
Permanent Technology Shock (Durable) SD	invg	0.4	2	0.32	0.30	0.33
Permanent Technology Shock (Common) SD	invg	0.4	2	0.28	0.27	0.30
Temporary Technology Shock (Common) SD	invg	5	5	0.79	0.78	0.81
Temporary Technology Shock (Non-durable) SD	invg	2	5	0.51	0.47	0.55
Monetary Policy Shock SD	invg	0.1	2	0.01	0.01	0.01
Net Worth Shock (FI) SD	invg	0.5	0.1	0.31	0.29	0.33
Net Worth Shock (Non-durable) SD	invg	0.5	0.1	0.40	0.37	0.42
Net Worth Shock (Durable) SD	invg	0.5	0.1	0.41	0.38	0.43
Demand Shock SD	invg	1	5	0.54	0.52	0.56
Investment Adjustment Shock (Non-durable) SD	invg	1	5	0.77	0.56	0.93
Investment Adjustment Shock (Durable) SD	invg	1	5	0.83	0.80	0.88
Price Markup Shock (Non-durable) SD	invg	0.5	5	0.32	0.30	0.33
Price Markup Shock (Durable) SD	invg	1.5	5	0.62	0.59	0.66
Nominal Wage Markup Shock (Non-durable) SD	invg	0.5	5	0.47	0.45	0.49
Nominal Wage Markup Shock (Durable) SD	invg	0.5	5	0.46	0.41	0.51
Capacity Utilization Rate Shock SD	invg	0.1	0.1	0.03	0.03	0.03

(2) Values of Calibrated Parameters

Elasticity of Labor Supply	1
Capital Share	0.32
Households' Discount Factor	0.99
Capital Depreciation Rate	0.025
Durable Stock Depreciation Rate	0.0375
Price Markup at Steady State (Non-durable)	5
Price Markup at Steady State (Durable)	5
Wage Markup at Steady State (Non-durable)	21
Wage Markup at Steady State (Durable)	21
FIs' Net Worth Ratio	0.1
Goods Production Sectors' Net Worth Ratio	0.6

Table 1: Estimated and calibrated parameters used in the current model (values are taken from MSY (2012). Estimated parameters are based on Japanese data from 1980s to 2000s.

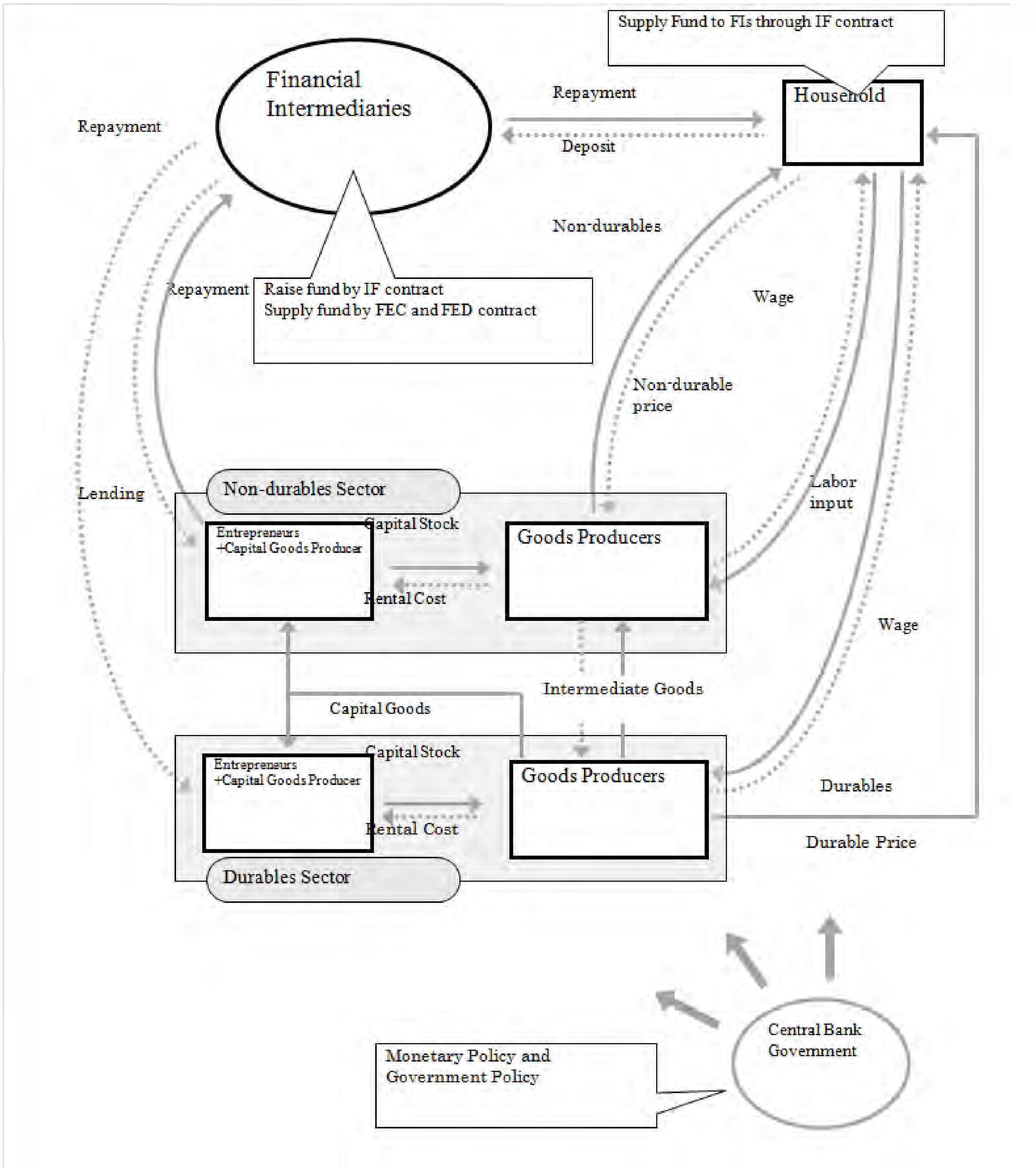

Figure 1: Outline of MSY (2012).

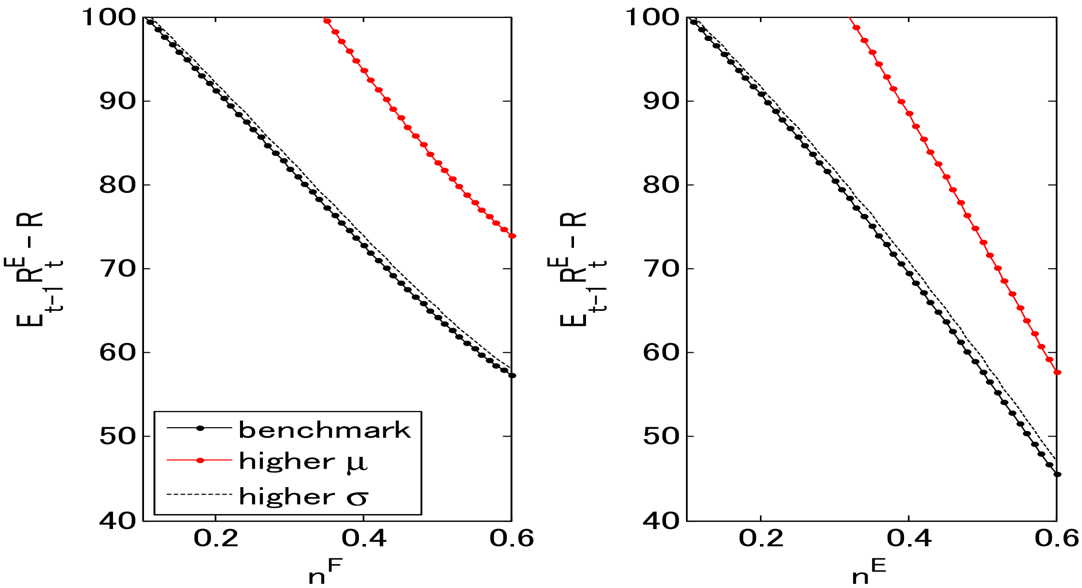

Figure 2: Credit spread $\mathrm{E}_t R_E\left(s^{t+1}|s^t\right)/R\left(s^t\right)$ as a function of creditworthiness of FIs and goods-producing sectors, $n_F\left(s^t\right)$ and $n_E\left(s^t\right)$, as well as degree of informational friction governed by monitoring technology μ_ξ and standard deviation of idiosyncratic productivity σ_ξ (riskiness).

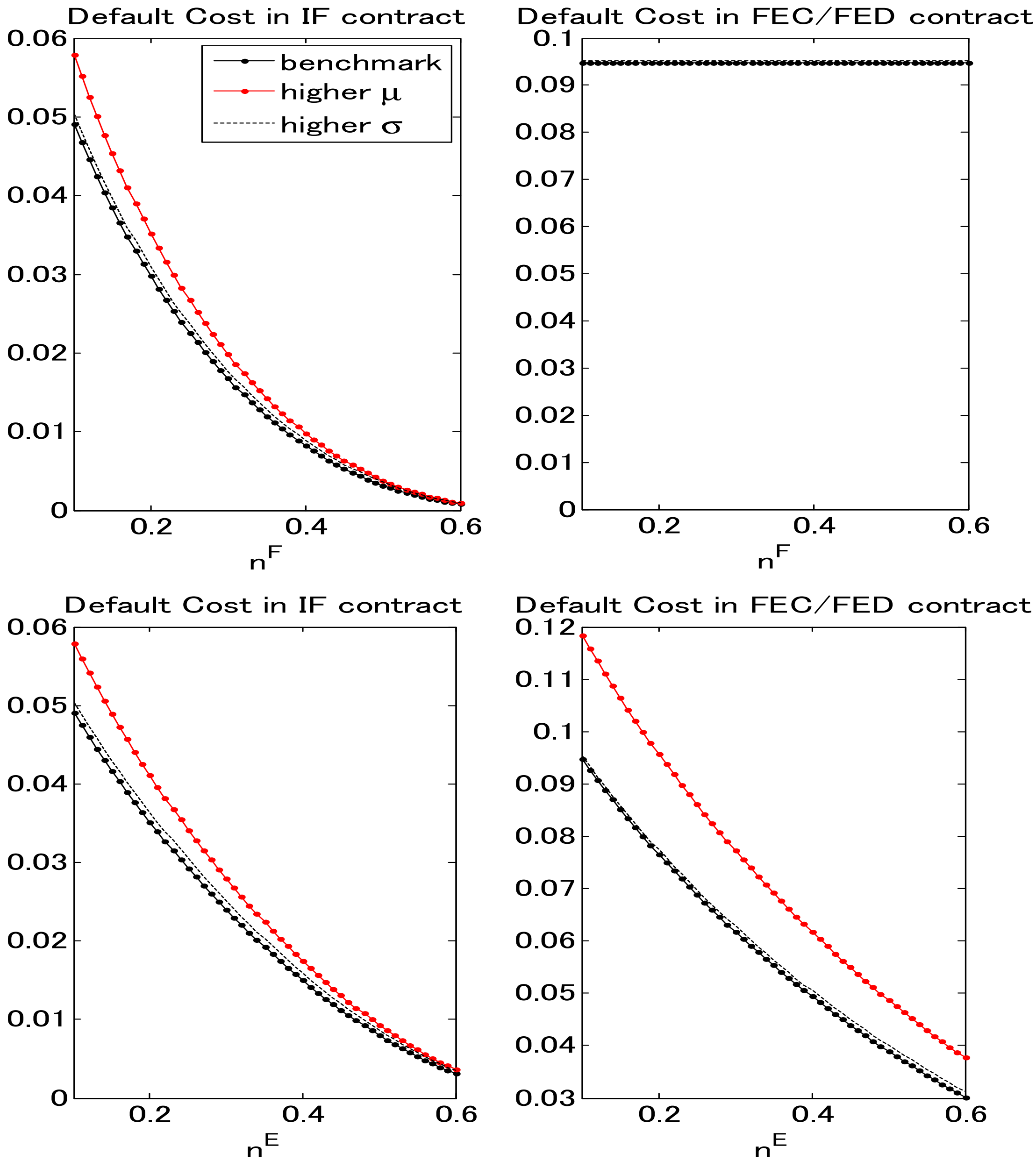

Figure 3: Expected default cost $\mu_\xi \int_0^{\overline{\omega}_\xi} \omega_\xi dF_\xi(\omega_\xi)$ in sector ξ as a function of creditworthiness of FIs and goods-producing sectors, $n_F(s^t)$ and $n_E(s^t)$, as well as degree of informational friction governed by monitoring technology μ_ξ and standard deviation of idiosyncratic productivity σ_ξ (riskiness).

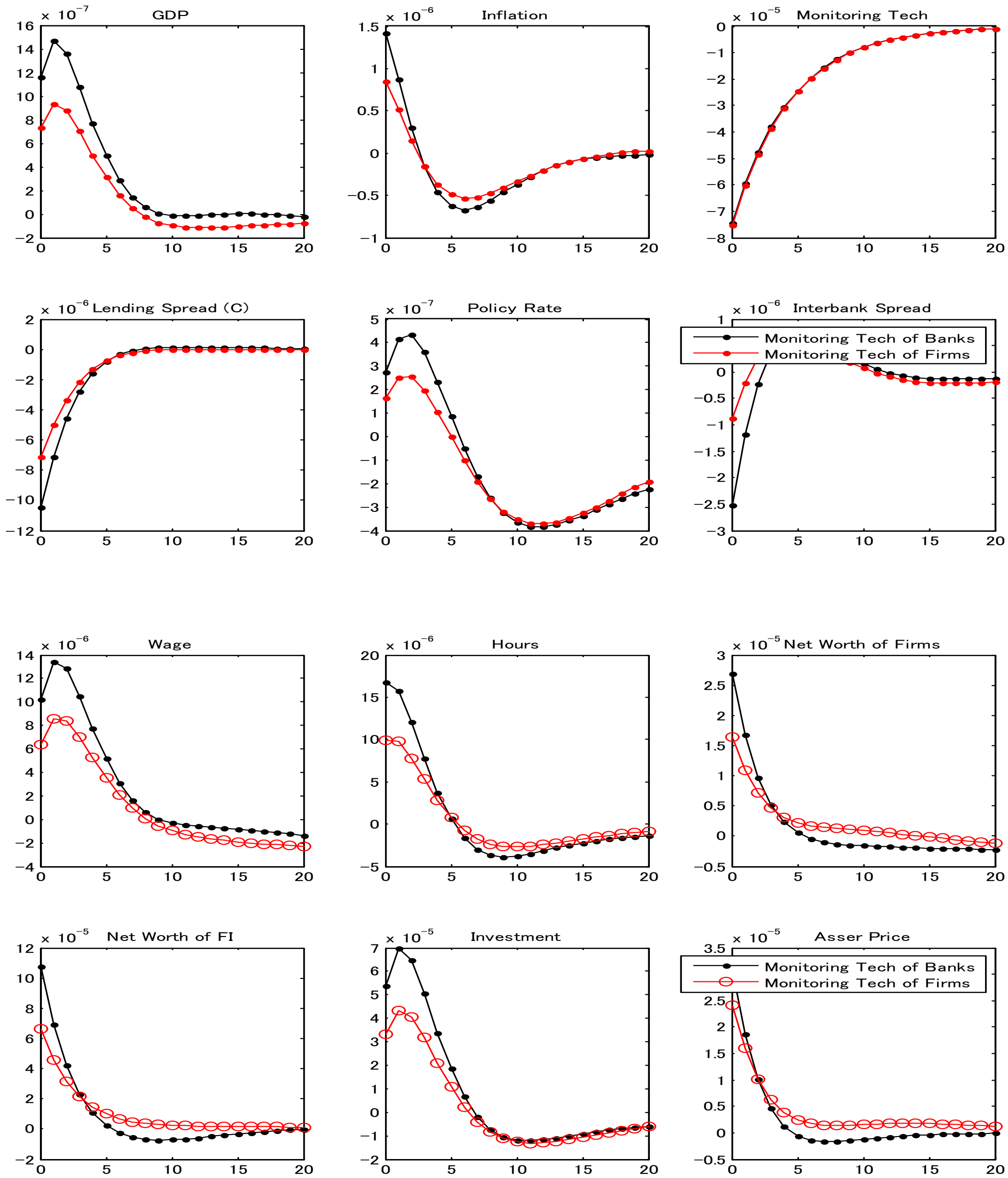

Figure 4: Equilibrium response of macroeconomic variables to an improvement of monitoring technology (decrease in a monitoring cost) in the interbank market (depicted in black line) and the lending market (depicted in red line).

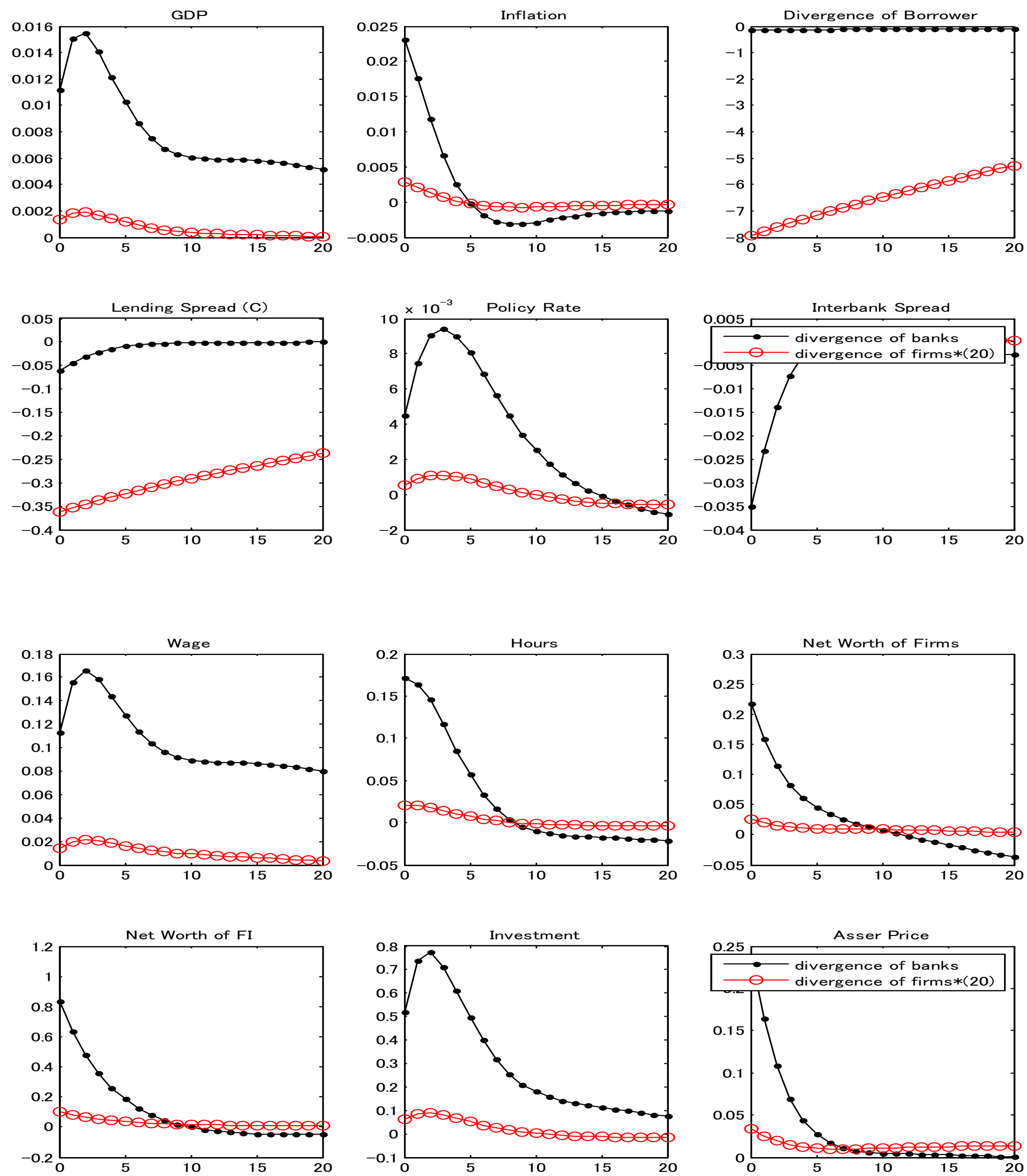

Figure 5: Equilibrium response of macroeconomic variables to an improvement of accuracy in public signal (decrease in a variance of public signal) and consequent decrease in riskiness of borrowers in the interbank market (depicted in black line) and the lending market (depicted in red line). The shock hitting the lending market is twenty times larger than that hitting the interbank market.

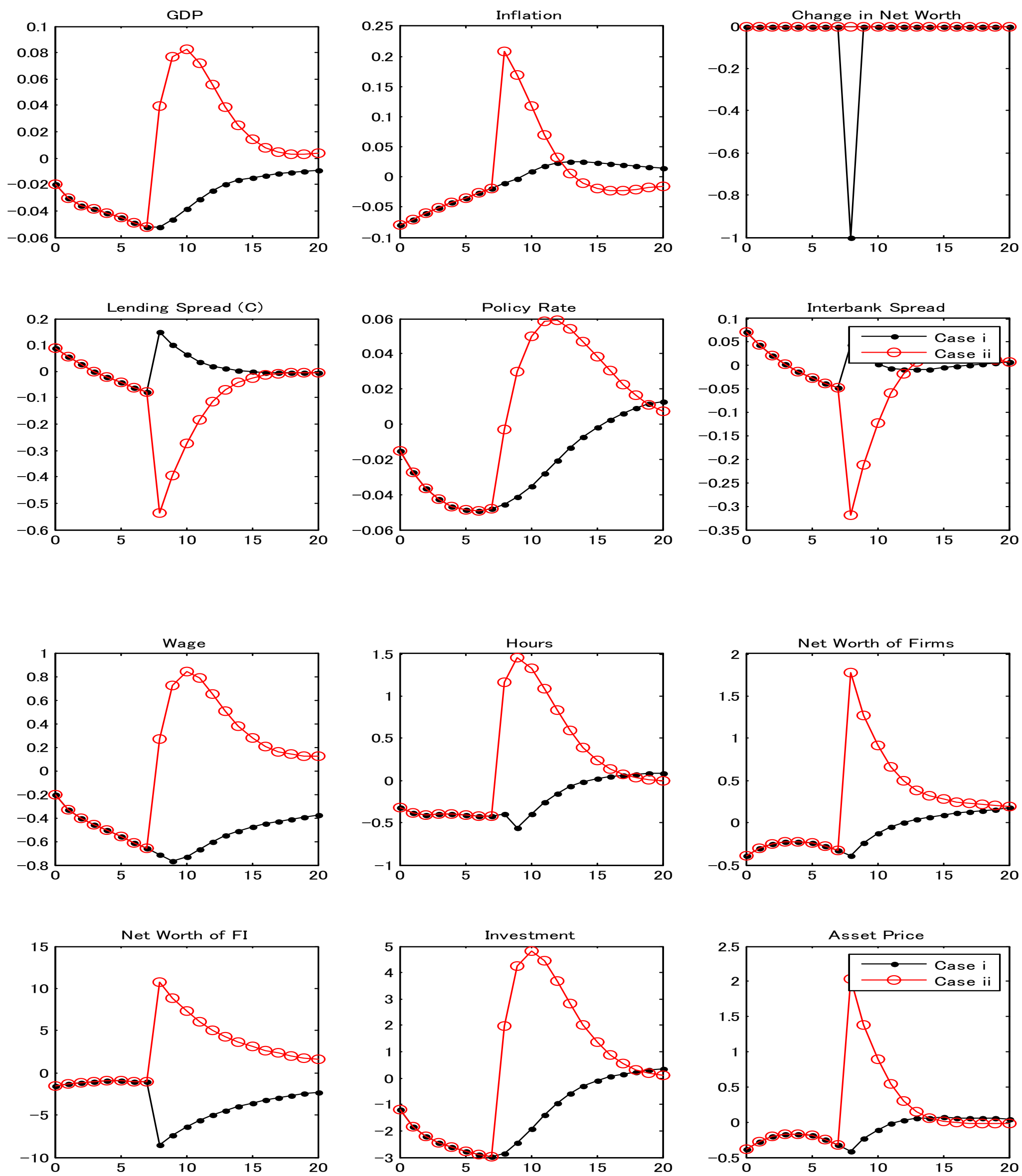

Figure 6: Equilibrium response of macroeconomic variables to an arrival of news regarding future disruption in the FIs' net worth for case i and case ii. The case i is a scenario when the bad news materializes two years after the arrival of the news and the case ii is a scenario when the bad news does not materialize.

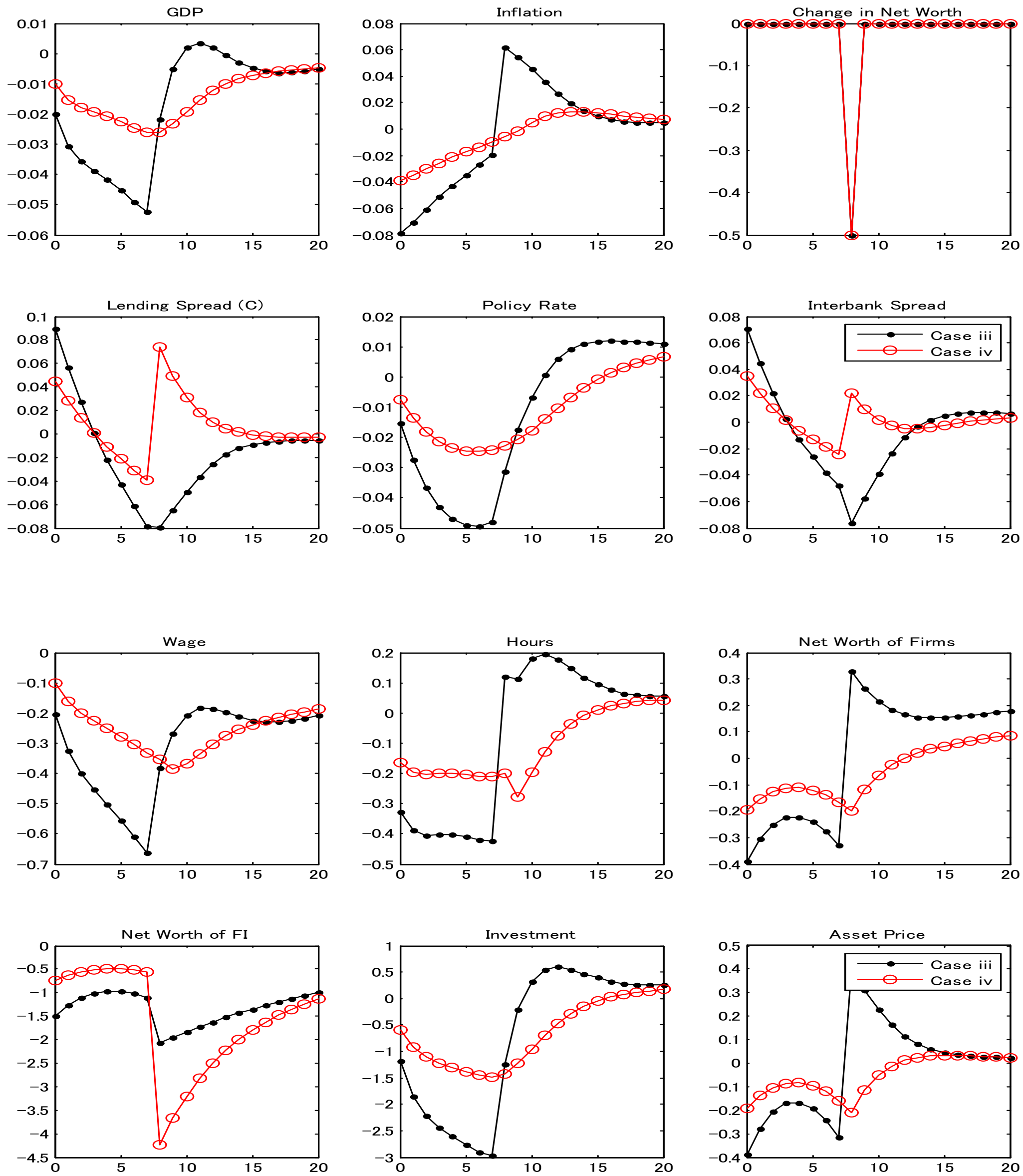

Figure 7: Equilibrium response of macroeconomic variables to an arrival of news regarding future disruption in the FIs' net worth for case iii and case iv. The case iii is a scenario when agents incorrectly forecast the realization of the net worth change and the case iv is a scenario when agents correctly forecast the realization of the net worth change.

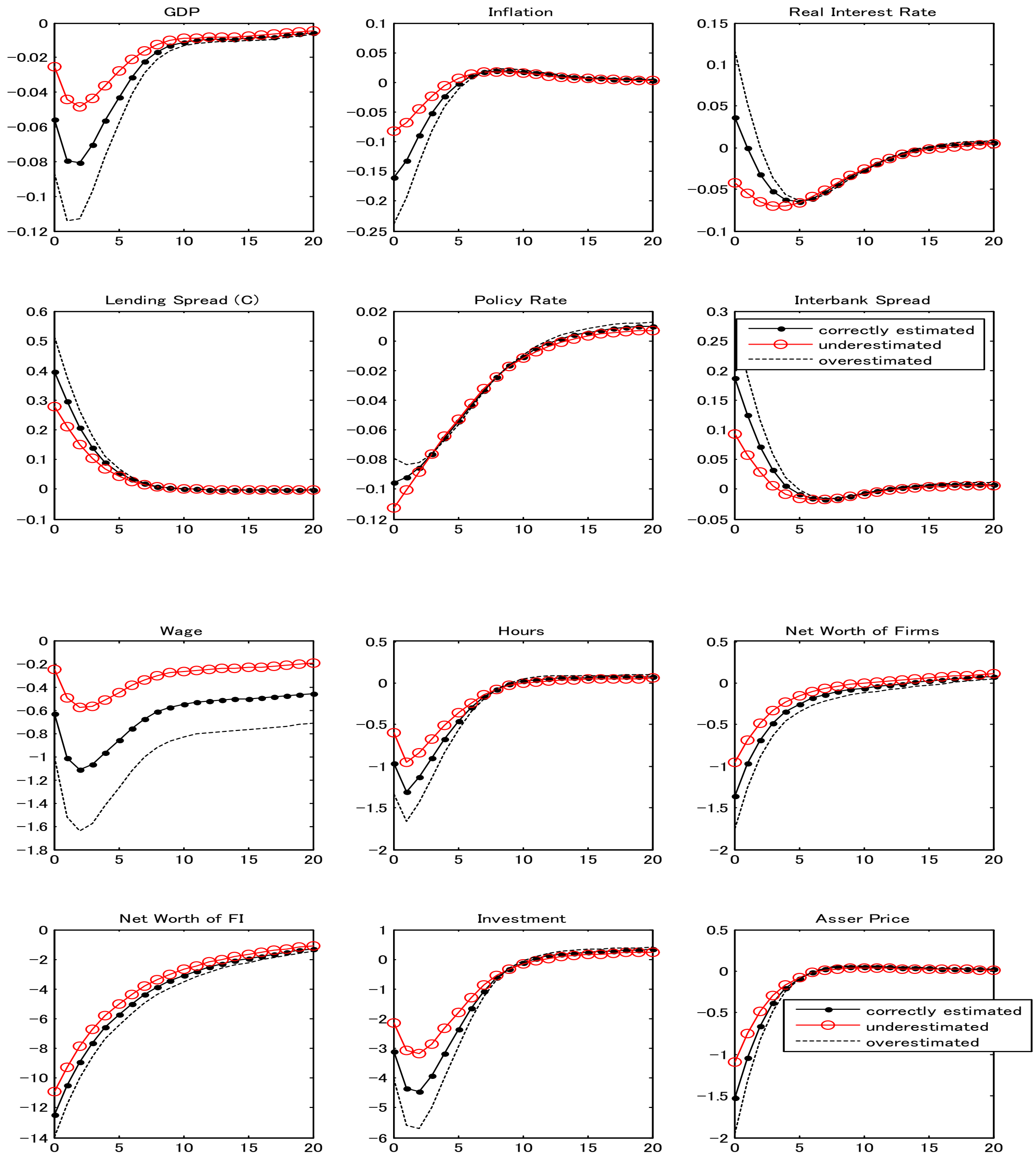

Figure 8: Equilibrium response of macroeconomic variables to a disruption of FIs' net worth under different monetary policy regimes.

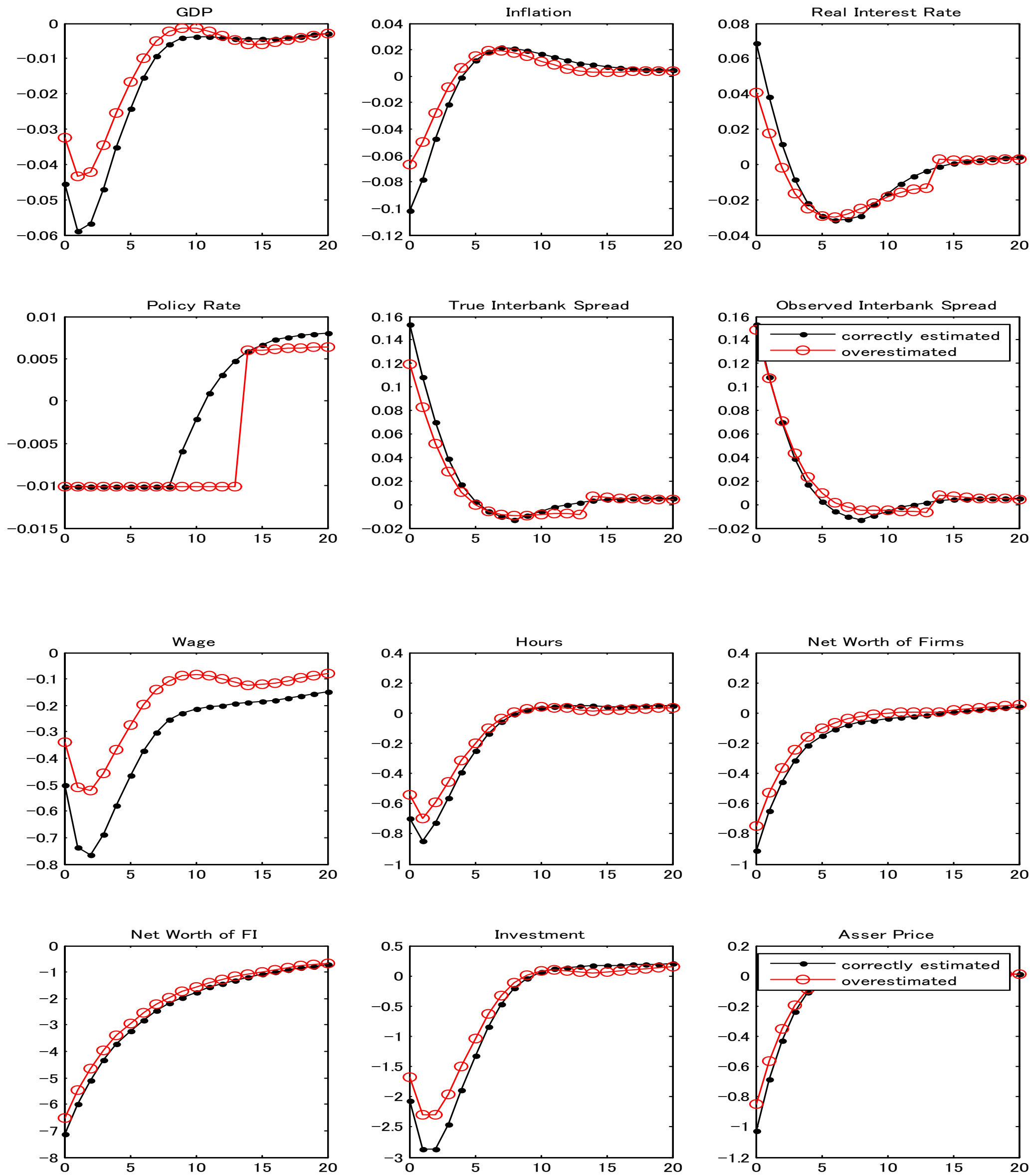

Figure 9: Equilibrium response of macroeconomic variables to a large disruption of FIs' net worth under different monetary policy regimes.