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Real Wage Fluctuations under the Pressure of Financial Crisis*

Kazuhiro Teramoto

Keio University, Faculty of Business and Commerce

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【Abstract】

Soon after the start of the Great Recession following the outbreak of the 2008 financial crisis, real wage in the U.S. decreased sharply, contrary to the lagging adjustment observed during normal times. In this paper, as a key channel to generate this extraordinary situation, we notice the influence of a sudden change in the credit market on the costs of production and wage payments. In order to discuss this effect, we develop a DSGE model incorporating financial shocks and the loan-rate-dependent working capital constraint. We have found that our model, under a negative credit supply shock, generates both a fast and large decline and a lagging decline in real wage, whereas the model without the working capital constraint generates only a lagging decline. Furthermore, comparing with the model in terms of the interest rate for working capital, we also have found that the responses of real wage our model generates are more plausible. Besides, a quantitative analysis has implied that the working capital constraint has substantial influences and can explain the fast and large decline in real wage after the 2008 financial crisis.

Keywords: Real wage, External financial premium, Financial shock, Working capital constraint

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1 Introduction

In this paper, we focus on the fluctuations in wage payments in the U.S. economy, particularly the fast, large decline in real wage during "the Great Recession" arising from the outbreak of the 2008 financial crisis. Conventional business cycle research and business practices suggest that the macroeconomic indicators related to job compensation can be seen as one of the lagging indicators. In business cycle literature, following Erceg *et al.* (2000), which reports that the introduction of nominal stickiness in both prices and wages is essential to implement monetary policy[1], it is standard to incorporate nominal wage stickiness into models being taken to the macro data. Moreover, the earliest work that incorporates it into a medium-scale DSGE model and estimates the model, Christiano, Eichenbaum and Evans (2005) points out that stickiness in nominal wages is stronger than stickiness in prices and that stickiness in nominal wages plays a more important role for the model's performance. The strong stickiness in nominal wages is also thought to be consistent with actual corporate activities that smooth the adjustment of wage payments and of the volume of employment by the rapidly adjusting of working hours. Contrary to these conventional views on the cycles of wage, at the onset of the Great Recession, the real wage in the U.S. decreased very sharply (see figure.1). From 2008:4Q to 2009:1Q, we saw a decline in the growth rate of real wage by more than 2% (per quarter).

Compared to other recessions, the Great Recession is distinguished by the chain of failures of major financial institutions and the malfunction in the financial market. Figure.2 shows the time series for the credit spread calculated as the difference between Moody's seasoned Baa corporate bond yield and yield on the 10-year constant maturity Treasury note. We can see that the credit spread increased from 2008:4Q to 2009:1Q, which peaked in the wake of the Lehman Brothers collapse. After seeing hardships during the Great Recession, a large number of studies have indicated that changes in the state of the credit market have been one of the most important factors that affect real economic activities.

Our motivation is to investigate the key channels that generate the rapid fluctuations in real wage after the changes in the credit markets, but generate conventional dynamics during

[1] Levin *et al.* (2006) uses a medium-scale DSGE model with Calvo-type nominal wage stickiness to discuss the monetary policy regime that maximizes conditional expected social welfare in detail. It also compares the performance of some policy rules and concludes that the rule that responds directly to nominal wage inflation shows better performance.

normal times. To address this, we extend the medium-scale DSGE model in two aspects. The first one is Bernanke, Gertler and Gilchrist (1999)-type financial friction and financial shocks in order to express the condition in the credit market. For making the discussion simple, in our model, we treat the financial crisis as a negative exogenous credit supply shock (increased loan interest rate), which is introduced in Gilchrist, Ortiz and Zakrajšek (2009).[2] The second is the working capital constraint introduced as friction in the markets for the factors of production; that is, firms need to pay a fraction of the wage payments before realizing the sales of products and borrow the advanced payments as working capital. In the literature on the (endogenous) cost channel, this constraint is used frequently and the cost of financing working capital is conventionally assumed to be the nominal risk-free interest rate (Christiano *et al.* (2005), Ravenna and Walsh (2006)). We replace this assumption and assume that the cost of financing working capital relies on the condition in the credit market. (We call "loan-rate-dependent working capital constraint".) The differences in the interest rate of financing working capital are of crucial importance in considering the cost of production after a financial shock. This is because working capital, as based on the conventional assumption, eases the constraint on the cost of production due to the reduction in the policy rate by monetary author. In contrast, working capital in our model tightens the constraint due to a rise in the loan interest rate. Hence, we analyze not only in terms of the magnitude of the constraint but the differences in the interest rate of financing working capital.

We obtain three main findings from the impulse response functions and the quantitative analysis. First, we find that if the working capital constraint exists and relies on the credit market, a negative credit supply shock generates both a fast and large decline and a lagging decline in real wage, but if the working capital constraint does not exist, the shock generates merely lagging decline in real wage. Furthermore, the degree of dependence on working capital has strong influence on the speed and magnitude of the decline. In this regard, our quantitative analysis shows that the degree of dependence on working capital is substantially strong. Second, the differences in the interest rate of financing working capital cause crucial differences in the responses of real wage to a credit supply shock in the existing model and our model: the

[2] The literature on the DSGE framework incorporating the financial sector has witnessed much development both theoretically and empirically. Macroeconomic models that explicate the banking sector's incentive more precisely (such as Gertler and Karadi (2011), Gertler and Kiyotaki (2010), Gertler *et al.* (2012), Hirakata *et al.* (2011), and Mendoza (2010)) help us discuss the source of a credit supply shock.

response which our model induce is more plausible. Third, as for a non-financial shock such as a technology shock or a monetary policy shock, our model induces almost the same response as the model without the working capital constraint and the model with the conventional working capital constraint. This implies that our model does accommodate business cycles during normal times.

The remainder of the paper proceeds as follows. Section 2 describes a DSGE model that focuses on our main two features. Section 3 reports the results of the simulations and the quantitative analysis. Finally, section 4 concludes. The appendices provide details on our model.

2 The Model

We incorporate the endogenous cost channel and the financial market friction proposed by Bernanke *et al.* (1999) into a medium-scale DSGE model, as in Smets and Wouters (2007) and Christiano *et al.* (2005). In this section, first, we illustrate the structure of the financial market friction and the characteristics of a financial shock. Next, we describe the loan-rate-dependent working capital constraint. Using this extension, we are capable of investigating the additional propagation channel of a financial shock. After discussing the core parts of the model, we present a full model for simulation and quantitative analysis.

2.1 Core of The Model

The are eight agents in the model: households, financial intermediaries, entrepreneurs, intermediate goods producers, retailers, final goods producer, capital stock owner, and monetary author. Among these agents, entrepreneurs play an important role. Each entrepreneur holds intermediate goods producers and makes in two kinds of borrowing for the production activity. One is intertemporal borrowing from financial intermediaries for purchase of the capital stock and the other is short-term borrowing[3] to finance working capital. We illustrate these borrowing contracts in detail.

[3]Here, short-term means that the debt is issued and paid back in the same period.

2.1.1 Financial Contract between Financial Intermediaries

We now illustrate the borrowing contract between financial intermediaries for the purchase of the capital stock. Each entrepreneur enters into a financial contract with financial intermediaries and decides the quantities of capital input used by intermediate goods producers who have production technology. It is assumed that when he enters into financial contracts with financial intermediaries, there is asymmetric information between both agencies, as in Bernanke *et al.* (1999).

In period t and after their production activity, Each entrepreneur purchase capital input K_t at the real price Q_t from the capital stock owner. In order to finance the cost of capital purchase, they can partially use their own net worth N_t and borrow the remaining amount B_t. Hence, entrepreneurs' financial statement at end of period t can be expressed as

$$Q_t K_t = B_t + N_t. \tag{1}$$

The left-hand side of (1) represents the total assets held and the right-hand side represents the liability and net worth at the end of period t.

Financial intermediaries obtain funds from households' deposits at the cost of the gross real risk-free interest rate $R_t^n / E_t \pi_{t+1}$ and lend them to entrepreneurs at the gross real loan interest rate $E_t r_{t+1}^e$. Seeing from the side of the entrepreneurs, $E_t r_{t+1}^e$ can be interpreted as a financing costs. Here, for the external financial cost, we apply the costly state verification problem to these debt contracts as in Bernanke *et al.* (1999). It shows that the optimal debt contract under asymmetric information about the uncertainty of borrowers' state requires an external finance premium, which depends on the state of the entrepreneurs' balance sheet. Consequently, the real loan interest rate comprises (real) risk-free interest rate and the external finance premium:

$$E_t r_{t+1}^e = \frac{R_t^n}{E_t \pi_{t+1}} F\left(\frac{N_t}{Q_t K_t}\right) e^{z_t^{efp}}, \tag{2}$$

where the external financial premium function $F(\cdot)$ is a decreasing function of the ratio of net worth to total asset value[4] ($N_t / Q_t K_t$, we call the net worth ratio henceforth); namely, it is an

[4] Strictly speaking, $F(\cdot)$ is a decreasing function of net worth ratio only when $N_t / Q_t K_t \leq 1$. This means that when entrepreneurs have enough funds the N_t to finance the cost of capital ($N_t \geq Q_t K_t$), they never have to access to the external finance. In such a situation, there is no agency problem and the lending interest rate becomes equal to the deposit rate. However, this situation is implausible in the neighborhood of the steady state because the firm's actual net worth ratio is close to 0.50 (the leverage ratio is close to 2). In this paper, all

increasing function of the leverage ratio. The last term, z_t^{efp}, denotes an exogenous shock to the external financial premium. This shock is introduced in Gilchrist *et al.* (2009) and Kaihatsu and Kurozumi (2010) as a "credit supply shock" and can be interpreted as an unanticipated and extraordinary change in the external financial cost beyond the level determined by the optimal debt contract.[5]

At the same time, each entrepreneur sells depreciated capital $((1-\delta(u_t))\,K_{t-1})$ to the capital stock owner at the real price Q_t and settle their borrowings. $\delta(u_t)$ is the capital depreciation rate assumed that a higher utilization rate of capital causes a larger depreciation of capital as in Greenwood *et al.* (1988). The depreciation function $\delta(u_t)$ satisfies $\delta'(\cdot) > 0$, $\delta''(\cdot) > 0$, $\delta(1) = \delta$ and $\mu = \delta'(1)/\delta''(1)$. The ex-post real revenue on a unit of capital owned by each entrepreneur from period $t-1$ to period t is described as

$$r_t^e = \frac{u_t r_t^k + Q_t\,(1-\delta(u_t))}{Q_{t-1}}.$$

Here, r_t^k denotes the marginal production of capital. The first term, $u_t r_t^k$, represents the income gain and the second term, $Q_t\,(1-\delta(u_t))$, represents the capital gain that the entrepreneur obtains from K_{t-1} at the period t. As in Bernanke *et al.* (1999), entrepreneurs are assumed to be risk-neutral. Thus, their demand for the capital is determined so that the expected marginal cost to and the expected marginal return on the purchase of an additional unit of capital are equal. Since to purchasing one unit of additional capital implies an increasing of one unit in the borrowing from financial intermediaries, the expected marginal cost is equivalent to the real loan interest rate. The demand for capital can be described as below:

$$E_t r_{t+1}^e = E_t\left[\frac{u_{t+1} r_{t+1}^k + Q_{t+1}\,(1-\delta(u_{t+1}))}{Q_t}\right]. \tag{3}$$

The entrepreneurs' net worth then evolves as follows:

$$N_t = \eta_t\left\{r_t^e Q_{t-1} K_{t-1} - E_{t-1} r_t^e B_{t-1}\right\} + (1-\eta_t)\,\omega Z_t \tag{4}$$

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equations are log-linearized around the steady state and we discuss the fluctuation in the neighborhood of the steady state, and so $F(\cdot)$ is a decreasing function of the net worth ratio.

[5]Gilchrist, Ortiz, and Zakrajške (2009) defines this shock as "a shock to the supply of credit that captures changes in the efficiency of the financial intermediation process or a shock to the financial sector that boosts the external finance premium beyond the level warranted by the current economic conditions and the current stance of monetary policy."

where $\eta_t \in (0,1)$ is the probability of surviving until the next period. Here, $\eta_t = \eta\, e^{\hat{z}_t^{nw}}/(1+\eta+\eta\, e^{\hat{z}_t^{nw}})$, where $\hat{z}_t^{nw}$ represents a shock to the probability of surviving and η is the steady state survival rate of entrepreneurs. In addition, ωZ_t is the (lump-sum) transfer to newly entering entrepreneurs from entrepreneurs who die at period t. (Z_t is a device to consider the growth trend described later.)

2.1.2 Working Capital and Endogenous Cost Channel

In this model, the key structure that generates the endogenous cost channel is the cost of working capital in the production process. Each entrepreneur is assumed to have to pay a fraction of the labor compensation before he receives the income from the sales of his products, and then has to borrow the advanced payments as working capital. This structure is analogous to Christiano *et al.* (2005) and Ravenna and Walsh (2006).[6] However, the type of working capital in our model is different from that in the previous works in that interest rate required to finance working capital is assumed to be the nominal loan interest rate $E_t R_{t+1}^e \equiv E_t r_{t+1}^e E_t \pi_{t+1}$ rather than the nominal risk-free interest rate R_t^n. This assumption enables us to capture the effect of the financial market on the cost for the input factors of production. In this paper, we call this type of working capital constraint, the "loan-rate-dependent working capital model," and, call the working capital constraint depending on the nominal risk-free interest rate, the "conventional working capital model."

Intermediate goods producers held by entrepreneurs have production technology give by

$$Y_t^{Int} = (Z_t l_t)^{1-\alpha} (u_t K_{t-1})^{\alpha} - \Phi Z_t \,, \tag{5}$$

where Y_t^{Int} is the identical intermediate goods output sold to retailers and l_t and $u_t K_{t-1}$ are labor input and utilized capital input at period t, respectively. The parameter $\alpha \in (0,1)$ is capital's share of output and $\Phi > 0$ is a fixed cost of production. Z_t represents the level of technological progress with the stochastic process:

$$\log Z_t - \log Z_{t-1} = \log z_{ss} + \varepsilon_t^z \,, \tag{6}$$

where z_{ss} is the gross growth trend rate and ε_t^z is the exogenous technology shock.

[6] Ravenna and Walsh (2006) estimate the New Keynesian Phillips Curve(NKPC) with the working capital constraint introduced in Christiano *et al.* (2005) by using the limited information approach (estimate only the modified NKPC by GMM as in Galí and Gertler (1999) and Galí *et al.* (2001)).

Each entrepreneur minimizes the cost for the input of factors of production including the the cost of financing working capital given by

$$\min_{l_t,k_t} \; \left(1-\varphi+\varphi\, E_t R^e_{t+1}\right) W_t l_t + r^k_t u_t K_{t-1},$$

under a Cobb-Douglas production function (5). Here, there are two differences from the "conventional working capital" as in Christiano *et al.* (2005). The first one is the interest rate required of financing the working capital. The second is the parameter φ. This parameter denotes the degree of dependence on working capital.[7] As such, $(1-\varphi)\, W_t l_t$ represents the cost of labor inputs without advance payment and $\varphi\, E_t R^E_{t+1} W_t l_t$ represents the cost of labor inputs required to pay in advance. For example, $\varphi = 1$ corresponds to the case where the whole cost of labor inputs must be paid and financed at the beginning of the period. Conversely, in the case of $\varphi = 0$, advanced financing is not needed at all. Let $\overline{W}_t$ denote the effective price of a labor input, which is described as $\overline{W}_t \equiv (1-\varphi+\varphi\, E_t R^e_{t+1}) W_t$, then, the cost-minimization condition is

$$\frac{u_t K_{t-1}}{l_t} = \frac{\alpha}{1-\alpha} \frac{\overline{W}_t}{r^k_t}, \tag{7}$$

and the real marginal cost can be derived as

$$mc_t = \left(\frac{\overline{W}_t}{(1-\alpha)Z_t}\right)^{1-\alpha} \left(\frac{r^k_t}{\alpha}\right)^{\alpha}. \tag{8}$$

Then, log-linearizing (8), we can have

$$\widetilde{mc}_t = (1-\alpha)\tilde{w}_t + \alpha \tilde{r}^k_t + (1-\alpha)\frac{\varphi R^e_{ss}}{1-\varphi+\varphi\, R^e_{ss}} E_t \widetilde{R}^e_{t+1}, \tag{9}$$

where subscript ss signifies the steady state of the certain variable. From (9), it is clear that $E_t R^e_{t+1}$ and φ play a crucial role in the marginal cost of production. When $\varphi = 0$, the marginal cost of production is independent of the financial market (equivalent to the ordinary DSGE model), and the larger the value of φ is, the more susceptible is it to the condition of the credit market.

In the conventional working capital model, the effective price of the labor input, $\overline{W}_t$, is replaced by $\overline{W}_t \equiv (1-\varphi+\varphi R^n_t) W_t$ and (9) is altered as

$$\widetilde{mc}_t = (1-\alpha)\tilde{w}_t + \alpha \tilde{r}^k_t + (1-\alpha)\frac{\varphi R^n_{ss}}{1-\varphi+\varphi R^n_{ss}} \widetilde{R}^n_t.$$

[7] This is also done in Christiano, Trabandt and Walentin (2010). It incorporates the conventional working capital and the degree of dependence on working capital into the monetary DSGE model and discusses about the relation between the Taylor principle and the the degree of dependence on working capital.

The different attributes of the working capital constraint in the loan-rate-dependent working capital model are as follows: the cost of labor input is affected by the nominal risk-free interest rate and the external financial premium that depends on the state of the firm's balance sheet and exogenous shock. In contrast, in the conventional working capital model ,the cost of labor input is affected by only the nominal risk-free interest rate.

2.2 Rest of The Model

We now give the other agents' incentive, market clearing, and growth trend in order to develop the full model.

2.2.1 Households

There are a continuum of households indexed by $h \in [0,1]$. Each household h lives infinity, purchases goods to consume $C_t(h)$, and supplies its differentiated labor services, $l_t(h)$ to entrepreneurs under monopolistic competition, and makes deposits, $D_t(h)$ in financial intermediaries. Households maximize the expected utility function

$$E_0 \sum_{t=0}^{\infty} \beta^t e^{z_t^b} \left\{ \frac{(C_t(h) - \theta\, C_{t-1}(h))^{1-\sigma}}{1-\sigma} - \frac{Z_t^{1-\sigma} e^{z_t^{\Xi}} l_t(h)^{1+\chi}}{1+\chi} \right\}$$

subject to the budget constraint and the demand schedule for household h's differentiated labor services:

$$C_t(h) + \frac{D_t(h)}{P_t} = W_t(h)\, l_t(h) + R_{t-1}^n \frac{D_{t-1}(h)}{P_t} + T_t(h), \tag{10}$$

$$l_t(h) = \left(\frac{W_t(h)}{W_t} \right)^{-\theta_t^w} l_t, \tag{11}$$

where E_t is the expectation operator conditional on information sets in period t, $\beta \in (0,1)$ is the subjective discount factor, $\theta \in (0,1)$ is the degree of internal habit persistence in consumption, χ is the inverse of Frisch labor supply elasticity, P_t is the price of the goods, $W_t(h)$ is the real wage, R_t^n is the gross nominal deposit rate, and T_t consists of lump-sum tax and profits received from firms. Moreover, z_t^b denotes an intertemporal preference shifter (called a preference shock, henceforth) and z_t^{Ξ} denotes a shock to labor supply; both of these follow the AR(1) process. $\theta_t^w > 1$ in (11) represents the time-varying elasticity of substitution between differentiated labor services input.

The first-order condition with respective to consumption and deposit is given by

$$\Lambda_t = e^{z_t^b}(C_t - \theta C_{t-1})^{-\sigma} - \beta\theta E_t e^{z_{t+1}^b}(C_{t+1} - \theta C_t)^{-\sigma}, \tag{12}$$

$$\Lambda_t = \beta E_t \left[\Lambda_{t+1}\frac{R_t^n}{\pi_{t+1}}\right], \tag{13}$$

where Λ_t is a Lagrangian multiplier associated with the budget constraint, which can be interpreted as the marginal utility of consumption at period t from (12).

We now describe the each household's labor supply and formulation of aggregate wage. Following Erceg *et al.* (2000), we incorporate the Calvo-type nominal stickiness on wage, and following Smets and Wouters (2003, 2007), we allow for an inertia of nominal wage adjustment. The labor union combines differentiated labor services into an aggregate labor input l_t by the CES function $l_t = \left(\int_0^1 l_t(h)^{(\theta_t^w-1)/\theta_t^w} dh\right)^{\theta_t^w/(\theta_t^w-1)}$, and sells it to entrepreneurs at the corresponding aggregate real wage give by

$$W_t = \left(\int_0^1 W_t(h)^{1-\theta_t^w} dh\right)^{\frac{1}{1-\theta_t^w}}. \tag{14}$$

Household h's real wage is set on a staggered basis à la Calvo (1983). In each period, a fraction $1 - \xi_w \in (0, 1)$ of wages is reoptimized, while the remaining fraction ξ_w of wages is renewed by the indexation rule that both the (steady-state) gross growth trend rate z_{ss}, and a weighted average of past inflation π_{t-1} and steady state inflation π are added to the past (nominal) wage. Therefore, real wage of j periods in the future, which has not been reoptimized for the next j periods, is

$$W_{t+j}(h) = z_{ss}^j W_t(h) \prod_{k=1}^{j} \left\{ \left(\frac{\pi_{t+k-1}}{\pi}\right)^{\gamma_w} \frac{\pi}{\pi_{t+k}} \right\}$$

Hence, a households' optimization problem on wage setting is to maximize

$$E_t \sum_{j=0}^{\infty} (\beta\xi_w)^j \left[\Lambda_{t+j} l_{t+j}(h) z_{ss}^j W_t(h) \prod_{k=1}^{j} \left\{ \left(\frac{\pi_{t+k-1}}{\pi}\right)^{\gamma_w} \frac{\pi}{\pi_{t+k}} \right\} - \frac{e^{z_{t+j}^b} Z_{t+j}^{1-\sigma} e^{z_{t+j}^{\Xi}} l_{t+j}(h)^{1+\chi}}{1+\chi}\right]$$

subject to

$$l_{t+j}(h) = \left[\frac{z_{ss}^j W_t(h)}{W_{t+j}} \prod_{k=1}^{j} \left\{ \left(\frac{\pi_{t+k-1}}{\pi}\right)^{\gamma_w} \frac{\pi}{\pi_{t+k}} \right\}\right]^{-\frac{1+\lambda_{t+j}^w}{\lambda_t^w}} l_{t+j}.$$

Let $\lambda_t^w \equiv 1/(\theta_t^w - 1)$ denote the wage markup. The first-order condition of $W_t(h)$ leads to the reoptimized price W_t^o given as

$$E_t \sum_{j=0}^{\infty} \left[\begin{array}{l} (\beta\xi_w)^j \dfrac{1}{\lambda_{t+j}^w} \Lambda_{t+j} l_{t+j} \left[\dfrac{z_{ss}^j W_t^o}{W_{t+j}} \displaystyle\prod_{k=1}^{j} \left\{ \left(\dfrac{\pi_{t+k-1}}{\pi} \right)^{\gamma_w} \dfrac{\pi}{\pi_{t+k}} \right\} \right]^{-\frac{1}{\lambda_{t+j}^w}-1} \\ \times \left\{ \begin{array}{l} z_{ss}^j W_t^o \prod_{k=1}^{j} \left\{ \left(\frac{\pi_{t+k-1}}{\pi} \right)^{\gamma_w} \frac{\pi}{\pi_{t+k}} \right\} - \left(1 + \lambda_{t+j}^w \right) \dfrac{e^{z_t^{\Xi}} e^{z_t^b} Z_{t+j}^{1-\sigma}}{\Lambda_{t+j}} \\ \times \left(l_{t+j} \left[\frac{z_{ss}^j W_t^o}{W_{t+j}} \prod_{k=1}^{j} \left\{ \left(\frac{\pi_{t+k-1}}{\pi} \right)^{\gamma_w} \frac{\pi}{\pi_{t+k}} \right\} \right]^{-\frac{1}{\lambda_{t+j}^w}-1} \right)^{\chi} \end{array} \right\} \end{array} \right] = 0 \,. \qquad (15)$$

Moreover, we can rewrite the aggregate real wage as.

$$W_t^{-\frac{1}{\lambda_t^w}} = (1-\xi_w) \left(W_t^{o\,-\frac{1}{\lambda_t^w}} + \sum_{j=1}^{\infty} \xi_w^j \left[z^j W_{t-j}^o \prod_{k=1}^{j} \left\{ \left(\frac{\pi_{t-k}}{\pi} \right)^{\gamma_w} \frac{\pi}{\pi_{t-k+1}} \right\} \right]^{-\frac{1}{\lambda_t^w}} \right) . \qquad (16)$$

2.2.2 Retailers and Final Goods Producer (Pricing)

There are a continuum of retailers indexed by $r \in [0,1]$, which is characterized by technology to differentiate identical intermediate goods at no cost. Each retailer r purchases identical intermediate goods from entrepreneurs at price mc_t, differentiates them, and sells the differentiated intermediate goods $Y_t(r)$ to the final goods producer under monopolistic competition. Then, retailers set the prices of their goods $P_t(r)$ on a staggered basis à la Calvo (1983). In each period, a fraction $1-\xi_p \in (0,1)$ of the retailers reoptimizes prices in the face of final goods producer's demand for differentiated goods (as given in (18)), while the remaining fraction ξ_p of retailers indexes prices to a weighted average of past inflation π_{t-1} and steady state inflation π, which is a device to consider an inertia of inflation. Therefore, retailers' prices of j period ahead, which has not been reoptimized for the next j periods in the future, is

$$P_{t+j}(r) = \pi_{t+j-1}^{\gamma_p} \pi^{1-\gamma_p} P_{t+j-1}(r) = P_t(r) \prod_{k=1}^{j} \left\{ \left(\frac{\pi_{t+k-1}}{\pi} \right)^{\gamma_p} \pi \right\} \ ,$$

where $\gamma_p \in [0,1]$ is the relative weight on the past inflation. Each retailer has the opportunity to revise prices in the current period to maximize conditional expected profits

$$E_t \sum_{j=0}^{\infty} \xi_p^j \left(\beta^j \frac{\Lambda_{t+j}}{\Lambda_t} \right) \left[\frac{P_t(r)}{P_{t+j}} \prod_{k=1}^{j} \left\{ \left(\frac{\pi_{t+k-1}}{\pi} \right)^{\gamma_p} \pi \right\} - mc_{t+j} \right] Y_{t+j}(r)$$

subject to

$$Y_{t+j}(r) = \left[\frac{P_t(r)}{P_{t+j}} \prod_{k=1}^{j} \left\{ \left(\frac{\pi_{t+k-1}}{\pi} \right)^{\gamma_p} \pi \right\} \right]^{-\theta_t^p} Y_{t+j} \ ,$$

where $\beta^j \Lambda_{t+j}/\Lambda_t$ is the stochastic discount factor between period t and period $t+j$ and $\theta_t^p > 1$ is the time-varying elasticity of substitution between differentiated intermediate goods input. Let $\lambda_t^p \equiv 1/(\theta_t^p - 1)$ denote the price markup. The first-order condition leads to the reoptimized price p_t^o given as

$$E_t \sum_{j=0}^{\infty} \left[\begin{array}{c} (\beta\xi_p)^j \dfrac{\Lambda_{t+j}}{\Lambda_t} \dfrac{1}{\lambda_{t+j}^p} \left[p_t^o \prod_{k=1}^{j} \left\{ \left(\dfrac{\pi_{t+k-1}}{\pi} \right)^{\gamma_p} \dfrac{\pi}{\pi_{t+k}} \right\} \right]^{-\frac{1+\lambda_t^p}{\lambda_t^p}} Y_{t+j} \\ \times \left[p_t^o \prod_{k=1}^{j} \left\{ \left(\dfrac{\pi_{t+k-1}}{\pi} \right)^{\gamma_p} \dfrac{\pi}{\pi_{t+k}} \right\} - \left(1 + \lambda_{t+j}^p\right) mc_{t+j} \right] \end{array} \right] = 0. \tag{17}$$

We turn to the final goods producer's behavior. The final goods producer purchases the quantities of integrated intermediate goods inputs under the each intermediate goods price $P_t(r)$ so as to maximize profit $P_t Y_t - \int_0^1 P_t(r) Y_t(r) dr$ subject to the CES production technology $Y_t = \left(\int_0^1 Y_t(r)^{(\theta_t^p - 1)/\theta_t^p} dr \right)^{\theta_t^p/(\theta_t^p - 1)}$. The first-order condition for profit maximization leads to the final goods producer's demand for intermediate-goods r:

$$Y_t(r) = \left(\frac{P_t(r)}{P_t} \right)^{-\theta_t^p} Y_t \ ; \tag{18}$$

then, under perfect competition, the final goods pricing rule is given as

$$P_t = \left(\int_0^1 P_t(r)^{1-\theta_t^p} dr \right)^{\frac{1}{1-\theta_t^p}} . \tag{19}$$

Using p_t^o, this aggregate price can be written as

$$1 = (1 - \xi_p) \left((p_t^o)^{-\frac{1}{\lambda_t^p}} + \sum_{j=1}^{\infty} \xi_p^j \left[p_{t-j}^o \prod_{k=1}^{j} \left\{ \left(\frac{\pi_{t-k}}{\pi} \right)^{\gamma_p} \frac{\pi}{\pi_{t-k+1}} \right\} \right]^{-\frac{1}{\lambda_t^p}} \right) . \tag{20}$$

2.2.3 Capital Stock Owner

The capital stock owner purchases capital $(1 - \delta(u_t)) K_{t-1}$ back at price Q_t from entrepreneurs and invests. With the quadratic investment adjustment cost $S(I_t/I_{t-1} z_{ss})$, this investment is accumulated as the next period's capital stock:

$$K_t = (1 - \delta(u_t)) K_{t-1} + I_t \left[1 - S\left(\frac{I_t}{I_{t-1} z_{ss}} \right) \right] , \tag{21}$$

where $S(\cdot)$ in the last term on the right-hand side satisfies

$$S\left(\frac{I_t}{I_{t-1} z_{ss}} \right) = \left(\frac{I_t}{I_{t-1} z_{ss}} - 1 \right)^2 / 2\zeta. \tag{22}$$

The capital stock owner chooses investment expenditure to maximize discounted profit

$$E_t \sum_{j=0}^{\infty} \left(\beta^j \frac{\Lambda_{t+j}}{\Lambda_t} \right) \left[Q_t \left(K_t - (1 - \delta(u_t)) K_{t-1} \right) - I_t \right] \tag{23}$$

subject to the capital accumulation process (21). We obtain the first-order condition given by

$$1 = Q_t \left[1 - S \left(\frac{I_t}{I_{t-1} z_{ss}} \right) - S' \left(\frac{I_t}{I_{t-1} z_{ss}} \right) \frac{I_t}{I_{t-1} z_{ss}} \right] + \beta E_t \frac{\Lambda_{t+1}}{\Lambda_t} Q_{t+1} S' \left(\frac{I_{t+1}}{I_t z_{ss}} \right) \left(\frac{I_{t+1}}{I_t z_{ss}} \right)^2 \frac{1}{z_{ss}}. \tag{24}$$

The optimal capital utilization rate is determined from the maximization of entrepreneurs' expect return to capital (3):

$$r_t^k = Q_t \delta' (u_t) \ . \tag{25}$$

2.2.4 Monetary Author

The monetary author conducts monetary policy by adjusting the nominal interest rate R_t^n, based on the Taylor (1993)-style monetary policy rule. Thus, the nominal interest rate is adjusted in response to the inflation and the output gap along with interest rate smoothing as follows:

$$\log R_t^n = \phi_r \log R_{t-1}^n + (1 - \phi_r) \left\{ \log R_{ss}^n + \phi_\pi \left(\frac{1}{4} \sum_{j=0}^{3} \log \frac{\pi_{t-j}}{\pi} \right) + \phi_y \log \frac{Y_t}{Y_t^{pot}} \right\} + z_t^r \ , \tag{26}$$

where $\phi_r \in [0, 1)$ is parameter as the degree of interest rate smoothing, and $\phi_\pi, \phi_y (> 0)$ show the degree of the response to inflation and output gap, respectively. z_t^r denotes the monetary policy shock that follows an AR(1) process. The output gap $\log(Y_t / Y_t^{pot})$ is defined as the deviation of the real yields from the potential output, which is measured by the production function approach.

$$Y_t^{pot} = (Z_t l_*)^{1-\alpha} (k_* Z_{t-1})^\alpha - \Phi Z_t. \tag{27}$$

2.2.5 Goods Market Clearing

The market clearing condition for the goods market is given by

$$Y_t = C_t + I_t + g Z_t e^{z_t^g}, \tag{28}$$

where the last term denotes the exogenous demand components defined as demand for goods other than for consumption and investment. Government expenditure and net export account for it and we capture it as an exogenous demand shock following an AR(1) process.

2.2.6 Stationary Equilibrium and Log-linearized Equilibrium conditions

In the model, since the levels of technology has unit roots with drift, some variables regarding other real economic activities have growth trend. In order to satisfy stationarity, we need to rewrite equilibrium conditions using detrended variables: $y_t = Y_t/Z_t$, $y_t^{pot} = Y_t^{pot}/Z_t$, $c_t = C_t/Z_t$, $i_t = I_t/Z_t$, $b_t = B_t/Z_t$, $n_t = N_t/Z_t$, $w_t = W_t/Z_t$, $k_t = K_t/Z_t$, and $\lambda_t = \Lambda_t Z_t^{\sigma}$. After we obtain the stationary equilibrium and the steady state condition, we log-linearly approximate each equations around the steady state. The stationary equilibrium and the log-linearized equilibrium conditions are listed in the Appendix in detail.

3 Simulation and Quantitative Analysis

In this section, we now use the DSGE model we have developed in the previous section to implement an analysis by calibration. We first mention the values of the parameters we set and then report the results of the impulse responses to various shocks. In the simulation experiment, the most serious concern is to investigate the responses of real wage after a shock corresponding to a financial crisis has happened. With respect to the shock, we regard a (negative) credit supply shock as a financial crisis derived from the stagnation of funds supply, such as the deterioration of financial institutions' lending stance, malfunction of the interbank market, and increase in the uncertainty in the banking system because these negative events in the financial market lead to the lowering of efficiency in the financial intermediary processes and considerably raise the external financial premium. Thus, we examine the impulse response functions to a negative credit supply shock to simulate a financial crisis and those to non financial shocks to simulate for normal times.

3.1 Parameterization

First, we need to assign values for the parameters. As a rule, the basic structural parameters (including $\alpha, \delta, \lambda_p, \lambda_w, \sigma, \theta, \chi, 1/\zeta, \mu, \phi, \gamma_w, \xi_w, \gamma_p, \xi_p, \phi_r, \phi_\pi$, and ϕ_y) are set to the values based on preceding empirical results, especially Justiniano *et al.* (2010) and Smets and Wouters (2007) that estimate medium-scale DSGE model similar to our model using the Bayesian approach; three financial parameters (including $\mu_e, \eta, n/k$, and R^e_{ss}) are based on Bernanke *et al.* (1999). Additionally, we set some steady values close to their data means. A list of the values we set are reported in Table 1.

The capital share α is set to 0.27. The capital share is traditionally assigned close to 1/3, but some estimation results of the medium-scale DSGE model show that the capital share is less than 0.3. Based on Justiniano *et al.* (2010), the quarterly depreciation rate of capital δ is 0.025, steady-state price mark-up λ_p is 0.25, and steady-state wage mark-up λ_w is 0.15. For six parameters related to household's preference and technology (inverse elasticity of intertemporal substitution σ, degree of consumption habit formation θ, inverse elasticity of labor supply (Frisch elasticity) χ, elasticity of the adjustment cost for investment $1/\zeta$, elasticity of the adjustment cost for utilization μ, and the share of fixed costs in production $\Phi/y = \phi$), we use reasonable conventional values. We now describe four parameters most relevant in the dynamics of inflation and wage. The ratios of indexation to the past inflation rates for both wage setting and price setting (γ_w, γ_p) are set as 0.33. This value is considerably consistent with the preceding estimation results that report less than 0.5 for these parameters. Besides, we take the Calvo parameter for wage setting (probability of no wage revision, ξ_w) as 0.50 and take that for price setting (probability of no price revision, ξ_p) as 0.75, which imply that the average durations for which wage and price are not optimized are two periods (a half year) and four periods (a year), respectively. For the steady-state ratio of exogenous demand to output g/y, steady-state gross inflation rate π_{ss}, and steady-state gross nominal risk-free interest rate R^n_{ss}, we take the values close to historical averages.

The values of some parameters related to the financial contract are consistent with Bernanke *et al.* (1999) and the empirical results in Christensen and Dib (2008). We take the steady-state elasticity of the external financial premium μ_e as 0.05, a value often assigned for this parameter. (For example, see Fukunaga (2002).)[8] Moreover, Christensen and Dib (2008) estimates this parameter and points out that the estimated value is not statistically different from 0.05. We set the steady-state ratio of net worth n/k as 0.50, survival rate of entrepreneurs η as 0.973 and steady-state external financial premium ($R^e_{ss} - R^n_{ss}$) as 200 basis points annually. The data for our period (from 1985:1Q to 2012:2Q) gives similar values.

The remaining parameters for which we have to assign values are related to the monetary policy rule. We set them with reference to Bayesian estimation results or single-equation estimation results as in Clarida *et al.* (1999) (ϕ_r=0.7, ϕ_π=1.8, ϕ_y=0.125).

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[8]This value is calculated using micro-foundation consistently from a reasonable set of estimates for the business failure rate and bankruptcy (monitoring) costs in Bernanke *et al.* (1999). They suggest that the figure will be approximately 0.05 to 0.066 (see Gilchrist (2004)).

3.2 Impulse Response Functions

We now examine the responses to three types of shocks: a credit supply shock, a technological trend shock, and a monetary policy shock. Figures 3, 4, and 5 show the responses of six endogenous variables, real wage, worked hours, real economic growth rate, inflation rate, external financial premium, and real asset prices, for each exogenous shocks.[9] Our main interest is in the response of real wage to a credit supply shock and how the responses are different between the types of working capital constraint. To make the differences clear, we make a comparison of responses between no working capital constraint case, conventional working capital case, and loan-rate-dependent working capital case. Furthermore, to verify that the model with the loan-rate-dependent working capital also generates an ordinary business cycle to non-financial shocks, we examine the responses to the representative two non-financial shocks, a technological trend shock, and a monetary policy shock.

First, we examine the responses to a credit supply shock. Here, we suppose exogenous events that raise the external financial premium by 1% beyond the level the state of firm's balance sheet implies. The results are illustrated in Figure 3. The black solid lines show the responses in the model without working capital, when $\varphi = 0$. According to this lines, it is clear that real wage will drop slowly and this is inconsistent with the actual data. The red solid and red dotted lines show the responses of the model with the loan-rate-dependent working capital with the dependency rate being 75% and 25%, respectively, while the gray solid and gray dotted lines show the the same for the conventional working capital model. First, we can find the differences in the directions of the responses of real wage by the differences in the types of working capital. This is because when a credit supply shock hits the economy, the nominal risk-free interest rate and nominal loan rate react in opposite directions along the following mechanisms. A credit supply shock raises the external financial premium, and this leads to a decline in the aggregate demand via a reduction in investments and then a lower inflation rate. The monetary author following the monetary policy rule, lowers the nominal risk-free interest rate. Hence, the nominal risk-free interest rate goes down, and in contrast, the external financial premium increases. The nominal loan rate, which consists of the nominal risk-free interest rate and the external financial premium, is determined relying on the relative strength of both. In this case, the rise in the external financial premium exceeds the fall in the

[9] These are measured as the percentage of deviation from the steady state economy.

nominal risk-free interest rate and then the nominal loan rate increases. This means that after a credit supply shock, the cost of financing the advanced payment to workers goes down at the case of conventional working capital but up at the case of the loan-rate-dependent working capital. These generate the differences in the responses of real wage. Second, we focus on the responses of real wage in the case of the loan-rate-dependent working capital. Unlike in the case of no working capital, the reduction in real wage happens in two stages: (1) in roughly the first ten periods after the shock hits (large, fast decline) and (2) in the periods afterward (lagging decline similar to in the no working capital case). Moreover, the scale of the first stage is subject to the degree of dependence on working capital φ: the stronger the dependence is, the larger is the decline in the first stage.

The responses of a positive technological trend shock are shown in Figure 4. The most remarkable point is that regardless of the type of working capital or the degree of dependence on it, in fact, regardless of whether or not there exists working capital channel, we cannot find much differences in the responses of the endogenous variables. This is because a technological trend shock does not affect inflation rate much, and thus the changes in the nominal risk-free interest rate controlled by a monetary policy are small and the changes in the cost of financing working capital are negligible. Moreover, since a technological trend shock does not directly have large influences on the state of a firm's balance sheet so as to fluctuate the loan rate. The differences in the type of working capital also does not yield significant dissimilarities. These suggest that our model's responses for a technological trend shock are almost similar to those of a model without the working capital channel.

The responses to a monetary policy shock shown in Figure 5 lead to a similar suggestion to those to a technological trend shock. Or, the differences in the types of working capital or the degree of the dependence on it do not generate much differences in the responses of the endogenous variables.

According to the impulse response analysis using the calibrated DSGE model, we have found that the model with loan-rate-dependent working capital could generate a fast, large decline in real wage after a credit supply shock and that the scale of the decline is affected by the degree of dependence on working capital (φ). In addition to this, our extensions of the model do not change the responses for other shocks. These findings raises a new issue: how large is the parameter φ. To address this question, we use actual macro-economic data to estimate some parameters including φ in the next subsection.

3.3 Quantitative Analysis

We now estimate some of the structural parameters using Bayesian methods. The following two subsections describe the data and strategy for estimating our model.

3.3.1 Data Set

We use nine quarterly time series from 1985:1Q to 2012:2Q in the estimation. Seven of these are key macroeconomic time series and are the same as those in Smets and Wouters (2007): the growth rate of output ($100\Delta \log Y_t$), the growth rate of consumption ($100\Delta \log C_t$), the growth rate of investment ($100\Delta \log I_t$), the growth rate of real wage ($100\Delta \log W_t$), inflation rate ($100 \log \pi_t$), total hours worked (($100 \log l_t$) translated into the scale of the deviation from the steady state), and short-term nominal interest rate ($100 \log R_t^n$). The others are the two time series related to the financial condition: external financial premium ($100 \log Spread_t$) and the ratio of net worth to total asset value ($100 \log N_t/Q_t K_t$).

The data for the external financial premium is calculated as Moody's Seasoned Baa Corporate Bond Yield minus the term premium and the Effective Federal Funds Rate (called the FF rate, henceforth). Here, we expediently regard the term premium as the yield spread between Ten-Year Treasury Constant Maturity Rate and the FF rate. The ratio of net worth to total asset value is the Board of Governors of the Federal Reserve System's Total Net Worth of Nonfarm Nonfinancial Corporate Business dividend from the Total Assets of Nonfarm Nonfinancial Corporate Business. More details about the data are given in Table 2.

We define $\mathbf{y_t}$ as the observed data vector, let $\mathbf{\hat{s}_t}$ denote a column vector of the unobservable endogenous variable, and let $\hat{\varepsilon}_\mathbf{t}$ denote a column vector of the endogenous $i.i.d$ disturbances. Using these vectors, we can describe the state space representation as follows

$$\begin{aligned} \mathbf{y_t} &= \mathbf{C}(\vartheta) + \mathbf{H}\,\mathbf{\hat{s}_t}\ , \qquad (29) \\ \mathbf{\hat{s}_t} &= \mathbf{\Phi_1}(\vartheta)\,\mathbf{\hat{s}_{t-1}} + \mathbf{\Phi_2}(\vartheta)\,\hat{\varepsilon}_\mathbf{t}\ , \end{aligned}$$

where ϑ is the column vector of structural parameters and $C(\vartheta)$, $\Phi_1(\vartheta)$, and $\Phi_2(\vartheta)$ are the coefficient matrices that consist of ϑ.

The corresponding observation equations are

$$\begin{bmatrix} 100\Delta\log Y_t \\ 100\Delta\log C_t \\ 100\Delta\log I_t \\ 100\Delta\log W_t \\ 100\log\pi_t \\ 100\log l_t \\ 100\log R^n_t \\ 100\log Spread_t \\ 100\log N_t/Q_tK_t \end{bmatrix} = \begin{bmatrix} z_* \\ z_* \\ z_* \\ z_* \\ \pi_* \\ l_* \\ R^n_* \\ r^e_* + \pi_* - R^n_* \\ n/k \end{bmatrix} + \begin{bmatrix} \tilde{y}_t - \tilde{y}_{t-1} + z^z_t \\ \tilde{c}_t - \tilde{c}_{t-1} + z^z_t \\ \tilde{i}_t - \tilde{i}_{t-1} + z^z_t \\ \tilde{w}_t - \tilde{w}_{t-1} + z^z_t \\ \tilde{\pi}_t \\ \tilde{l}_t \\ \tilde{R}^n_t \\ E_t\tilde{r}^e_{t+1} - \left(\tilde{R}^n_t - E_t\tilde{\pi}_{t+1}\right) \\ \tilde{n}_t - \tilde{q}_t - \tilde{k}_t \end{bmatrix}, \qquad (30)$$

where $z_* = 100\log z_{ss}$, $\pi_* = 100\log\pi_{ss}$, and $R^n_* = 100\log R^n_{ss}$, $r^e_* = 100\log r^e_{ss} = 100\left(\log R^e_{ss}/\pi_{ss}\right)$. The steady-state value of hours worked l_* and the steady-state ratio of net worth to total asset value n/k are estimated.

3.3.2 Strategy for Estimation

Most parameters of the model are estimated, but some are fixed to avoid identification problems. The steady-state ratio of exogenous demand to output, steady-state inflation rate, and steady-state nominal risk-free interest rate are set at the sample mean (period: from 1985.1Q to 2012.2Q): $g/y = 0.17$, $\pi_* = 0.585$, and $R^n_* = 1.088$. Based on Justiniano *et al.* (2010), the capital share α is set to 0.27, the quarterly depreciation rate of capital δ is 0.025, the steady-state price mark-up λ_p is 0,25, and the steady-state wage mark-up λ_w is 0.15. These fixed values are listed in Table 3.

The prior distribution of the parameters is shown in Table 4. For the structural parameters also estimated in the model of Smets and Wouters (2007), we give the same prior mean and prior standard deviations as them.[10] Because the specification of the adjustment cost of the capital utilization rate differs from Smets and Wouters (2007), we take the Gamma distribution with mean one and standard deviation 0.25 for μ. The priors of the trend rates of balanced growth are set to be the Gamma distribution with standard deviation 0.25 and mean based on the sample mean of $100\Delta\log Y_t$. As for the parameters connected with financial friction, we

[10] As for the forms of the prior distribution, we change them appropriately depending on the property of the parameters.

set the prior distribution of μ_e and η based on Bernanke *et al.* (1999), Christensen and Dib (2008), and Gilchrist *et al.* (2009). Further, the prior distribution of n/k is set to be the Beta distribution with mean as the sample mean and standard deviation 0.01. The steady-state real loan rate r_*^e too is estimated, whose prior distribution is set to be Gamma distribution with mean as the sample mean and and the standard deviation of 0.025. The priors of shock persistence parameters ($\rho_x,\ x \in (b, w, g, \nu, p, r, efp, nw)$) are set to be the Beta distribution with mean 0.50 and standard deviation 0.20, and the priors of the standard deviations of the shock innovations ($\sigma_x,\ x \in (z, b, w, g, \nu, p, r, efp, nw)$) are set to be the Inverse-Gamma distribution with mean 0.25 and standard deviation infinity. As for the parameter regarding the degree of dependence on working capital φ, we choose fairly wide prior distributions: the Beta distribution with mean 0.5 and standard deviation 0.25.

The procedures for estimation in this paper follow those in recent studies to estimate DSGE model by Maximum Likelihood approach. That is, we use the Kalman filter to compute a likelihood function of the state space representation (30) and invoke the Random Walk Metropolis-Hastings algorithm, one of the Markov chain Monte Carlo (MCMC) methods, to sample from the posterior distribution for the model parameters.

3.4 Estimation Results

We now present our estimation results. We first illustrate the estimates of the parameters, and then, report the impulse response functions of real wage to a negative credit supply shock in the estimated model and the history of the credit supply shock.

3.4.1 Parameter Estimations

In the last two columns of Table 5, we report the estimates of the model parameters. We present posterior means and 90% credible intervals. The key parameter φ is reported in the fourteenth row. According to this, our estimate of the degree of dependence on working capital, 0.418, is significantly large. However, this is different from the estimate of Ravenna and Walsh (2006), which estimates the degree of dependence on conventional working capital using the GMM methodology and reports it is to be close to unity. Our estimate of some parameters related to preference, technology, and monetary policy response (i.e., $\sigma, \theta, \phi_\pi, \phi_y, z_*, l_*$) are not different from those in Smets and Wouters (2007) and Justiniano *et al.* (2010). However, as for the inverse elasticity of labor supply χ, the elasticity of the adjustment cost for investment $1/\zeta$, and the share of fixed cost in production ϕ, we obtain smaller estimates than those in various previous studies.[11] Four parameters related to stickiness in prices and wages (i.e., γ_w, ξ_w, γ_p, ξ_p) are estimated to be roughly consistent with previous works, with the exception being the Calvo parameter of wage setting is smaller (that is, wages are more flexible). With respect to the parameter for the degree of financial friction, our estimate of the elasticity of the external financial premium of $\mu_e = 0.071$ is bigger than that in Gilchrist *et al.* (2009) ($\mu_e = 0.04$) and Christensen and Dib (2008) ($\mu_e = 0.042$). This result depends on the sample period and the difference in the data used in estimation.[12]

3.4.2 Bayesian Impulse Response Functions

In order to better examine the response of real wage to the shock of an increase in financing costs, we exploit the estimated DSGE model to perform additional analysis. Figures 6 and 7 display the Bayesian impulse response function of real wage and that of the growth rate of real wage, respectively. The Bayesian impulse response function is the computed posterior distribution of the impulse response function to each shock, consisting of one estimated standard deviation from the steady state economy. The figures report the estimated actual mean response, the 10% and 90% posterior intervals and the counterfactual mean response to the credit supply shock. The counterfactual response is the response at $\varphi = 0$ (no working capital constraint). According to this, the first stage decline is observed also in the estimated model. In particular, the estimated actual mean response in Figure 7 shows that the shock sharply decreases the growth rate of real wage in the first two periods (a half year), which is consistent with the inference in Figure 1 that the decline was the largest between 2008:4Q and 2009:1Q.

Furthermore, the history of the credit supply shock $\{\varepsilon_t^{efp}\}_{t \in T}$ calculated by Kalman smoothing (Kalman smoother) is shown in Figure 8. In this figure, we can see the extraordinarily big negative credit supply shock (increased external financial premium) in 2008:3Q. These results imply that the working capital constraint we have introduced generated a fast, large decline in

[11] The elasticity of the adjustment cost for investment has an important impact on the financial accelerator mechanism (see Christensen and Dib (2008)). Kaihatsu and Kurozumi (2010) reports small estimates as well.

[12] As for the financial data used in estimation, Gilchrist *et al.* (2009) adopts only the proxy for the external finance premium while Christensen and Dib (2008) does not introduce a financial shock and nor uses financial data.

real wage after the outbreak of the 2008 financial crisis.

4 Concluding remarks

In this paper, we have stated that during the Great Recession, real wage in the U.S. fell considerably very fast and that the conventional views on the cycles of wage could not catch these fluctuations. To investigate the driving forces behind this, we have developed the DSGE model with two main features. First, we have incorporated the financial friction of Bernanke *et al.* (1999) and financial shocks in order to capture an extraordinary increase in financing costs, which is considered as a major factor of the Great Recession. Second, we have also introduced the loan-rate-dependent working capital and the degree of dependence on the working capital constraint, which have enabled us to discuss the direct effects on the cost of production by an increase in financing costs. Our impulse response analysis using the calibrated medium-scale DSGE model has shown that our model generates the fast, large decline in real wage soon after a credit supply shock and gives that the scale of the decline is influenced by the degree of dependence on working capital. Moreover, the dependency has been shown to be significantly large by our quantitative analysis using the Bayesian methodology. The impulse response analysis also demonstrated that the loan-rate-dependent working capital yields more plausible results than the conventional working capital not only in terms of actual economic activity after a negative financial shock but also in the responses of real wage to the shock. Further, for a non-financial shock, our model induces almost the same responses as the model without the working capital constraint. These results imply that our model, on the one hand, generates a faster, larger decline in real wage after a credit supply shock, and on the other hand, maintains conventional dynamics to the other shocks.

While our model has illustrated an additional propagation channel for the bad condition in credit market as an influence on the cost of financing working capital, some researches focus on the limitations on the quantity of working capital. Jermann and Quadrini (2012) assumes that the liquidation value of capital stock firms is one of the collaterals for working capital and illustrates the mechanisms in which a lowering of market liquidity cuts down the value of the collaterals and the quantity of working capital. Whether the working capital constraint should be based on the cost of production or on the collateral constraint is one direction of future research.

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Table 1: Parameter Values for Calibration without φ

α	δ	λ_p	λ_w	σ	θ	χ	$1/\zeta$	μ
0.27	0.025	0.25	0.15	1.50	0.75	3.0	2.0	0.50
ϕ	γ_w	ξ_w	γ_p	ξ_p	g/y	R^e_{ss}	π_{ss}	R^n_{ss}
0.25	0.33	0.50	0.33	0.75	0.17	1.017	1.005	1.012
n/k	μ_e	η	ϕ_r	ϕ_π	ϕ_y	z_{ss}		
0.50	0.05	0.973	0.70	1.80	0.125	1.004		

Table 2: Data Appendix

Variable	Series description		Definition
$100\Delta \log Y_t$	Real GDP	Growth rate	LN(GDPC05/LNSindex) $*$ 100¶
$100\Delta \log C_t$	Cosumption	Growth rate	LN((PCEC/GDPDEF)/LNSindex) $*$ 100¶
$100\Delta \log I_t$	Investment	Growth rate	LN((FPI/GDPDEF)/LNSindex) $*$ 100¶
$100\Delta \log W_t$	Real wage	Growth rate	LN(PRS[Wage]/GDPDEF) $*$ 100¶
$100 \log \pi_t$	Inflation rate	per quarter (%)	LN(GDPDEF/GDPDEF(-1)) $*$ 100
$100 \log l_t$	Hours worked	Demean	LN((PRS[Hours] $*$ CE/100)/LNSindex) $*$ 100¶¶
$100 \log R^n_t$	Intereste rate	per quarter (%)	FEDFUNDS/4
$100 \log Spread_t$	External financial premium	per quarter (%)	(LoanRate$^+$ $-$ FEDFUNDS)/4
$100 \log N_t/Q_tK_t$	Firm's net worth-assets ratio	Demean	LN(TNWMVBSNNCB/TABSNNCB)¶¶

Explanation

LoanRate$^+$ is calculated by BAA - (GS10 -FEDFUNDS).

¶ : the difference form the past value

¶¶ : the difference form mean

1. **GDPC05**: Real Gross Domestic Product, Chained Dollars –Billions of chained 2005 dollars– Seasonally adjusted at annual rates (Source: U.S. Department of Commerce: Bureau of Economic Analysis)

2. **PCEC**: Personal Consumption Expenditures –Billions of dollars– Seasonally adjusted at annual rates (Source: U.S. Department of Commerce: Bureau of Economic Analysis)

3. **FPI**: Private Fixed Investment –Billions of dollars– Seasonally adjusted at annual rates (Source: U.S. Department of Commerce: Bureau of Economic Analysis)

4. **GDPDEF**: Implicit Price Deflators for Gross Domestic Product (Index: 2005=100) Seasonally adjusted (Source: U.S. Department of Commerce: Bureau of Economic Analysis)

5. **LNSindex**: Labor Force Status : Civilian noninstitutional population, Age 16 years and over (Index: 1992:3Q=1), Seasonally Adjusted (Source: U.S. Bureau of Labor Statistics)

6. **PRS[Wage]**: PRS85006063 Nonfarm Business Sector, Compensation (Index: 2005=100), Seasonally adjusted (Source: U.S. Department of Labor: Bureau of Labor Statistics)

7. **PRS[Hours]**: PRS85006023 Nonfarm Business Sector, Average Weekly Hours (Index: 2005=100), Seasonally adjusted (Source: U.S. Department of Labor: Bureau of Labor Statistics)

8. **CE**: CE16OV Civilian Employment Thousands of Persons (16 years of age and older), Seasonally Adjusted (Source: U.S. Bureau of Labor Statistics)

9. **FEDFUNDS**: Effective Federal Funds Rate (%), Not Seasonally Adjusted (Source: Board of Governors of the Federal Reserve System)

10. **BAA**: Moody's Seasoned Baa Corporate Bond Yield (%), Not Seasonally Adjusted (Source: Board of Governors of the Federal Reserve System)

11. **GS10**: 10-Year Treasury Constant Maturity Rate (%), Not Seasonally Adjusted (Source: Board of Governors of the Federal Reserve System)

12. **TNWMVBSNNCB**: Total Net Worth (Market Value) –Balance Sheet of Nonfarm Nonfinancial Corporate Business– End of Period, Not Seasonally Adjusted (Source: Board of Governors of the Federal Reserve System)

13. **TABSNNCB**: Total Assets –Balance Sheet of Nonfarm Nonfinancial Corporate Business– End of Period, Not Seasonally Adjusted (Source: Board of Governors of the Federal Reserve System)

Table 3: Fixed Parameters for Estimation

Params	Value	Definition	Reference
α	0.27	capital's share of output	Smets and Wouters (2007)
δ	0.025	(quarterly) depreciation rate	Smets and Wouters (2007)
λ_p	0.25	steady-state price mark-up	Justiniano *et al.* (2010)
λ_w	0.15	steady-state wage mark-up	Justiniano *et al.* (2010)
g/y	0.17	steady-state ratio of the exogenous demand to output	Sample mean (1985:1Q–2012:2Q)
π_*	0.585	steady-state (net) inflation rate	Sample mean (1985:1Q–2012:2Q)
R_*^n	1.088	steady-state (net) nominal risk-free interest rate	Sample mean (1985:1Q–2012:2Q)

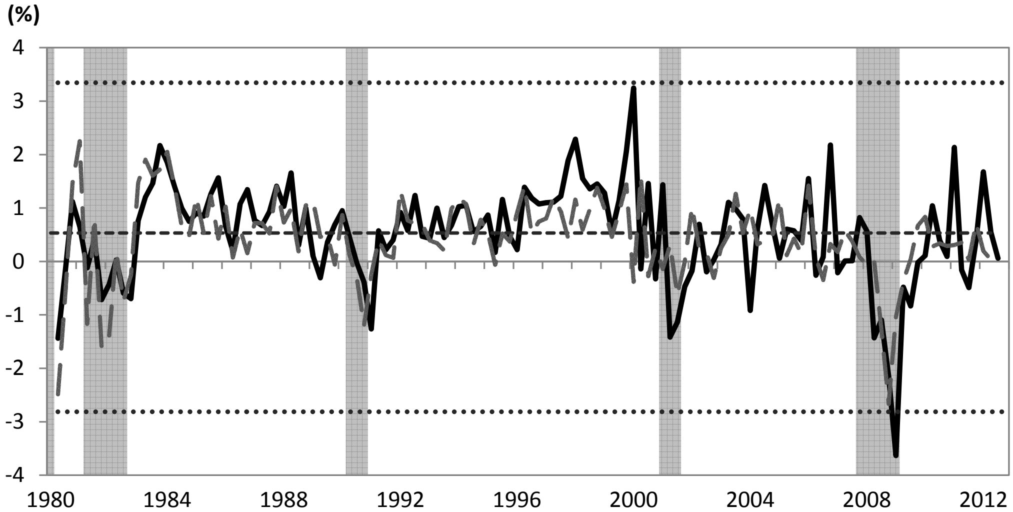
Table 4: Prior distribution

Params	Distribution	Mean	S.D.	Definition	Reference
Structural parameters					
σ	Gamma	1.500	0.375	inverse elasticity of interteporal substitution	Smets and Wouters (2007)
θ	Beta	0.700	0.100	degree of consumption habit formation	Smets and Wouters (2007)
χ	Gamma	2.000	0.750	inverse elasticity of labor supply	Smets and Wouters (2007)
$1/\zeta$	Gamma	4.000	1.500	elasticity of adjustment cost for investment	Smets and Wouters (2007)
μ	Gamma	1.000	0.250	elasticity of adjustment cost for utilization	Greenwood *et al.* (1988)
ϕ	Gamma	0.250	0.125	the share of fixed cost in production	Smets and Wouters (2007)
γ_w	Beta	0.500	0.150	degree of indexation to past wage	Smets and Wouters (2007)
ξ_w	Beta	0.500	0.100	Calvo parameter about wage setting	Smets and Wouters (2007)
γ_p	Beta	0.500	0.150	degree of wage indexation	Smets and Wouters (2007)
ξ_p	Beta	0.500	0.100	Calvo parameter about price setting	Smets and Wouters (2007)
n/k	Beta	0.520	0.010	steady-state net worth ratio of entrepreneurs	Sample mean
μ_e	Gamma	0.050	0.020	elasticity of external financial premium	Bernanke *et al.* (1999)
η	Beta	0.973	0.020	survival rate of entrepreneurs	Bernanke *et al.* (1999)
φ	Beta	0.500	0.250	dependence on working capital	my setting
ϕ_r	Beta	0.750	0.100	interest smoothing (monetary policy rule)	Smets and Wouters (2007)
ϕ_π	Gamma	1.500	0.250	response to inflation (monetary policy rule)	Smets and Wouters (2007)
ϕ_y	Gamma	0.125	0.050	response to output gap (monetary policy rule)	Smets and Wouters (2007)
z_*	Gamma	0.440	0.025	(net) steady-state technology growth rate	Sample mean
l_*	Normal	0.000	0.025	hours worked	Smets and Wouters (2007)
r_*^e	Gamma	1.070	0.025	(net) steady-state real loan rate (%)	Sample mean
persistency of exogenous shocks					
ρ_b	Normal	0.500	0.200	persistency of preference shock	
ρ_w	Normal	0.500	0.200	persistency of wage mark-up shock	
ρ_g	Normal	0.500	0.200	persistency of exogenous demand shock	
ρ_ν	Normal	0.500	0.200	persistency of investment adjustment cost shock	
ρ_p	Normal	0.500	0.200	persistency of price mark-up shock	
ρ_r	Normal	0.500	0.200	persistency of monetary policy shock	
ρ_{efp}	Normal	0.500	0.200	persistency of credit supply shock	
ρ_{nw}	Normal	0.500	0.200	persistency of net worth shock	
Standard deviation (Stdv.) of exogenous shocks					
σ_z	Inv. Gamma	0.250	Inf	Stdv. of technology trend shock	
σ_b	Inv. Gamma	0.250	Inf	Stdv. of preference shock	
σ_w	Inv. Gamma	0.250	Inf	Stdv. of wage mark-up shock	
σ_g	Inv. Gamma	0.250	Inf	Stdv. of exogenous demand shock	
σ_ν	Inv. Gamma	0.250	Inf	Stdv. of investment adjustment cost shock	
σ_p	Inv. Gamma	0.250	Inf	Stdv. of price mark-up shock	
σ_r	Inv. Gamma	0.250	Inf	Stdv. of monetary policy shock	
σ_{efp}	Inv. Gamma	0.250	Inf	Stdv. of credit supply shock	
σ_{nw}	Inv. Gamma	0.250	Inf	Stdv. of net worth shock	

Table 5: Posterior distributions of parameters

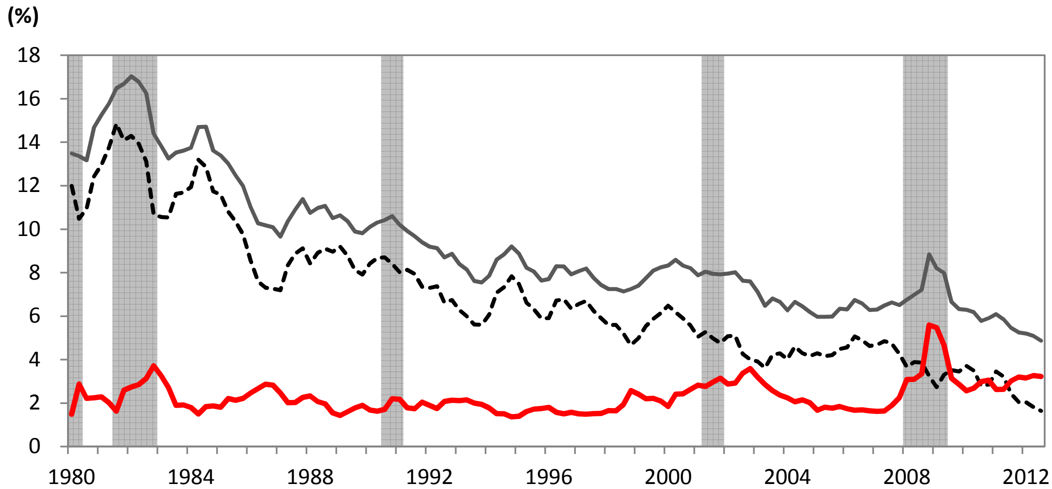
	Prior distribution			Posterior distribution	
Parameters	Distribution	Mean	S.D.	Mean	90% Credible Interval
σ	Gamma	1.500	0.375	1.121	[0.950 , 1.294]
θ	Beta	0.700	0.100	0.679	[0.574 , 0.797]
χ	Gamma	2.000	0.750	1.345	[0.826 , 1.851]
$1/\zeta$	Gamma	4.000	1.500	1.299	[0.683 , 1.884]
μ	Gamma	1.000	0.250	0.570	[0.325 , 0.795]
ϕ	Gamma	0.250	0.125	0.045	[0.012 , 0.078]
γ_w	Beta	0.500	0.150	0.498	[0.265 , 0.729]
ξ_w	Beta	0.500	0.100	0.413	[0.347 , 0.476]
γ_p	Beta	0.500	0.150	0.089	[0.028 , 0.143]
ξ_p	Beta	0.500	0.100	0.782	[0.742 , 0.822]
n/k	Beta	0.520	0.010	0.565	[0.552 , 0.580]
μ_e	Gamma	0.050	0.020	0.071	[0.046 , 0.095]
η	Beta	0.973	0.020	0.916	[0.867 , 0.967]
φ	Beta	0.500	0.250	0.418	[0.034 , 0.798]
ϕ_r	Beta	0.750	0.100	0.551	[0.462 , 0.641]
ϕ_π	Gamma	1.500	0.250	1.463	[1.325 , 1.591]
ϕ_y	Gamma	0.125	0.050	0.039	[0.023 , 0.054]
z_*	Gamma	0.440	0.025	0.433	[0.393 , 0.471]
l_*	Normal	0.000	0.025	0.002	[-0.040 , 0.042]
r^e_*	Gamma	1.070	0.025	1.075	[1.035 , 1.115]
ρ_b	Normal	0.500	0.200	0.725	[0.595 , 0.857]
ρ_w	Normal	0.500	0.200	0.209	[0.064 , 0.345]
ρ_g	Normal	0.500	0.200	0.987	[0.971 , 1.000]
ρ_ν	Normal	0.500	0.200	0.730	[0.626 , 0.838]
ρ_p	Normal	0.500	0.200	0.983	[0.966 , 1.000]
ρ_r	Normal	0.500	0.200	0.702	[0.638 , 0.765]
ρ_{efp}	Normal	0.500	0.200	0.908	[0.863 , 0.954]
ρ_{nw}	Normal	0.500	0.200	0.980	[0.961 , 0.999]
σ_z	Inv. Gamma	0.250	Inf	0.760	[0.669 , 0.847]
σ_b	Inv. Gamma	0.250	Inf	2.520	[1.788 , 3.243]
σ_w	Inv. Gamma	0.250	Inf	0.755	[0.619 , 0.888]
σ_g	Inv. Gamma	0.250	Inf	2.360	[2.105 , 2.621]
σ_ν	Inv. Gamma	0.250	Inf	0.990	[0.581 , 1.389]
σ_p	Inv. Gamma	0.250	Inf	0.090	[0.061 , 0.119]
σ_r	Inv. Gamma	0.250	Inf	0.113	[0.098 , 0.128]
σ_{efp}	Inv. Gamma	0.250	Inf	0.089	[0.078 , 0.098]
σ_{nw}	Inv. Gamma	0.250	Inf	0.237	[0.178 , 0.291]

Figure 1: The growth rate of the real wage in the U.S. (after 1980)



Note : Heavy solid line indicates time series for the growth rate of the real wage and long broken line (in gray) indicates thats for the growth rate of the real output per capita. Horizontal broken line shows the sample mean of the growth rate of the real wage and two dotted lines show the sample mean ±3 standard deviations.

Figure 2: The fluctuation of credit spread in the U.S. (after 1980)



Note : Broken line indicates time series for 10-Year Treasury Constant Maturity Rate(%) and thin solid line (in gray) indicates Moody's Seasoned Baa Corporate Bond Yield (%). Heavy solid line (in red) is time series for the credit spread defined as the spread of these interest rate.

Figure 3: Responses to a credit supply shock

Rising in external financial premium by 1%

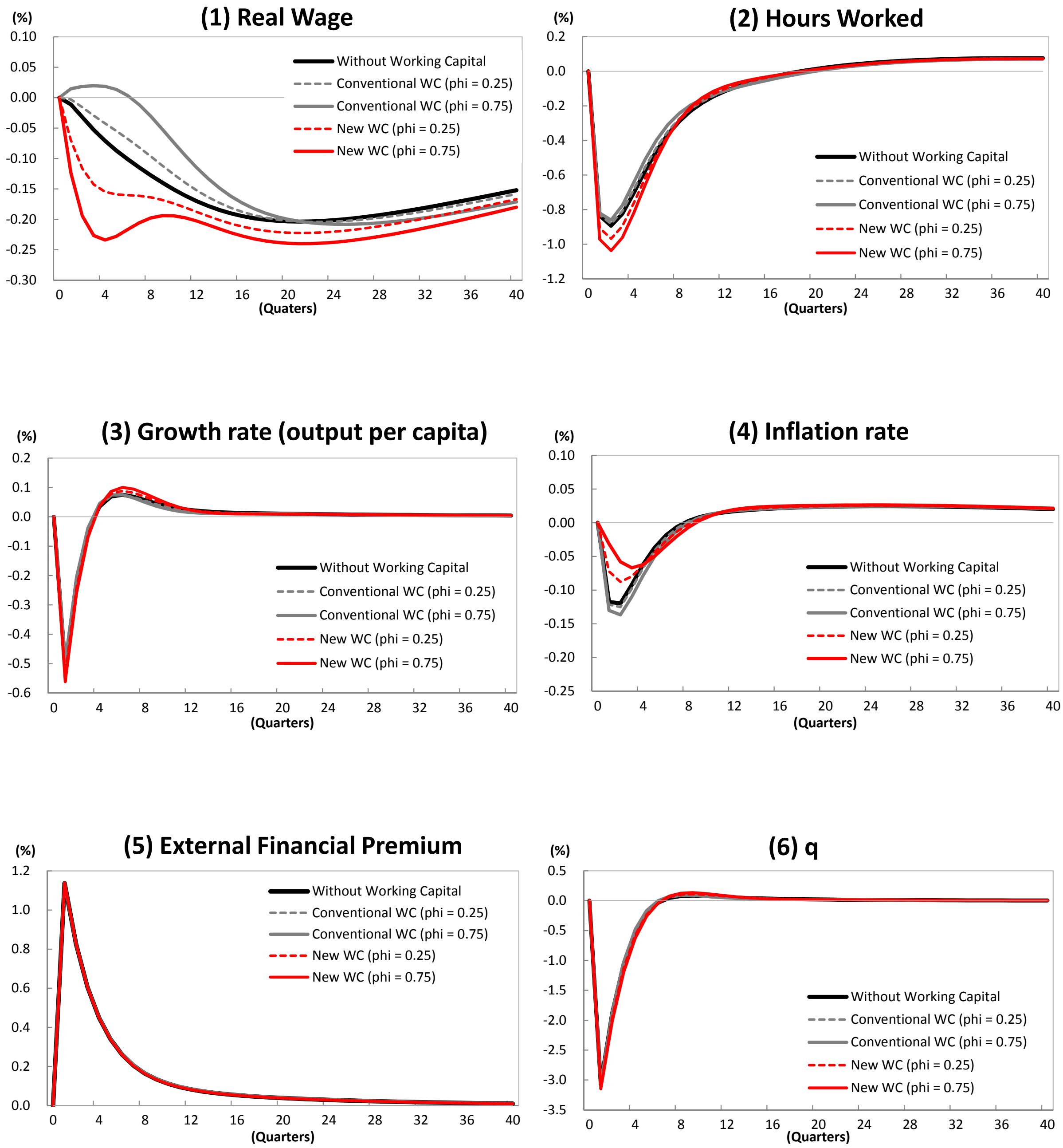
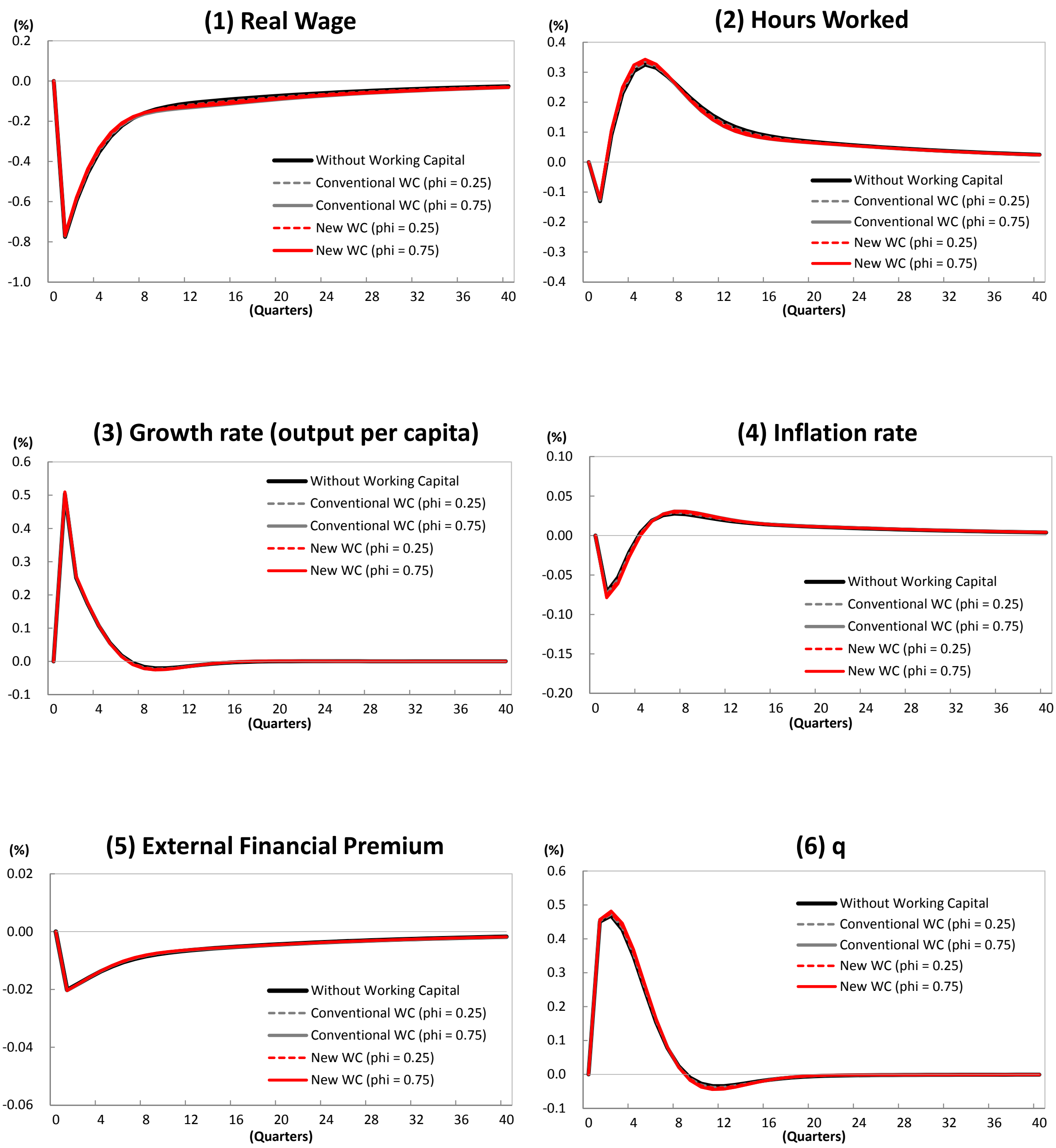


Figure 4: Responses to a technological trend shock

Rising in technology growth rate by 1% [14]



[14] The response of variables with the trend is measured by the percent deviation from the growth trend. Here, the response of real wage corresponds to this. Because this shock affects the growth trend, we need to take the effect into consideration.

Figure 5: Responses to a monetary policy shock

Rising in risk-free interest rate by 1%

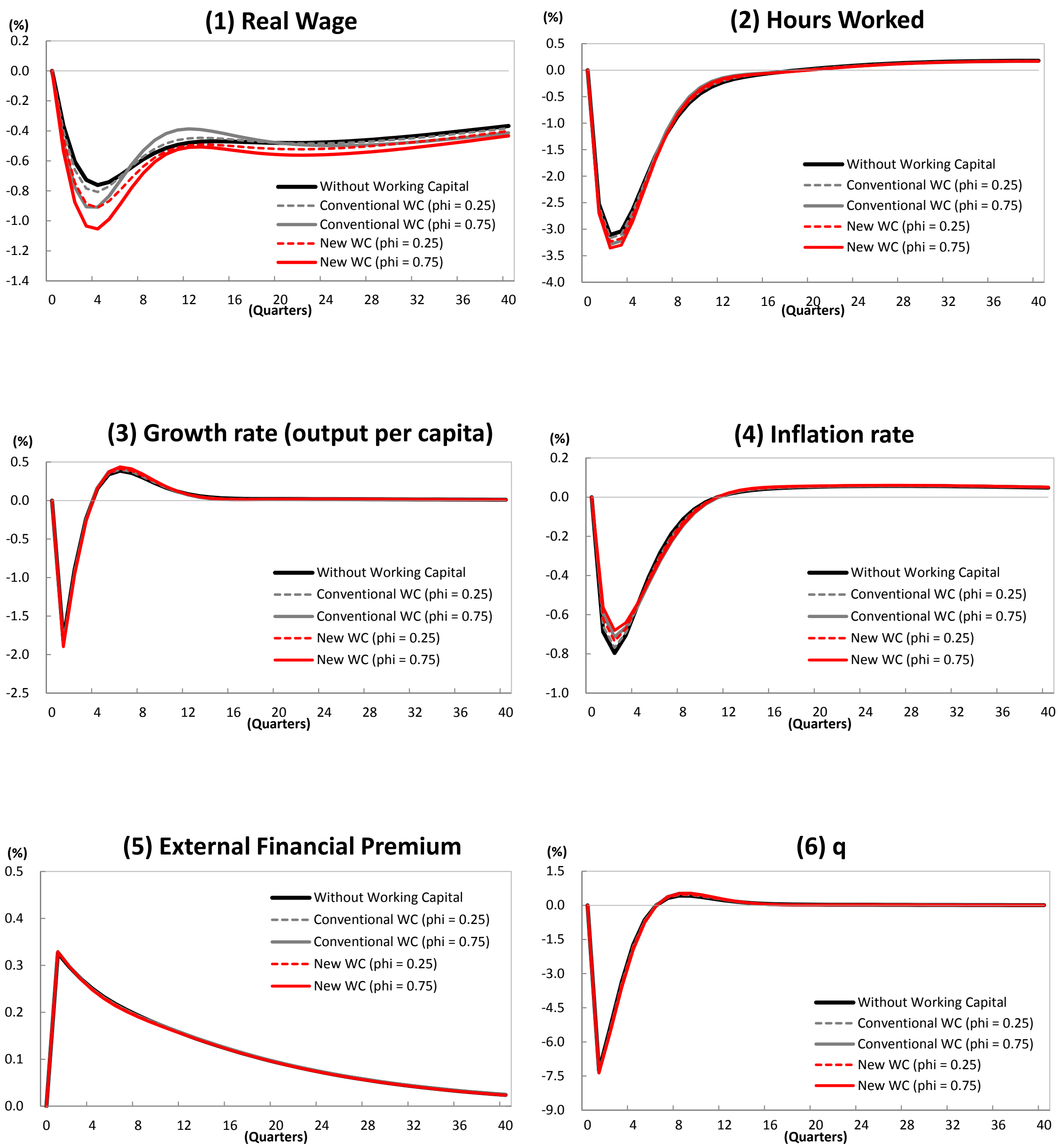


Figure 6: Bayesian Impulse Response Function of real wage to a credit supply shock.

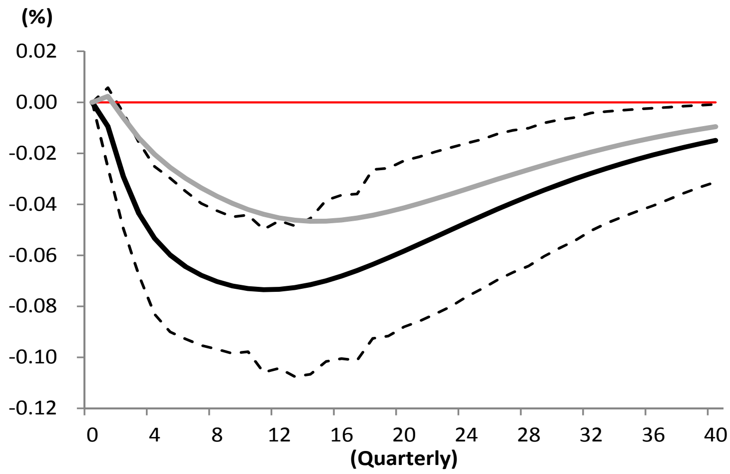
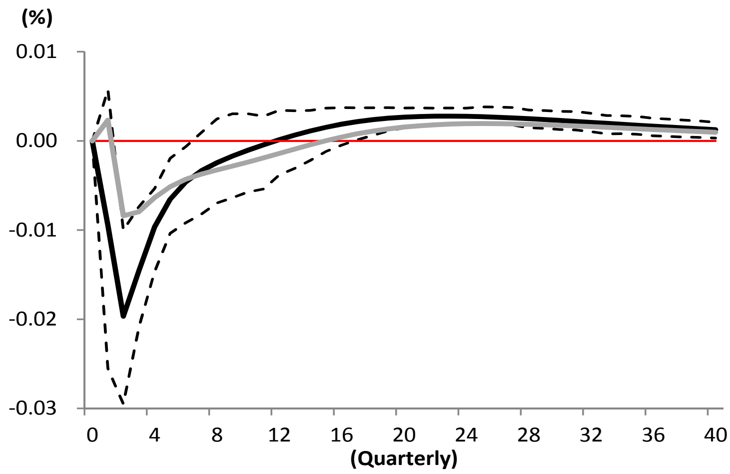
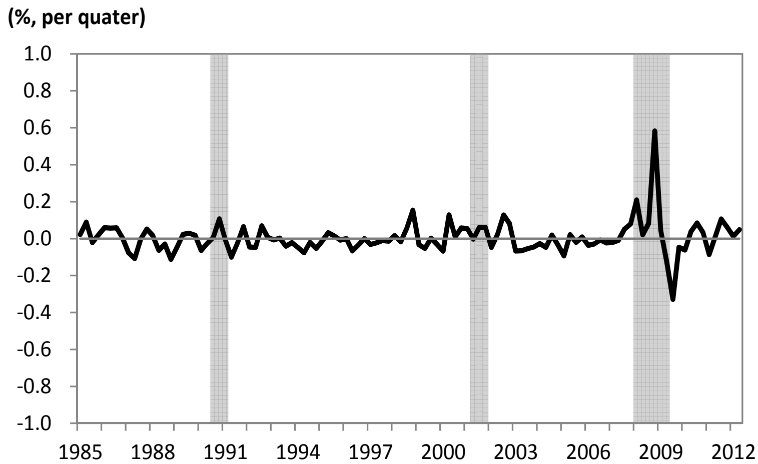


Figure 7: Bayesian Impulse Response Function of the growth rate of real wage to a credit supply shock.



Note : The size of credit supply shock is one standard error which is estimated mean ($\sigma_{efp} = 0.089$). The solid line represents the estimated actual mean response and the broken lines represent the 10% and 90% posterior interval. The gray line represent the the counterfactual no working capital constraint responses. ($\varphi = 0$)

Figure 8: Smoothed Shocks “credit supply shock”



Note : The solid line represents the history of $\{\varepsilon_t^{efp}\}_{t\in T}$ calculated by Kalman smoothing.

A Stationary Equilibrium

A.1 Benchmark Model

Consumption, Labor, and Wage

$$\lambda_t = e^{z_t^b}\left(c_t - \frac{\theta}{z_{ss}e^{z_t^z}}c_{t-1}\right)^{-\sigma} - \frac{\beta\theta}{z_{ss}^{\sigma}}E_t e^{z_{t+1}^b}\left(e^{z_{t+1}^z}c_{t+1} - \frac{\theta}{z_{ss}}c_t\right)^{-\sigma} \tag{A.1}$$

$$\lambda_t = \frac{\beta}{z_{ss}^{\sigma}}E_t\left[\lambda_{t+1}\frac{1}{\left(e^{z_{t+1}^z}\right)^{\sigma}}\frac{R_t^n}{\pi_{t+1}}\right] \tag{A.2}$$

$$E_t\sum_{j=0}^{\infty}\left[\begin{array}{l} \left(\frac{\beta\xi_w}{z_{ss}^{\sigma-1}}\right)^j \frac{\lambda_{t+j}l_{t+j}}{\lambda_{t+j}^w}\prod_{k=1}^j\left(e^{z_{t+k}^z}\right)^{1-\sigma} \\ \times\left[\frac{w_t^o}{w_{t+j}}\prod_{k=1}^j\left\{\left(\frac{\pi_{t+k-1}}{\pi}\right)^{\gamma_w}\frac{\pi}{\pi_{t+k}}\frac{1}{e^{z_{t+k}^z}}\right\}\right]^{-\frac{1}{\lambda_{t+j}^w}-1} \\ \times\left\{\begin{array}{l} w_t^o\prod_{k=1}^j\left\{\left(\frac{\pi_{t+k-1}}{\pi}\right)^{\gamma_w}\frac{\pi}{\pi_{t+k}}\frac{1}{e^{z_{t+k}^z}}\right\} - \left(1+\lambda_{t+j}^w\right)\frac{e^{z_{t+j}^{\Xi}}e^{z_{t+j}^b}}{\lambda_{t+j}} \\ \times\left(l_{t+j}\left[\frac{w_t^o}{w_{t+j}}\prod_{k=1}^j\left\{\left(\frac{\pi_{t+k-1}}{\pi}\right)^{\gamma_w}\frac{\pi}{\pi_{t+k}}\frac{1}{e^{z_{t+k}^z}}\right\}\right]^{-\frac{1}{\lambda_{t+j}^w}-1}\right)^{\chi} \end{array}\right\} \end{array}\right] = 0 \tag{A.3}$$

$$w_t^{-\frac{1}{\lambda_t^w}} = (1-\xi_w)\left(w_t^{o^{-\frac{1}{\lambda_t^w}}} + \sum_{j=1}^{\infty}\xi_w^j\left[w_{t-j}^o\prod_{k=1}^j\left\{\left(\frac{\pi_{t-k}}{\pi}\right)^{\gamma_w}\frac{\pi}{\pi_{t-k+1}}\frac{1}{e^{z_{t-k+1}^z}}\right\}\right]^{-\frac{1}{\lambda_t^w}}\right) \tag{A.4}$$

Production and Inflation

$$y_t d_t = l_t^{1-\alpha}\left(\frac{u_t k_{t-1}}{z_{ss}e^{z_t^z}}\right)^{\alpha} - \Phi \tag{A.5}$$

$$\frac{u_t k_{t-1}}{l_t z_{ss}e^{z_t^z}} = \frac{\alpha}{1-\alpha}\frac{(1-\varphi+\varphi\, E_t R_{t+1}^e)w_t}{r_t^k} \tag{A.6}$$

$$mc_t = \left(\frac{w_t}{1-\alpha}\right)^{1-\alpha}\left(\frac{r_t^k}{\alpha}\right)^{\alpha}\left(1-\varphi+\varphi\, E_t R_{t+1}^e\right)^{1-\alpha} \tag{A.7}$$

$$E_t R_{t+1}^e = E_t r_{t+1}^e E_t \pi_{t+1} \tag{A.8}$$

$$E_t\sum_{j=0}^{\infty}\left[\begin{array}{c} \left(\frac{\beta\xi_p}{z_{ss}^{\sigma-1}}\right)^j\frac{\lambda_{t+j}}{\lambda_t\lambda_{t+j}^p}\prod_{k=1}^j\left(e^{z_{t+k}^z}\right)^{\sigma-1}\left[p_t^o\prod_{k=1}^j\left\{\left(\frac{\pi_{t+k-1}}{\pi}\right)^{\gamma_p}\frac{\pi}{\pi_{t+k}}\right\}\right]^{-\frac{1+\lambda_{t+j}^p}{\lambda_{t+j}^p}} \\ \times y_{t+j}\left[p_t^o\prod_{k=1}^j\left\{\left(\frac{\pi_{t+k-1}}{\pi}\right)^{\gamma_p}\frac{\pi}{\pi_{t+k}}\right\} - \left(1+\lambda_{t+j}^p\right)mc_{t+j}\right] \end{array}\right] = 0 \tag{A.9}$$

$$1 = (1-\xi_p)\left((p_t^o)^{-\frac{1}{\lambda_t^p}} + \sum_{j=1}^{\infty}\xi_p^j\left[p_{t-j}^o\prod_{k=1}^j\left\{\left(\frac{\pi_{t-k}}{\pi}\right)^{\gamma_p}\frac{\pi}{\pi_{t-k+1}}\right\}\right]^{-\frac{1}{\lambda_t^p}}\right) \tag{A.10}$$

$$d_t = (1-\xi_p)\left((p_t^o)^{-\frac{1+\lambda_t^p}{\lambda_t^p}} + \sum_{j=1}^{\infty}\xi_p^j\left[p_{t-j}^o\prod_{k=1}^j\left\{\left(\frac{\pi_{t-k}}{\pi}\right)^{\gamma_p}\frac{\pi}{\pi_{t-k+1}}\right\}\right]^{-\frac{1+\lambda_t^p}{\lambda_t^p}}\right) \tag{A.11}$$

Capital, Utilization, and Investment

$$k_t = (1-\delta(u_t))\, k_{t-1}\frac{1}{z_{ss}e^{z_t^z}} + i_t\left[1-\frac{1}{2\zeta}\left(\frac{i_t}{i_{t-1}z_{ss}}e^{z_t^z}-1\right)^2\right] \tag{A.12}$$

$$r_t^k = Q_t\delta'(u_t) \tag{A.13}$$

$$\begin{aligned} 1 &= Q_t\left[1-\frac{1}{2\zeta}\left(\frac{i_t}{i_{t-1}}e^{z_t^z}-1\right)^2-\frac{1}{\zeta}\left(\frac{i_t}{i_{t-1}}e^{z_t^z}-1\right)\frac{i_t}{i_{t-1}}e^{z_t^z}\right] \\ &\quad +\frac{\beta}{z_{ss}^{\sigma}}E_t\frac{\lambda_{t+1}}{\lambda_t}\left(\frac{1}{e^{z_t^z}}\right)^{\sigma}Q_{t+1}\frac{1}{\zeta}\left(\frac{i_{t+1}}{i_t}e^{z_{t+1}^z}-1\right)\left(\frac{i_{t+1}}{i_t}e^{z_{t+1}^z}\right)^2 \end{aligned} \tag{A.14}$$

Financial contract

$$Q_tk_t = b_t+n_t \tag{A.15}$$

$$E_tr_{t+1}^e = \frac{R_t^n}{E_t\pi_{t+1}}F\left(\frac{n_t}{Q_tk_t}\right)e^{z_t^{efp}} \tag{A.16}$$

$$E_tr_{t+1}^e = E_t\left[\frac{u_{t+1}r_{t+1}^k+Q_{t+1}\left(1-\delta(u_{t+1})\right)}{Q_t}\right] \tag{A.17}$$

$$n_t = \frac{\eta_t}{z_{ss}e^{z_t^z}}\left\{r_t^eQ_{t-1}k_{t-1}-E_{t-1}r_t^e\, b_{t-1}\right\}+(1-\eta_t)\,\omega \tag{A.18}$$

$$\left(\eta_t = \eta\, e^{\hat{z}_t^{nw}}/(1+\eta+\eta\, e^{\hat{z}_t^{nw}})\right) \tag{A.19}$$

Goods market clearing and Potential output

$$y_t = c_t+i_t+g\, e^{z_t^g} \tag{A.20}$$

$$y_t^{pot} = (l_*)^{1-\alpha}\left(\frac{k_*}{e^{z_t^z}}\right)^{\alpha}-\Phi \tag{A.21}$$

Monetary policy rule

$$\log R_t^n = \phi_r\log R_{t-1}^n+(1-\phi_r)\left\{\phi_\pi\left(\frac{1}{4}\sum_{j=0}^{3}\log\frac{\pi_{t-j}}{\pi}\right)+\phi_y\log\frac{y_t}{y_t^{pot}}\right\}+z_t^r \tag{A.22}$$

B Log-linearized Equilibrium

B.1 Benchmark Model

Consumption, Labor, and Wage

$$\left(1-\frac{\theta}{z_{ss}}\right)\left(1-\frac{\beta\theta}{z_{ss}^{\sigma}}\right)\tilde{\lambda}_t = -\sigma\left\{\tilde{c}_t-\frac{\theta}{z_{ss}}\left(\tilde{c}_{t-1}-z_t^z\right)\right\}+\left(1-\frac{\theta}{z_{ss}}\right)z_t^b + \frac{\beta\theta}{z_{ss}^{\sigma}}\left[\left\{E_t\tilde{c}_{t+1}+E_tz_{t+1}^z-\frac{\theta}{z_{ss}}\tilde{c}_t\right\}-\left(1-\frac{\theta}{z_{ss}}\right)E_tz_{t+1}^b\right] \quad \text{(B.1)}$$

$$\tilde{\lambda}_t = \tilde{R}_t^n + E_t\tilde{\lambda}_{t+1} - E_t\tilde{\pi}_{t+1} - \sigma E_t z_{t+1}^z \quad \text{(B.2)}$$

$$\tilde{w}_t-\tilde{w}_{t-1}+\tilde{\pi}_t-\gamma_w\tilde{\pi}_{t-1} = \beta z_{ss}^{1-\sigma}\left(E_t\tilde{w}_{t+1}-\tilde{w}_t+E_t\tilde{\pi}_{t+1}-\gamma_w\tilde{\pi}_t+E_tz_{t+1}^z\right) + \frac{1-\xi_w}{\xi_w}\frac{\left(1-\beta\xi_w z_{ss}^{1-\sigma}\right)\lambda^w}{\lambda^w+\chi\left(1+\lambda^w\right)}\left(\chi\tilde{l}_t-\tilde{\lambda}_t-\tilde{w}_t+z_t^b\right)+z_t^w \quad \text{(B.3)}$$

Production and Inflation

$$\tilde{y}_t = \left(1+\frac{\Phi}{y}\right)\left\{(1-\alpha)\tilde{l}_t+\alpha\left(\tilde{u}_t+\tilde{k}_{t-1}-z_t^z\right)\right\} \quad \text{(B.4)}$$

$$\tilde{u}_t+\tilde{k}_{t-1} - \tilde{l}_t - z_t^z = \tilde{w}_t-\tilde{r}_t^k+\frac{\varphi R_{ss}^e}{1-\varphi+\varphi R_{ss}^e}E_t\widetilde{R}_{t+1}^e \quad \text{(B.5)}$$

$$\widetilde{mc}_t = (1-\alpha)\tilde{w}_t+\alpha\tilde{r}_t^k+(1-\alpha)\frac{\varphi R_{ss}^e}{1-\varphi+\varphi R_{ss}^e}E_t\widetilde{R}_{t+1}^e \quad \text{(B.6)}$$

$$E_t\widetilde{R}_{t+1}^e = E_t\tilde{r}_{t+1}^e+E_t\tilde{\pi}_{t+1} \quad \text{(B.7)}$$

$$\tilde{\pi}_t = \gamma_p\tilde{\pi}_{t-1}+\beta z_{ss}^{1-\sigma}\left(E_t\tilde{\pi}_{t+1}-\gamma_p\tilde{\pi}_t\right)+\frac{\left(1-\xi_p\right)\left(1-\beta\xi_p z_{ss}^{1-\sigma}\right)}{\xi_p}\widetilde{mc}_t+z_t^p \quad \text{(B.8)}$$

Capital, Utilization, and Investment

$$\tilde{k}_t = \frac{1-\delta}{z_{ss}}\left(\tilde{k}_{t-1}-z_t^z\right)-\frac{z_{ss}^{\sigma}/\beta-1+\delta}{z_{ss}}\tilde{u}_t+\left(1-\frac{1-\delta}{z_{ss}}\right)\tilde{i}_t \quad \text{(B.9)}$$

$$\tilde{u}_t = \mu\left(\tilde{r}_t^k-\tilde{q}_t\right) \quad \text{(B.10)}$$

$$\tilde{q}_t = \frac{1}{\zeta}\left(\tilde{i}_t-\tilde{i}_{t-1}+z_t^z\right)-\frac{\beta z_{ss}^{1-\sigma}}{\zeta}\left(E_t\tilde{i}_{t+1}-\tilde{i}_t+E_tz_{t+1}^z\right)+z_t^{\nu} \quad \text{(B.11)}$$

Financial contract

$$\tilde{q}_t + \tilde{k}_t = \left(1-\frac{n}{k}\right)\tilde{b}_t+\frac{n}{k}\tilde{n}_t \quad \text{(B.12)}$$

$$E_t\tilde{r}_{t+1}^e = \tilde{R}_t^n-E_t\tilde{\pi}_{t+1}+\mu^e\left(\tilde{q}_t+\tilde{k}_t-\tilde{n}_t\right)+z_t^{efp} \quad \text{(B.13)}$$

$$E_t\tilde{r}_{t+1}^e = \left(1-\frac{1-\delta}{r_{ss}^e}\right)E_t\tilde{r}_t^k+\frac{1-\delta}{r_{ss}^e}E_t\tilde{q}_{t+1}-\tilde{q}_t \quad \text{(B.14)}$$

$$\frac{z_{ss}}{\eta r_{ss}^e}\tilde{n}_t = \frac{1}{n/k}\tilde{r}_t^e-\left(\frac{1}{n/k}-1\right)E_{t-1}\tilde{r}_t^e+\tilde{n}_{t-1}-z_t^z+z_t^{nw} \quad \text{(B.15)}$$

Goods market clearing and Potential output

$$\tilde{y}_t = \left(1 - \frac{i}{y} - \frac{g}{y}\right)\tilde{c}_t + \frac{i}{y}\,\tilde{i}_t + \frac{g}{y}\,z_t^g \tag{B.16}$$

$$\tilde{y}_t^{pot} = -\alpha\left(1 + \frac{\Phi}{y}\right)z_t^z \tag{B.17}$$

Monetary policy rule

$$\tilde{R}_t^n = \phi_r \tilde{R}_{t-1}^n \,(1-\phi_r)\left\{\phi_\pi\left(\frac{1}{4}\sum_{j=0}^{3}\tilde{\pi}_{t-j}\right) + \phi_y\left(\tilde{y}_t - \tilde{y}_t^{pot}\right)\right\} + z_t^r \tag{B.18}$$

Shock process

$$z_t^z = \varepsilon_t^z \tag{B.19}$$

$$z_t^s = \rho_s z_{t-1}^s + \varepsilon_t^s \quad s \in (b, w, g, \nu, p, r, efp, nw) \tag{B.20}$$

B.2 Model with the conventional working capital constraint

Replace (B.5) and (B.6) to

$$\tilde{u}_t + \tilde{k}_{t-1} - \tilde{l}_t - z_t^z = \tilde{w}_t - \tilde{r}_t^k + \frac{\varphi R_{ss}^n}{1-\varphi+\varphi R_{ss}^n}\widetilde{R}_t^n \tag{B.21}$$

$$\widetilde{mc}_t = (1-\alpha)\tilde{w}_t + \alpha\tilde{r}_t^k + (1-\alpha)\frac{\varphi R_{ss}^n}{1-\varphi+\varphi R_{ss}^n}\widetilde{R}_t^n \tag{B.22}$$

B.3 Steady state condition

$$\beta = \frac{z_{ss}^\sigma \pi_{ss}}{R_{ss}^n} \tag{C.1}$$

$$r_{ss}^k = r_{ss}^e - 1 + \delta \tag{C.2}$$

$$w_{ss} = \frac{1-\alpha}{(1-\varphi+\varphi\, r_{ss}^e \pi_{ss})}\left(\frac{1}{1+\lambda_p}\right)^{\frac{1}{1-\alpha}}\left(\frac{r_{ss}^k}{\alpha}\right)^{-\frac{\alpha}{1-\alpha}} \tag{C.3}$$

$$\frac{k}{l} = \frac{z_{ss}\alpha\,(1-\varphi+\varphi\, r_{ss}^e \pi_{ss} w_{ss})}{(1-\alpha) r_{ss}^k} \tag{C.4}$$

$$\frac{k}{y} = (1+\phi)\, z_{ss}^\alpha \left(\frac{k}{l}\right)^{1-\alpha} \tag{C.5}$$

$$\frac{i}{y} = \left(1 - \frac{1-\delta}{z_{ss}}\right)\frac{k}{y} \tag{C.6}$$