Economics Department
Discussion Papers Series

A Note on Simple Monetary Policy Rules with Labour Market and Financial Frictions

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Paper number 16/01

A Note on Simple Monetary Policy Rules with Labour Market and Financial Frictions[*]

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March 18, 2016

Abstract

We consider a New-Keynesian model with financial and labour market frictions where firms borrowing is limited by the enforcement constraint. The wage is set in a bargaining process where the firm's shareholder and worker share the production surplus. As debt service is considered to be a part of production costs, firms borrow to reduce the surplus which allows to lower the wage. We study the model's response to financial shock under two Taylor-type interest rate rules: first one responds to inflation and borrowing, second - to inflation and unemployment. We have found that the second rule delivers better policy in terms of the welfare measure. Additionally, we show that the feedback on unemployment in this rule depends on the extent of workers' bargaining power.

Keywords: Labour Market Frictions, Financial Frictions, Optimal Monetary Policy, Monetary Policy Rules

JEL classification: E52, E43, E24

1 Introduction

Studying simple monetary policy rules is an important topic in monetary economics. Many papers have shown that such rules work remarkably well and often provide good approximations to fully optimal policy (Taylor 1999). However, relative performance of the particular rule depends on the economic environment postulated in the model. Therefore evaluating the robustness of a specific interest rate rule is very important for policy makers (Cote et. al 2004).

In this note we investigate how the presence of financial frictions affects the performance of a Taylor-type monetary policy. In particular, we are interested in the rule with reaction to inflation and unemployment which was advocated in Walsh (2005), Faia (2008, 2008a), Blanchard and Gali (2010) among others. We extend the previous analysis by adding firms' financial market frictions and show that the same result holds: the rule with response to inflation and unemployment still performs better than the rule which responds to inflation and borrowing as in Faia (2008). We also find that the coefficient on unemployment in this rule depends on the extent of workers' bargaining power.

As a starting point we use the model considered in Monacelli, Trigari and Quadrini (2011) and extend it in several ways. First, we introduce sticky prices by using a Calvo (1983) framework and derive a New-Keynesian Phillips curve. Second, we compute optimal monetary policy and use it as a benchmark to compare all other regimes. Third, we use the Benigno and Woodford (2012) algorithm to asses the performance of various monetary policy rules in terms of the welfare measure.

The main novelty of Monacelli, Trigari and Quadrini (2011) paper as compared to the previous literature is the connection between financial markets and labour markets. Firms have the incentive to borrow because of the wage bargaining process. That is, they are issuing debt to reduce the bargaining surplus, defined as firm's profit net debt redemption, which in turn reduces the wage paid to workers. For any given value of workers' bargaining power, a higher debt results in a lower wage.

This is a different transmission channel of financial frictions than that of Petrosky-Nadeau (2014) and Petrosky-Nadeau and Wasmer (2013) where firms participate in a credit market to finance the vacancy costs. In their works, the source of frictions in the economy is the evolving condition of the credit market (the tightness of the borrowing constraint). As credit becomes more easily accessible to firms during the boom, they create more vacancies and thus, there is a fall in unemployment.

Such approach is also different from that of Mumtaz and Zanetti (2014) where entrepreneurs are borrowing to finance their production cost. In their model, when there is a financial shock, firms are forced to cut their production because of the shortage of capital. In our case, the negative financial shock reduces firms' credit, thus increasing the surplus and, as a result, firms' bargaining ability deteriorates resulting in an increase in wage and unemployment.

As in Faia (2008, 2009) and Blanchard and Gali (2010) we derive optimal monetary policy and analyze its responses. In our case, as compared to previous literature, firms borrowing adds extra term which can either increase or reduce the value of bargaining surplus. Therefore the central bank can affect firms hiring decision by changing interest rate which in turn alters borrowing.

However, as in Faia (2008, 2009) and Blanchard and Gali (2010), the central bank faces a trade-off between unemployment, inflation and financial market stabilization since it has only one instrument - interest rate - that can affect economy. The source of such trade-off comes from search and matching frictions, price stickiness and the firms borrowing constraint. We investigate both optimal and non-optimal (Taylor-type rule) responses of the policy maker by examining the role of Hosios (1990) condition as in Faia (2009).

According to Hosios (1990), when share of unemployed workers in the matching function is equal to bargaining power of workers then unemployment is at the socially optimal level. If workers bargaining power is larger than the value of matching function parameter, then unemployment is above the efficient level since firms have little incentive to create new vacancies. The situation is the opposite when bargaining power is lower than the share of unemployed workers in the matching technology.

We find that response to labour market (aggregate level of unemployment) in Taylor-type interest rate rule is positive when unemployment is above the social optimum whereas response is negative when unemployment is below the socially optimal level. For example, were the central bank to lower the interest, borrowing would become cheaper and firms would increase their debt. As a result, they would reduce the bargaining surplus, thus lowering the wage. Therefore, by setting the interest rate, the central bank could alter the level of unemployment. Because of this indirect relationship between labour market and interest rate, the reaction on unemployment in the policy rule depends on the extent of workers' bargaining power.

The note is structured as follows. First, we present a model with imperfect financial markets similar to that of Monacelli, Trigari and Quadrini (2011). Then, we introduce labour market frictions using Pissarides' (1987) framework. In the third section, we derive optimal monetary policy and discuss the relation between the interest rate and the workers' bargaining power. Then, we compute the welfare measure using the Beningo and Woodford (2005) algorithm. The last section concludes the note.

2 Model

There are four key components that form the model. First, there are households that consume the final goods, make a choice to be employed or unemployed, save in riskless assets which yield an interest rate and shares of firms that pay dividends. Second, we have intermediary goods producers that participate in the labour market by posting vacancies, employing agents and borrowing against their expected future profit. Third, there are final good producers that take the wholesale goods and sell them to households in the sticky prices (Calvo (1983)) environment. Finally, there is a central bank which conducts monetary policy.

2.1 Firms

The model is populated by two kinds of firms: intermediary goods producers that participate in the labour and financial markets by posting vacancies and borrowing and final goods producers that take the intermediary goods and sell them to households in the sticky prices (Calvo (1983)) environment.

2.1.1 Intermediary good producers

As in Monacelli, Quadrini and Trigari (2011), there are two types of intermediary goods producers: entrant firms and old firms. Entrant firms are created when the posted vacancy is matched with the worker. After its creation entrant firm chooses its borrowing which is immediately distributed to the shareholders (households). In the next period, if the match is not separated, entrant firm starts to produce and pays the wage. It is important to note that here we use the same timing convention as in Monacelli, Quadrini and Trigari (2011): entrant firms raise the debt before the bargaining with worker takes place.

Old firms are the matches, which were not separated during the last period. They must bargain with the current worker and pay a wage, make a decision about future borrowing and produce.

Firms in our model have incentives to increase borrowing since high debt reduces the bargaining surplus which, in turn, decreases the wage paid to workers. In addition, the firms borrowing decision is affected by the interest rate which is set by the monetary authority. For example, reduction in the cost of borrowing (interest rate) would encourage firms to issue more debt for the given number of posted vacancies. As a result, this would decrease wage and increase unemployment.

- **Entrant Firms**

A new (entrant) firm is created when the new match occurs between worker and a posted vacancy. Then, the new vacancy, which is filled by the worker, holds the following value

$$Q_t = \frac{E_t[\pi_{t+1}]}{i_t} b_{t+1} + \beta(1-\eta)E_t[S_{t+1}].\tag{1}$$

where i_t is the nominal interest rate set by the central bank, S_{t+1} is bargaining surplus, b_{t+1} captures firms borrowing, and π_{t+1} is inflation of final goods defined as $\pi_{t+1} = \frac{P_{t+1}}{P_t}$. The only decision made by the entrant firm in the first period is the level of b_{t+1} which is distributed to shareholders.

Firms post vacancies as long as the value of a vacancy is positive. In other words, the value of the filled vacancy Q_t must be greater than the incurred cost k. Thus, we can write the condition under which firms will keep on posting vacancies as

$$q_t Q_t = k,\tag{2}$$

where q_t is the probability that the posted vacancy is going to be filled. Rearranging equations 1 and 2 we obtain the following expression which links the cost of the labour market (the probability that

a posted vacancy will be filled) with the financial market (the firms' borrowing):

$$\frac{k}{q_t} = \frac{E_t\left[\pi_{t+1}\right]}{i_t}b_{t+1} + \beta(1-\eta)E_t\left[S_{t+1}\right]. \tag{3}$$

In the next period, if the match is not separated the entrant firm will become old.

- Old Firms

We begin our presentation by defining the production function of old firms where the only input is labour

$$Y_t = zN_t, \tag{4}$$

with z being the constant productivity parameter and N_t capturing the number of employed workers. We can intuitively define the number of unemployed agents u_t by normalizing the total number of workers in the model to 1 and subtracting those who are employed

$$u_t = 1 - (1-\lambda)N_{t-1}. \tag{5}$$

Here λ is the exogenously given probability that a match will be separated. Now N_t is defined as

$$N_t = (1-\lambda)N_{t-1} + m(u_t, v_t), \tag{6}$$

where $(1-\lambda)N_{t-1}$ are matches from the last period which were not separated and $m(u_t, v_t)$ captures newly created matches as in (Pissarides 1987) with v_t denoting the number of posted vacancies, ς being a matching parameter and α being a vacancy elasticity of matches. The CRS matching function is given by

$$m(u_t, v_t) = \varsigma v_t^{\alpha} u_t^{1-\alpha}, \tag{7}$$

where v_t is the number of available vacancies. The probability that the posted vacancy will be filled, q_t, is defined as

$$q_t = \frac{m(u_t, v_t)}{v_t}. \tag{8}$$

In the same way, the probability that a worker will find a job, p_t^E, is equal to

$$p_t^E = \frac{m(u_t, v_t)}{u_t}. \tag{9}$$

Using the two above equations and a particular form of the matching function (7), we obtain the relationship between the probability that a vacancy will be filled and the probability that a worker will find a job

$$p_t^E = q_t^{-\frac{\alpha}{1-\alpha}}\varsigma^{\frac{\alpha}{1-\alpha}}. \tag{10}$$

Making use of the definition of labour market tightness, $\theta_t = \frac{v_t}{u_t}$, we can rewrite equation (10) as

$$p_t^E = \varsigma\theta_t^{\alpha}. \tag{11}$$

Now by substituting equations 5, 6 and 11, we can derive the relation between the level of employment and the probability that a worker will find a job

$$N_t = (1-\lambda)N_{t-1} + \varsigma\theta_t^{\alpha}\left(1 - (1-\lambda)N_{t-1}\right). \tag{12}$$

Similarly to Monacelli, Quadrini and Trigari (2011) we set up an equation which defines wholesale

firms' equity value in terms of productivity, real wage and borrowing

$$J_t = \frac{z}{X_t} - w_t - b_t + \frac{E_t[\pi_{t+1}]}{i_t}b_{t+1} + \beta(1-\lambda)E_t[J_{t+1}],$$ (13)

where w_t is wage, β - discount factor and X_t is a markup defined as the price ratio $\frac{p_t^w}{P_t}$, with p_t^w denoting the wholesale good price. The above equation states that the firm's value depends on the wage paid to workers and on the size of the loan. Hence, we can see the same result as in Monacelli, Quadrini and Trigari (2011): the firm's choice of a new debt b_{t+1} does not depend neither on current debt b_t nor on current wage w_t. However, term $E_t[J_{t+1}]$ in equation 13 captures the fact that choice of b_{t+1} will affect futures wages.

Now we can define the bargaining surplus S_t which is split between the worker and the firm

$$S_t = \frac{z}{X_t} - a - b_t + \frac{E_t[\pi_{t+1}]}{i_t}b_{t+1} + (1-\lambda)\beta E_t[S_{t+1}] - \eta\beta p_t^E E_t[S_{t+1}].$$ (14)

When the worker is employed in a wholesale firm, his value is

$$V_t = w_t + \beta E_t[(1-\lambda)V_{t+1} + \lambda U_{t+1}],$$ (15)

where U_t is the value of being unemployed which is derived using equations 13, 14, 15:

$$U_t = a + \beta E_t[p_t^E V_{t+1} + (1-p_t^E)U_{t+1}].$$ (16)

Here the term in brackets denotes the trade-off between being employed and unemployed. Notice, that using equations 15 and 16 we can express bargaining surplus as $S_t = J_t + V_t - U_t$.

Finally, the real wage is given by

$$w_t = (1-\eta)a + \eta\left(\frac{z}{X_t} - b_t\right) + \frac{\eta k\left(\phi_t + p_t^E \beta\right)}{q_t\left(\phi_t + \beta\right)},$$ (17)

where ϕ_t is the firms borrowing parameter subject to a negative shock and η is the workers bargaining power. As we can see, wage negatively depends on b_t. That is, the higher is the borrowing, the lower is the current wage since the worker gets a fraction of output *net* debt. Therefore, for the given value of workers bargaining power higher borrowing reduces the wage. See the appendix for details on wage derivation.

2.1.2 Intermediary Goods Producers Financial Market

To begin with, we do not explicitly model the financial institutions which are providing loans to firms. We simply assume that they can issue the required amount of credit. Second, if a match is separated and, as a result, the firm defaults, then its value is equal to 0 and the lender does not get any compensation. To ensure that firms do not default when the match is not separated, lenders impose a borrowing constraint whose tightness is defined by the parameter ϕ_t. Third, as in Monacelli, Quadrini and Trigari (2011), both old firm and entrant firm will choose the same level of debt because they are limited by the same borrowing constraint since choice of b_{t+1} does not depend on wage paid to workers as could be seen from equation 13.

The borrowing constraint can be expressed as

$$\frac{E_t[\pi_{t+1}]}{i_t}b_{t+1} = \phi_t(1-\eta)E_t[S_{t+1}].$$ (18)

Economically speaking, it has two important implications. First, it implies that firms are borrowing

against their future profit (denoted as their part of the expected bargaining surplus $E_t[S_{t+1}]$) which depends on workers' bargaining power, η. Second, we can think of ϕ_t as being the probability that the firm will repay its debt, hence it must be between 0 and 1. If it drops, then it means that most of the firms are not able to meet their financial commitments and, as a result, the aggregate level of borrowing falls.

We specify the $AR(1)$ process which perturbs the financial market (firms' repayment probability) as

$$\phi_t = \alpha_\phi \phi_{t-1} - \varepsilon_{\phi,t}, \tag{19}$$

where $\varepsilon_{\phi,t}$ is Gaussian white noise processes with 0 mean and variance σ^2 and α_ϕ is the persistency parameters of shock. It is noteworthy that the shock is negative in ϕ_t.

- **Choice of Debt**

Firms (entrant and old) will choose the maximum possible level of debt only when the borrowing (enforcement) constraint is binding. To see this, let firms maximize their equity value (13) subject to the borrowing constraint (18). If we denote the corresponding Lagrange multiplier by φ_t and substitute $E_t[J_{t+1}]$ using $J_t = (1-\eta)S_t$, the maximization exercise will become

$$\max \quad \frac{z}{X_t} - w_t - b_t + \frac{E_t[\pi_{t+1}]}{i_t} b_{t+1} + \beta(1-\lambda)(1-\eta)E_t[S_{t+1}], \tag{20}$$

$$\text{s.t.} \quad \frac{E_t[\pi_{t+1}]}{i_t} b_{t+1} = \phi_t(1-\eta)E_t[S_{t+1}].$$

First order conditions yield the following expression of the Lagrange multiplier

$$\varphi_t = \frac{\frac{E_t[\pi_{t+1}]}{i_t} - \beta(1-\lambda)(1-\eta)}{\frac{E_t[\pi_{t+1}]}{i_t} + \phi_t(1-\eta)}. \tag{21}$$

Since we have that $\frac{\pi}{i} = \beta$ in the steady state, equation 21 could be rearranged to

$$\varphi = \frac{\beta\left(1 - (1-\lambda)(1-\eta)\right)}{\beta + \phi(1-\eta)}. \tag{22}$$

From the above expression we can clearly see that in the steady state φ is positive if we restrict parameters λ, η and β to be in the interval between 0 and 1. Furthermore, we assume that shocks are 'small enough' as in Iacoviello (2005) and thus constraint is binding. This claim is formally summarized below.

Lemma 1 *The borrowing constraint is binding in the steady state if workers have any bargaining power ($\eta \in (0;1)$) and the match separation probability is positive ($\lambda \in (0;1)$).*

Proof. Follows directly from the first-order conditions of firms' optimization problem. ∎

2.1.3 Final Good Producers and Price Setting

We assume that the final good producers take the intermediary good and sell it to households in the sticky prices (Calvo 1983) framework and do not participate in either the financial or the labour market. They produce according to the following production function where ε is the elasticity of substitution and Y_t^f is the production of final goods

$$Y_t^f = \left(\int_0^N y_t^\varepsilon(i)di\right)^{\frac{1}{\varepsilon}}. \tag{23}$$

We assume that final goods are imperfectly substituted and that consumption is defined over the Dixit-Stiglitz (1977) basket of goods, $Y_t^f = \left[\int_0^1 Y_t(i)^{\frac{\varepsilon-1}{\varepsilon}} di\right]^{\frac{\varepsilon}{\varepsilon-1}}$. The average price level of the final good P_t, is known to be $P_t = \left[\int_0^1 p_t(i)^{1-\varepsilon} di\right]^{\frac{1}{1-\varepsilon}}$. The demand for each retailer's final good is given by

$$Y_t(i) = \left(\frac{p_t(i)}{P_t}\right)^{-\varepsilon} Y_t^f, \tag{24}$$

where $p_t(i)$ is the nominal price of the final good produced in industry i and $Y_t(i)$ denotes aggregate demand for a good produced in the i-th sector. Each retailer chooses the sale price $p_t(i)$ and buys the intermediary good at a price p_t^w which is taken as given. The final good sale price $p_t(i)$ could only be changed with probability $1 - \varpi$. Let us call the new price $p_t^*(i)$ and the corresponding demand $Y_{t+k}^* = \left(\frac{p_t^*(i)}{P_{t+k}}\right)^{-\varepsilon} Y_t^f$. The final good producers' profit maximization problem could be written as follows

$$\Pi_t(i) = \left(\frac{p_t^*(i)}{P_t} - \frac{P_t^w}{P_t}\right)\left(\frac{p_t^*(i)}{P_t}\right)^{-\varepsilon} Y_t^f. \tag{25}$$

For the sake of simplicity, we can substitute $\frac{p_t^*(i)}{P_{t+\tau}} = \frac{p_t^*(i)}{P_t}\frac{P_t}{P_{t+\tau}}$. Now we rewrite the optimization problem

$$\max_{p_t^*(i)} E_t \sum_{\tau=0}^{\infty} \varpi^{\tau} \beta^{\tau} \frac{\Lambda_{t+\tau}}{\Lambda_t}\left[\frac{p_t^*(i)}{P_t}\frac{P_t}{P_{t+\tau}} - \frac{P_{t+\tau}^w}{P_{t+\tau}}\right]\left(\frac{p_t^*(i)}{P_t}\frac{P_t}{P_{t+\tau}}\right)^{-\varepsilon} Y_{t+\tau}^f. \tag{26}$$

Because of the assumption that only a proportion of firms could change the prices every period, we know that the price index evolves according to the following law of motion

$$P_t = \left(\varpi P_{t-1}^{1-\varepsilon} + (1-\varpi)p_t^*(i)^{1-\varepsilon}\right)^{\frac{1}{1-\varepsilon}}. \tag{27}$$

Solving final good producers' optimization problem and using the law of motion of prices, we derive a standard New-Keynesian Phillips curve:

$$\beta\widehat{\pi}_{t+1} = \iota\widehat{X}_t + \widehat{\pi}_t, \tag{28}$$

where variables with hats denote deviations from the steady state and $\iota = \frac{(1-\varpi)(1-\varpi\beta)}{\varpi}$.

2.2   Households

There is a continuum of agents of total mass 1 with a lifetime utility. At any point in time, agents can be employed (and receive wage for labour provided) with probability p_t^E or unemployed with probability $\left(1 - p_t^E\right)$. We follow Ravenna and Walsh (2011) and use a CRRA functional form for households' utility

$$U_t^H = E_t \sum_{t=0}^{\infty} \beta^t \left[\frac{C_t^{1-\sigma}}{1-\sigma}\right], \tag{29}$$

where σ is a relative risk aversion. Households consume two kinds of goods: final goods C_t^m and domestically produced goods by unemployed agents captured by $a(1 - N_t)$

$$C_t = C_t^m + a(1 - N_t), \tag{30}$$

where a is the value of labour in domestic production (in real terms). We assume that everything that is produced in the economy is consumed by households, C_t^m, and firms, kv_t:

$$Y_t = C_t^m + kv_t. \tag{31}$$

Using definition of labour market tightness, θ_t, we rewrite equation 31 as

$$Y_t = C_t^m + k\theta_t u_t. \tag{32}$$

Rearranging (30) to $C_t^m = C_t - a(1 - N_t)$ and substituting it into (32), we obtain the economy's resource constraint

$$Y_t = C_t - a(1 - N_t) + k\theta_t u_t. \tag{33}$$

In addition, we show how the number of employed agents N_t affects output. For this purpose, substitute equations 5 and 33

$$Y_t = C_t - a(1 - N_t) + k\theta_t(1 - (1 - \lambda)N_{t-1}). \tag{34}$$

This expression shows that output increases with N_t.

The household's liquidity position I_t is defined as the sum of income received from employed members and value of domestically produced goods by unemployed members

$$I_t = w_t N_t + a(1 - N_t). \tag{35}$$

We also let households hold assets that could be used as savings. Next period's assets A_{t+1}^h (in nominal terms) are defined as follows

$$A_{t+1}^h = A_t^h i_t - P_t C_t + W_t N_t + a(1 - N_t)P_t + \Pi_t, \tag{36}$$

where W_t is the nominal wage and the nominal profit of firms is captured by Π_t.

Now we can state the household optimization problem

$$\max E_t \sum_{t=0}^{\infty} \beta^t \left[\frac{C_t^{1-\sigma}}{1 - \sigma} \right], \tag{37}$$

$$\text{s.t. } A_{t+1}^h = A_t^h i_t - P_t C_t + W_t N_t + a(1 - N_t)P_t,$$

which leads to the following definitions. The marginal utility of consumption (in real terms)

$$\Lambda_t = \frac{C_t^{-\sigma}}{P_t}, \tag{38}$$

and the interest rates

$$\frac{1}{i_t} = \beta E_t \left[\frac{\Lambda_{t+1}}{\Lambda_t} \right]. \tag{39}$$

Combining the two above equations, we obtain household's Euler equation

$$\frac{1}{i_t} = \beta E_t \left[\frac{C_{t+1}^{-\sigma}}{C_t^{-\sigma} \pi_{t+1}} \right]. \tag{40}$$

2.3 Parametrization and Solution

We analytically solve for the steady state and use the values for simulating the model. Furthermore, we find that in the optimal steady state, prices are stable, that is $\pi = 1$, where π is the steady state inflation. This result could be seen from the policy maker's optimization problem.

As in Ravenna and Walsh (2011) we assume the period to be one quarter and set the discount factor to $\beta = 0.99$. The bargaining power parameter η is set to be equal to 0.5 because there is no direct evidence of a different estimate. Then, we follow Monacelli, Quadrini and Trigari (2011) and

set matching parameters $\varsigma = 0.76$ and $\alpha = 0.5$. The value of the constant ς in the Cobb-Douglas matching function is consistent with the Hall (2003) estimate. Steady state productivity is normalized to 1 and we take the values of firms' repayment probability ϕ, the cost of posting the vacancy k and value of labour in domestic production a from the Monacelli, Quadrini and Trigari (2011) calibration. The price adjustment probability ϖ is taken to be standard and equal to 0.25 together with the price elasticity parameter $\varepsilon = 6$ (Basu and Fernald 1997). We take relative risk aversion σ to have its usual value (for instance Ravenna and Walsh 2011) and set it equal to 2. Finally, we set persistence parameters of shocks to 0.9 to smooth the impulse response functions. All values are summarized in Table 1 in the appendix.

We solve the model by taking a log-linear approximation around the local and deterministic steady state. Shocks are assumed to be small enough and occurring in the neighborhood of the steady state and therefore, the equilibrium conditions are satisfied.

2.4 Welfare Computation

We use the Benigno and Woodford (2012) methodology to compute the welfare measure and rank the policy rules according to their performance as is suggested in Damjanovic et al. (2011).

To construct welfare measure, we let the policy maker optimize households' utility (equation 29) subject to the constraints of the economy captured by the following equations 3, 4, 10, 11, 12, 34, 14, 18, 28 and 40. According to Benigno and Woodford (2012), the general expression of the welfare approximation W_t is given by

$$W_t = U_t + \sum_{t=0}^{\infty} \Gamma_t S_t^W + t.i.p. + O^3 \tag{41}$$

where U_t is the household utility function, S_t^W are constraints, $t.i.p.$ are terms independent of policy and O^3 are terms of the higher order which can be disregarded. We approximate welfare up to the second order (see Kim and Kim (2003) for details). System of equations is provided in the Appendix.

We use this algorithm to compare different monetary policy regimes and rank policy rules according to the welfare loss. Additionally, we look at the consumption equivalence, which shows how much consumption agents are willing to give up when in the optimal policy regime in order to be as good as in the other regime. Based on the households' utility function (29) we can write the following definition

$$W^0 = x^{1-\sigma} W^P, \tag{42}$$

where W^O is the welfare measure in the optimal policy regime, W^P is welfare in any other regime and x is defined the as consumption equivalence. Then x is given by

$$x = \left(\frac{W^0}{W^P}\right)^{\frac{1}{1-\sigma}}. \tag{43}$$

This is the consumption equivalence used in Table 2 expressed in percentage terms.

3 Monetary Policy

In this section, we investigate the policy maker's reaction to the financial market shock. First, we derive the optimal monetary policy reaction. Second, we introduce two policy rules in the spirit of Taylor (1993). Finally, we rank monetary policy regimes according to the welfare measure and the consumption equivalence.

3.1 Optimal Policy

To derive the optimal policy reaction, we let the central bank maximize households' utility (29) subject to the behavioral constraints presented in equations 3, 4, 10, 11, 12, 14, 18, 28, 34 and 40 which are summarized in Table 3 provided in the Appendix. The formal specification of the optimal monetary policy is showed in the Appendix.

3.2 Monetary Policy Rules

We consider these monetary policy rules:[1] (1) Inflation and unemployment response and (2) Inflation and firms' borrowing response.

To investigate the monetary authority's preferences towards the response variables in the monetary policy rules, we search numerically for the values which would give the highest welfare. We consider all parameters in the intervals where Blanchard-Kahn (1980) conditions are satisfied. The parameter values that we received from searching the highest welfare are provided in the table below. We use these to compute impulse response functions and compare monetary policy regimes.

Table 1. Monetary Policy Rules and Parameter Values

Policy	Functional Form	Parameter Values	Parameter Intervals
1.	$\widehat{i}_t = \alpha_\pi \widehat{\pi}_t + \alpha_u \widehat{u}_t$	$\alpha_\pi = 1.5$, $\alpha_u = -0.17$,	$\alpha_\pi = [1.5; 3.0]$, $\alpha_u = [-2.0; 0.05]$
2.	$\widehat{i}_t = \alpha_\pi \widehat{\pi}_t + \alpha_b \widehat{b}_t$	$\alpha_\pi = 3.0$, $\alpha_b = 0.23$.	$\alpha_\pi = [1.5; 3.0]$, $\alpha_b = [0.01; 2.0]$

As we can see from Table 2, according to both welfare and consumption equivalence measures, the interest rate rule with inflation and unemployment responses is better than the rule with inflation and borrowing responses. Optimal policy, as expected, gives the highest welfare.

Table 2. Monetary Policy Rules and Welfare

Policy	Welfare	Consumption Equivalence
Inflation and Unemployment Response	-2.858	44%
Inflation and Borrowing Response	-3.108	57%
Optimal policy	-1.975	–

3.3 Relation between Labour Market Response and Bargaining Power

In the previous literature (for example Faia (2008, 2009) and Proano (2012)), it was pointed out that the aggregate level of unemployment should have a relatively large positive coefficient in the interest rate rule. In this section, we show that the sign next to the unemployment response in the Taylor rule depends on the extent of the bargaining power of workers.

To begin with, we set $\alpha_\pi = 3.0$ in the first policy rule from Table 1 and simulated the model for two cases: $\alpha_u = -2.0$ and $\alpha_u = 0.01$. Then we computed welfare for various values of workers bargaining power, η, and provided the result in the left panel of Figure 1. In addition, we calculated values of unemployment and borrowing in the steady state for the range of η (depicted in the right panel of Figure 1). We have found that if $\eta < 0.5$, then the policy maker should set α_u to -2.0 to achieve higher welfare; if $\eta > 0.5$ then α_u should be 0.01.

To further illustrate the relation between workers bargaining power, borrowing, wage and surplus, we expressed wage and surplus as functions of borrowing in the steady state. They are given by the

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[1]We have also investigated a standard Taylor rule with an inflation and output response as well as a rule with an inflation only response. The results from using these rules are almost the same as the inflation and borrowing response.

following expressions[2]

$$S(b) = ((1-\lambda)\beta - 1) S - \eta\beta \left(\frac{k}{(\phi+\beta)(1-\eta)} \right)^{-\frac{\alpha}{1-\alpha}} \varsigma^{\frac{\alpha}{1-\alpha}} S^{\frac{1}{1-\alpha}} + \frac{z}{X} - a - b + \beta b, \qquad (44)$$

$$w(b) = \underbrace{(1-\eta)\, a + \eta \left(\frac{z}{X} - b \right)}_{\text{Direct Effect}} + \underbrace{(1-\eta)\eta \left(S^b \phi + (S^b)^{\frac{1}{1-\alpha}} \left(\frac{k}{(\phi+\beta)(1-\eta)} \right)^{-\frac{\alpha}{1-\alpha}} \varsigma^{\frac{\alpha}{1-\alpha}} \beta \right)}_{\text{Value Effect}}, \qquad (45)$$

where S^b in (45) is given by the positive solution to (44). Then we numerically evaluated $\frac{\partial S(b)}{\partial b}$ and $\frac{\partial w(b)}{\partial b}$ in the range of $\eta \in (0;1)$, $\phi \in (0;1)$ and at a prevailing steady state value of borrowing. The results are provided in Figure 2.

Expression 45 shows that borrowing has direct and value effects on wage. The direct effect decreases wage as borrowing increases and the extent of it depends on workers bargaining power. The value effect increases with S and is negatively related to b. Therefore as borrowing falls (due to decrease in ϕ) both effects decrease wage as it is illustrated in Figure 2.

The position that policy maker should respond negatively to unemployment in the policy rule when $\eta < 0.5$ could be summarized as follows: when workers have little bargaining power, then in the steady state borrowing is high (this could be seen from expression 18), unemployment is low. This case is showed in Figure 1, right panel. When the financial shock hits, ϕ falls and as a result borrowing drops as could be seen from equation 18. Then surplus increases at a decreasing rate (showed in Figure 2, left panel) which reduces wage (Figure 2, right panel). Also, notice that the convex shape of $\frac{\partial S(b)}{\partial b}$ has one more intuitive interpretation: when $\eta < 0.5$ and borrowing is high, returns of one extra unit of debt increases surplus at an increasing rate as η tends to 0. This means that as workers loose their bargaining power, wage is falling at a decreasing rate (which could also be seen from Figure 2, right panel). In this case policy maker should respond negatively to unemployment in the policy rule and reduce interest rate. This encourages firms to issue more debt which in turn decreases unemployment to the previous level.

Figure 1. Welfare and Workers' Bargaining Power, $\alpha = 0.5$

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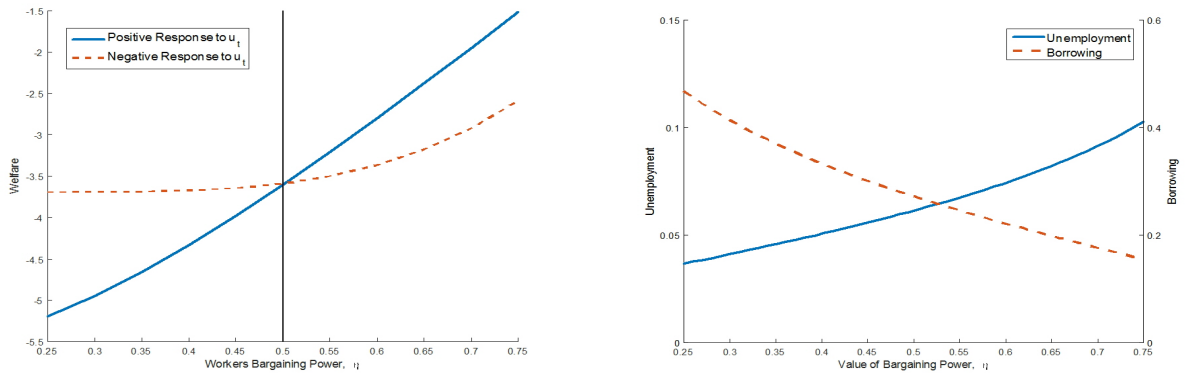
[2] Both (44) and (45) can be derived using steady state solution of the model. Also notice, that assuming $\alpha = 0.5$ (which is the case) (44) simplifies to quadratic equation with one positive and one negative solution. To obtain figure 2, we have differentiated the positive solution with respect to b.

Figure 2. Derivatives of $S(b)$ and $w(b)$ w.r.t. b, $\alpha = 0.5$
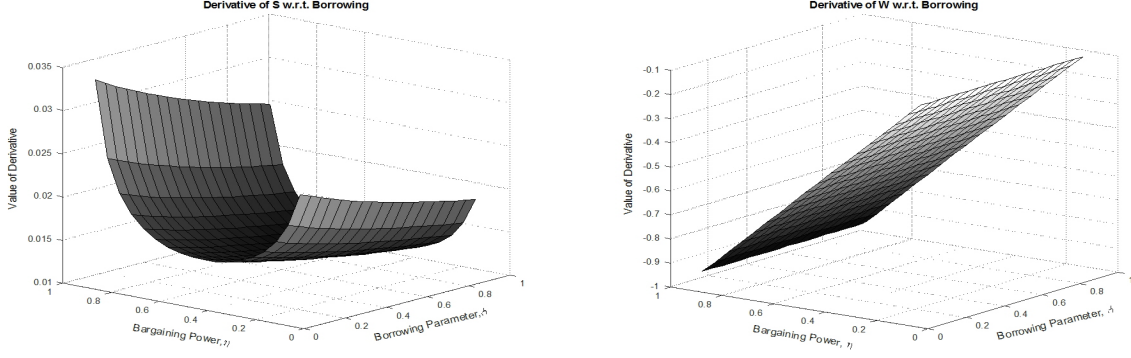
On the other hand, when $\eta > 0.5$ borrowing is low (could be seen from expression 18), unemployment is high in steady state (shown in Figure 1 right panel). The reason for this is the fact that the bargaining surplus now is large (due to small debt) and as a result wage paid to workers is high too. This decreases firms demand for labor and therefore unemployment is high. When ϕ falls, borrowing is reduced which increases surplus and increases both wage and unemployment even further. As wage is higher, inflation increases too. The central bank in this case should respond positively to an increase in unemployment and raise interest rates. This would discourage firms to issue more debt and as a result bargaining surplus would increase bringing back wage and unemployment to the initial levels.

In addition, as could be seen from Figure 2, left panel, when $\eta > 0.5$ and ϕ falls, each extra unit of borrowing raises surplus at an increasing rate. When the value of workers bargaining power is large and ϕ deteriorates, wage decreases at higher rate than in the case when $\eta < 0.5$.

To investigate how the optimal policy responds to financial market shock we have computed impulse responses of selected variables for different values of η (bargaining power of workers) as in Faia (2009). According to Hosios (1990), when the workers bargaining power is equal to the share of unemployed workers in the matching function (captured by parameter α), unemployment is at the socially efficient rate. If bargaining power is above this value, then equilibrium unemployment is larger than the socially optimum level and vice versa.

Figure 3. Optimal Policy Response to Negative Financial Shock, $\alpha = 0.5$
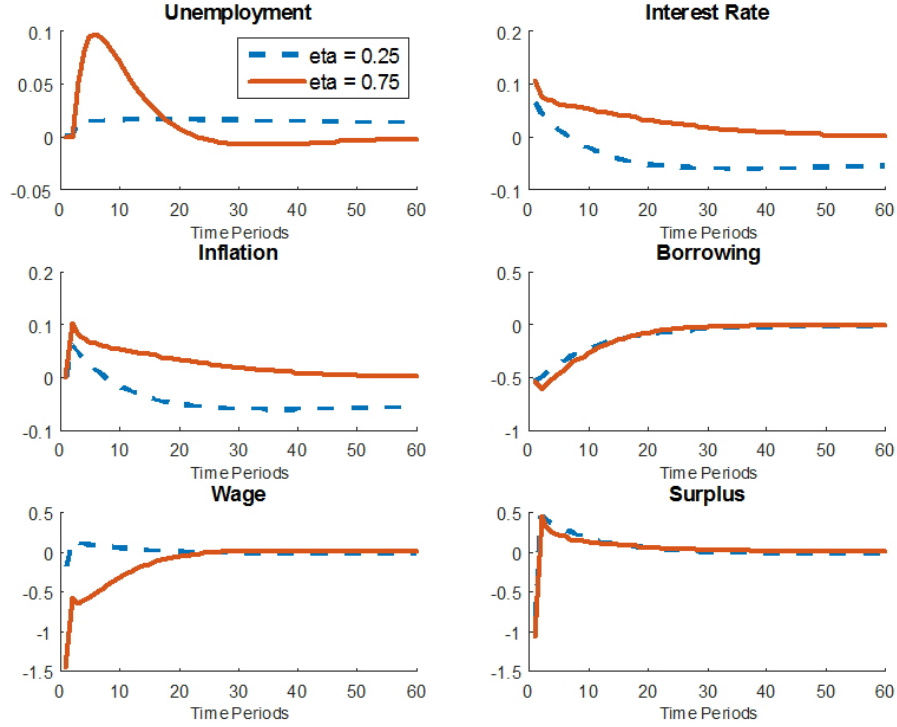
When unemployment is below the optimal level ($\eta < 0.5$) firms have to increase wage since there is a shortage of available workers; higher wages implies higher inflation too. To mitigate such effects occurring due to the financial market shock, monetary authority reduces interest rate which in turn stimulates borrowing thus reducing wage and lowering inflation.

In contrast to Faia (2008, 2009) that investigated Ramsey monetary policy in the framework without the financial market, in this case firms borrowing adds extra term which can increase or decrease bargaining surplus (equation 14) dependent on the interest rate and borrowing parameter ϕ. That is, central bank can alter the incentive of firms to post vacancies by changing interest rate.

These findings are also similar to Blanchard and Gali (2010) where it is shown that optimal monetary policy should respond to both inflation and unemployment fluctuations when the productivity shock hits. The presence of the labour market frictions which results in substantial fluctuations in unemployment is the reason why strict inflation only response is not able to stabilize the economy. Therefore, the monetary authority should respond to both unemployment and inflation as in Blanchard and Gali (2010). We find that such Taylor-type rule is the closest one to the optimal policy in terms of the welfare measure as it shown in Table 2.

In summary, when according to the Hosios condition unemployment is above social optimum, the monetary authority (in optimal case) has to increase interest rate to reduce firms borrowing. This in turn decreases level of unemployment as shown above. Whereas, when unemployment is below social optimum the central bank shifts its efforts towards reducing cost of inflation. This is achieved by reducing interest rate and thus increasing firms borrowing which in turn decreases both surplus and wage that causes unemployment to rise. As a result wage and inflation fall as can be seen from Figure 3.

3.4 Relation between the Financial and the Labour Market

To illustrate the channel through which the financial market influences the labour market, we computed the steady state wage and unemployment for different values of the borrowing parameter ϕ. As we can see from Figure 4, a higher value of ϕ reduces unemployment and increases wage. We can distinguish two cases. First, if ϕ has a very high value, firms can easily issue more debt, thus decreasing the bargaining surplus and wage. As a result unemployment falls. However, due to the decrease in unemployment, it is harder for firms to find the right match and thus, they are forced to increase wage.

Second, if ϕ has a very low value, firms cannot access the financial market and thus, borrowing is low and the bargaining surplus is large (as could be seen from equation 14). For this reason, the wage paid to workers is high. As a result, unemployment increases as we can see from Figure 4. Since unemployment is high, firms can reduce the wage because it becomes easier to find a match.

Figure 4. Financial and Labour Markets
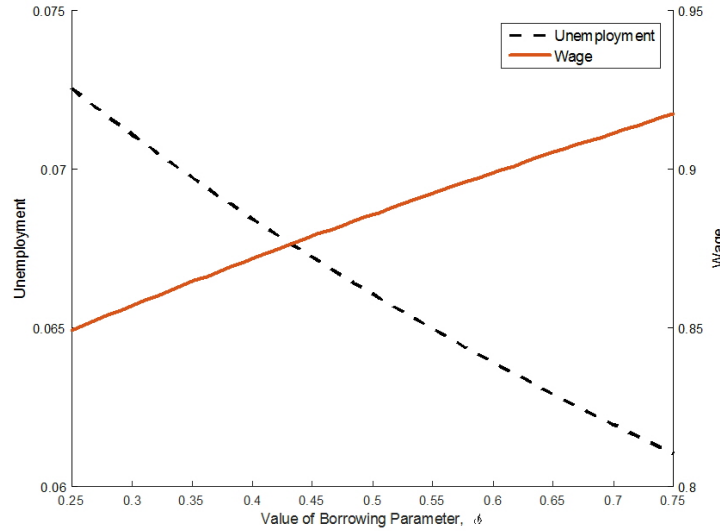
It is noteworthy that a similar relation between wage and unemployment is also found in some empirical studies, such as Apergis (2008) where 10 different OECD countries are examined in the period 1995-2005, finding that wage decrease as unemployment increases. In addition, our result suggests that the less stringent borrowing constraint of firms (higher value of ϕ) decreases unemployment which agrees with Acemoglu's (2001) remark that easier access to the financial market may reduce unemployment. In the next section, we compute impulse response functions to illustrate how this mechanism works in more detail.

3.5 Response to a Financial Market Shock

We can see that the shock to the repayment probability ϕ_t causes a significant drop in firms' borrowing and as a result of the mechanism described earlier, an increase in unemployment. This is intuitive, because as ϕ_t drops, borrowing falls. The vacancy filling probability q_t is affected through the same channel. As borrowing falls, bargaining surplus increases and hence, firms start laying off workers as can be seen in Figure 5. This results in an increase in the vacancy filling probability because now there are more available workers than vacancies and hence, it becomes easier for the firm to find the right match for the posted vacancy.

Figure 5 shows that the rule that entails a response to the labor market and inflation, increases unemployment and interest rate. The optimal policy (shown in straight line) demonstrates the quickest convergence back to the steady state levels as compared to other regimes.

Figure 5. Impulse Response Functions to Repayment Probability Shock
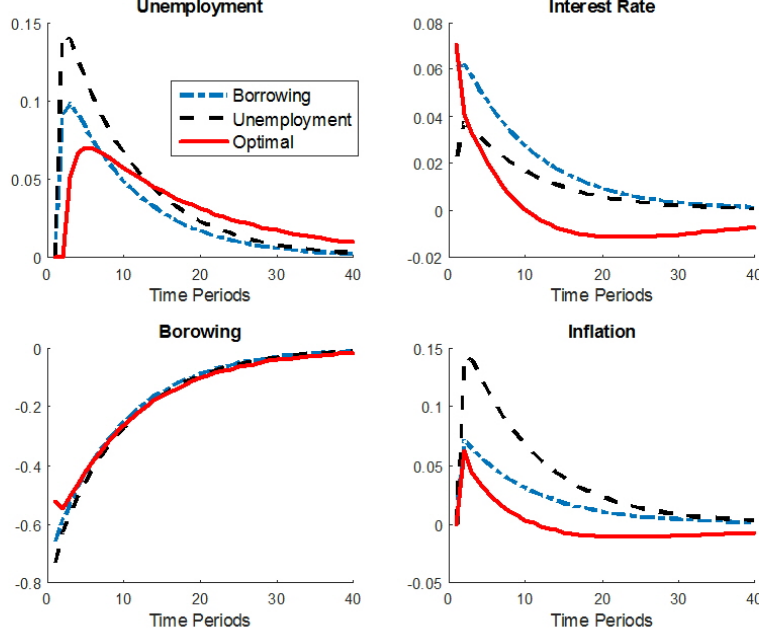
From Figure 5, we can see that the mechanism described in the previous section does indeed work. For example, we can see that after firms' borrowing falls (due to the reduction in ϕ_t), the bargaining surplus increases and workers receive lower wage (top left panel in Figure 6) in the next period since entrant firms start paying wages only in the next period.

For old firms, the wage dynamics could be explained in the following way. The wage that is paid to workers when the shock occurs had been bargained in the previous period and thus, cannot be changed. It means that the income received by parties over their lifetime will not change. But since both parties anticipate that the wage will increase in the future, the current wage has to fall. This can be seen in Figure 6, top left panel. Furthermore, firms prefer having a higher debt because it allows them to reduce their future wages. At the same time, workers anticipate this by demanding higher current wages for the given level of unemployment.

Figure 6. Impulse Response Functions to Repayment Probability Shock
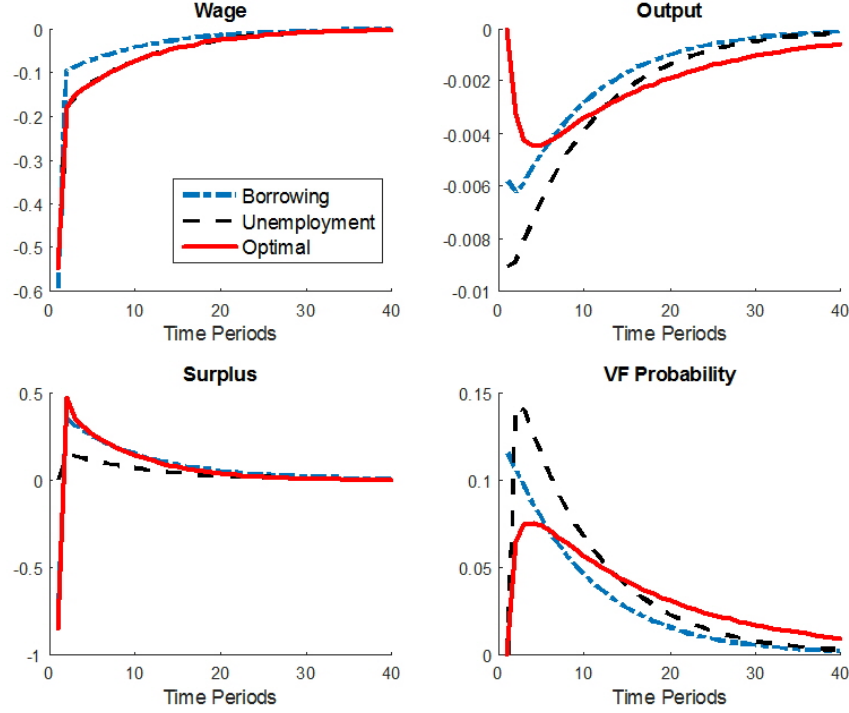
Moreover, the dynamics of the model vary depending on which monetary policy rule is implemented. Consider the regime with inflation and borrowing response first. As shown in Figure 5, borrowing falls, but the surplus only increases in the next period because firms issue debt based on the expected future surplus. As a result, there is a decrease in wage (Figure 6, top left panel) and output. Since borrowing falls, the interest rate also decreases because of the mechanism described in subsection 3.4.

In summary, it is clear that firms' borrowing parameter ϕ_t affects the labour market through the wage bargaining process. To minimize the negative effect of financial market shock, the central bank should use the interest rate rule with inflation and unemployment responses as it is the closest one to the optimal policy in terms of the welfare measure.

4   Conclusion

In this note, we have presented an economy with labour and financial market frictions. We have used a matching model (Pissarides 1987) to account for the imperfections in the labour market and the enforcement constraint (as in Monacelli, Quadrini and Trigari 2011) to account for financial frictions which let us investigate the relation between firms' borrowing and unemployment. Further to this, we have derived the optimal policy reaction of the central bank. Then, we have introduced two different Taylor type monetary policy rules and ranked them according to the consumption equivalence and the welfare measure which was computed using Beningno and Woodford (2012) methodology. The key findings can be summarized as follows.

First, due to relation between financial market and labour market the model suggests that changes in unemployment can be partially explained by the changes in firms' credit market.

Second, the monetary policy rule with response to inflation and labour market frictions (the aggregate level of unemployment) performs closest to the optimal policy in terms of the welfare measure and the consumption equivalence.

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Third, the feedback on unemployment in the interest rate rule depends on the size of workers' bargaining power. Firms in our model are borrowing to reduce the bargaining surplus and therefore, the policy maker can indirectly influence the outcome of the wage bargaining process by changing the interest rate, thus altering the firms' borrowing decision. If, for example, workers have much less bargaining power than firms and negative financial shock hits, then the policy maker should reduce the interest rate, i.e. respond negatively to unemployment in the interest rate rule. This would encourage firms to issue more debt (because of a lower interest rate), thus reducing the bargaining surplus and the wage which would stabilize unemployment.

5   Appendix

Table 3. List of Parameter Values

Parameter	Description	Value
β	Households' discount factor	0.99
η	Workers' bargaining power	0.5
ε	Price elasticity parameter	6
ς	Matching parameter	0.76
λ	Probability of match separation	0.05
k	Cost of posting vacancy	0.598
a	Value of labour in domestic production	0.5
z	Productivity	1.0
ϕ	Borrowing parameter	0.86
ϖ	Probability that price will not change	0.75
σ	Relative risk aversion	2.0
α	Matching parameter (elasticity)	0.5
α_ϕ	Financial market shock persistence	0.9

Table 4. Model Summary

Description	Equation
Bargaining Surplus	$S_t = \frac{z}{X_t} - a - b_t + \frac{E_t[\pi_{t+1}]}{i_t} E_t[b_{t+1}] + (1-\lambda)\beta E_t[S_{t+1}] - \eta\beta p_t^E E_t[S_{t+1}]$
Borrowing Constraint (Firms)	$\frac{E_t[\pi_{t+1}]}{i_t} E_t[b_{t+1}] = \phi_t(1-\eta)E_t[S_{t+1}]$
Borrowing and Labour Market	$\frac{k}{q_t} = \frac{E_t[\pi_{t+1}]}{i_t} E_t[b_{t+1}] + \beta(1-\eta)E_t[S_{t+1}]$
Euler Equation (Households)	$\frac{1}{i_t} = \beta E_t\left[\frac{C_{t+1}^{-\sigma}}{C_t^{-\sigma}\pi_{t+1}}\right]$
Phillips Curve (Linearized)	$\beta\widehat{\pi}_{t+1} = \iota\widehat{X}_t + \widehat{\pi}_t$
Output and Employment	$Y_t = C_t - a(1-N_t) + k\theta_t u_t$
Job Finding Probability	$p_t^E = q_t^{-\frac{\alpha}{1-\alpha}} \varsigma^{\frac{\alpha}{1-\alpha}}$
Labor Market Tightness	$p_t^E = \varsigma\theta_t^\alpha$
Final Good Production	$Y_t = zN_t$
Number of Employed Agents	$N_t = (1-\lambda)N_{t-1} + \varsigma\theta_t^\alpha(1 - (1-\lambda)N_{t-1})$

5.1 Derivation of wage equation

First, consider equation (1) from the paper that defines the value of the filled vacancy. By using the borrowing constraint (18) to eliminate $\frac{E[\pi_{t+1}]}{i_t} b_{t+1}$ and by employing the vacancy posting condition (2) we obtain

$$E_t\left[S_{t+1}\right] = \frac{k}{q_t(1-\eta)\left(\phi_t + \beta\right)}. \tag{46}$$

Now we use the expression for the bargaining surplus (14) and substitute $\frac{E[\pi_{t+1}]}{i_t} b_{t+1}$ from (18):

$$S_t = \frac{z}{X_t} - a - b_t + \frac{E\left[\pi_{t+1}\right]}{i_t} b_{t+1} + \left(\phi_t(1-\eta) + \left(1 - \lambda - \eta p_t^E\right)\beta\right) E_t\left[S_{t+1}\right] \tag{47}$$

Substitution of $E_t\left[S_{t+1}\right]$ from (46) yields

$$S_t = \frac{z}{X_t} - a - b_t + \frac{k\left(\phi_t(1-\eta) + \left(1 - \lambda - \eta p_t^E\right)\beta\right)}{q_t(1-\eta)\left(\phi_t + \beta\right)}. \tag{48}$$

Next, consider the net value of a worker given by $V_t - U_t$ (equations 15 and 16):

$$V_t - U_t = w_t - a + \beta\left(1 - \lambda - p_t^E\right)\left(V_{t+1} - U_{t+1}\right), \tag{49}$$

since we know that $V_t - U_t = \eta S_t$, we can use this to simplify the above expression

$$\eta S_t = w_t - a + \beta\left(1 - \lambda - p_t^E\right)\eta E_t\left[S_{t+1}\right]. \tag{50}$$

Now, use equation (46) to eliminate $E_t\left[S_{t+1}\right]$

$$\eta S_t = w_t - a + \frac{k\beta\left(1 - \lambda - p_t^E\right)\eta}{q_t(1-\eta)\left(\phi_t + \beta\right)}. \tag{51}$$

Finally, combining expressions (48) and (51) and solving for wage, we obtain

$$w_t = (1 - \eta)a + \eta\left(\frac{z}{X_t} - b_t\right) + \frac{\eta k\left[\phi_t + p_t^E \beta\right]}{q_t\left(\phi_t + \beta\right)}, \tag{52}$$

which is exactly the same as we have in the main text.

5.2   Optimal Monetary Policy

Policy maker's optimization problem is given by:

$$
L = E_t \sum_{t=0}^{\infty} \beta^t \left[
\begin{array}{c}
\frac{C_t^{1-\sigma}}{1-\sigma} \\
+\Gamma_{1,t}\left(S_t - \frac{z}{X_t} + a + b_t - \frac{E[\pi_{t+1}]}{i_t}b_{t+1} - (1-\lambda)\beta E_t\left[S_{t+1}\right] + \eta\beta q_t^{-\frac{\alpha}{1-\alpha}}\varsigma^{\frac{\alpha}{1-\alpha}}E_t\left[S_{t+1}\right]\right) \\
+\Gamma_{2,t}\left(\frac{E[\pi_{t+1}]}{i_t}b_{t+1} - \phi_t(1-\eta)E_t\left[S_{t+1}\right]\right) \\
+\Gamma_{3,t}\left(\frac{k}{q_t} - \frac{E[\pi_{t+1}]}{i_t}b_{t+1} - \beta(1-\eta)E_t\left[S_{t+1}\right]\right) \\
+\Gamma_{4,t}\left(\frac{1}{i_t} - \beta E_t\left[\frac{C_{t+1}^{-\sigma}}{C_t^{-\sigma}\pi_{t+1}}\right]\right) \\
+\Gamma_{5,t}\left(\left[\frac{1-w\pi_t^{\epsilon-1}}{1-w}\right]^{\frac{1}{1-\epsilon}}K_t - \frac{\epsilon}{\epsilon-1}Z_t\right) \\
+\Gamma_{6,t}\left(K_t - zN_t - w\frac{1}{i_t}\pi_{t+1}^{\epsilon-1}K_{t+1}\right) \\
+\Gamma_{7,t}\left(Z_t - \frac{zN_t}{X_t} - w\frac{1}{i_t}\pi_{t+1}^{\epsilon}Z_{t+1}\right) \\
+\Gamma_{8,t}\left(zN_t - C_t + a(1-N_t) - kq_t^{-\frac{1}{1-\alpha}}\varsigma^{\frac{2\alpha-1}{\alpha(1-\alpha)}}\left(1-(1-\lambda)N_{t-1}\right)\right) \\
+\Gamma_{9,t}\left(N_t - (1-\lambda)N_{t-1} - q_t^{-\frac{\alpha}{1-\alpha}}\varsigma^{\frac{\alpha}{1-\alpha}}\left(1-(1-\lambda)N_{t-1}\right)\right)
\end{array}
\right]
$$

where $\Gamma_{1,t} - \Gamma_{9,t}$ are Lagrange multipliers of corresponding constraints.

5.3   Second Order Welfare Approximation

To compare welfare under different monetary policy regimes we compute second order approximation using Benigno and Woodford (2005). It is done by applying the following formula to policy maker's constraints:

$$
S^W(X_t, Y_t) = \frac{\partial S^2}{\partial^2 X}X^2\widehat{X}_t^2 + \frac{\partial S^2}{\partial^2 Y}Y^2\widehat{Y}_t^2 + 2\frac{\partial S^2}{\partial Y\partial X}YX\widehat{Y}_t\widehat{X}_t
$$

where S^W is the constraint of policy maker's optimization problem. The second order approximation is then given by:

$$S_0^W = -\sigma C^{1-\sigma}\widehat{C}_t^2$$

$$
\begin{aligned}
S_1^W =\ & -2\frac{z}{X}\widehat{X}_t^2 + 2\frac{b}{i}\widehat{i}_t\widehat{b}_{t+1} + 2\frac{b}{i}\widehat{i}_t\widehat{\pi}_{t+1} - 2\frac{b}{i}\widehat{b}_{t+1}\widehat{\pi}_{t+1} - 2\frac{b}{i}\widehat{i}_t^2 \\
& -2\frac{\alpha}{1-\alpha}\eta\beta q^{-\frac{\alpha}{1-\alpha}}\varsigma^{\frac{\alpha}{1-\alpha}}S\widehat{S}_{t+1}\widehat{q}_t + \frac{\alpha}{1-\alpha}\frac{1}{1-\alpha}\eta\beta q^{-\frac{\alpha}{1-\alpha}}\varsigma^{\frac{\alpha}{1-\alpha}}S\widehat{q}_t^2
\end{aligned}
$$

$$S_2^W = -2\frac{b}{i}\widehat{b}_{t+1}\widehat{i}_t - 2\frac{b}{i}\widehat{i}_t\widehat{\pi}_{t+1} + 2\frac{b}{i}\widehat{b}_{t+1}\widehat{\pi}_{t+1} - 2\phi\widehat{\phi}_t(1-\eta)S\widehat{S}_{t+1} + 2\frac{b}{i}\widehat{i}_t^2$$

$$S_3^W = 2\frac{k}{q}\widehat{q}_t^2 + 2\frac{b}{i}\widehat{i}_t\widehat{b}_{t+1} + 2\frac{b}{i}\widehat{i}_t\widehat{\pi}_{t+1} - 2\frac{b}{i}\widehat{b}_{t+1}\widehat{\pi}_{t+1} - 2\frac{b}{i}\widehat{i}_t^2$$

$$S_4^W = 2\frac{1}{i}\widehat{i}_t^2 - 2\beta\widehat{\pi}_{t+1}^2 + \beta\sigma(-\sigma-1)\widehat{C}_{t+1}^2 - \sigma\beta(\sigma-1)\widehat{C}_t^2 + 2\beta\sigma^2\widehat{C}_t\widehat{C}_{t+1}$$

$$S_5^W = \frac{w}{1-w}K\left(\varepsilon\left(\frac{w}{1-w}\right) + (\varepsilon-2)\right)\widehat{\pi}_t^2 + 2\frac{w}{1-w}K\widehat{K}_t\widehat{\pi}_t$$

$$
\begin{aligned}
S_6^W =\ & -w(\varepsilon-1)(\varepsilon-2)\frac{K}{i}\widehat{\pi}_{t+1}^2 - 2w\frac{1}{i}K\widehat{i}_t^2 + 2w(\varepsilon-1)\frac{1}{i}K\widehat{i}_t\widehat{\pi}_{t+1} \\
& +2w\frac{1}{i}K\widehat{i}_t\widehat{K}_{t+1} - 2w(\varepsilon-1)\frac{1}{i}K\widehat{K}_{t+1}\widehat{\pi}_{t+1}
\end{aligned}
$$

$$
\begin{aligned}
S_7^W =\ & -w\varepsilon(\varepsilon-1)\frac{1}{i}Z\widehat{\pi}_{t+1}^2 - 2w\frac{1}{i}Z\widehat{i}_t^2 + 2\frac{zN}{X}\widehat{N}_t\widehat{X}_t - 2\frac{zN}{X}\widehat{X}_t^2 \\
& +2w\varepsilon\frac{1}{i}\widehat{i}_t\widehat{\pi}_{t+1}Z - 2w\frac{\varepsilon}{i}Z\widehat{Z}_{t+1}\widehat{\pi}_{t+1} + 2w\frac{1}{i}Z\widehat{Z}_{t+1}\widehat{i}_t
\end{aligned}
$$

$$S_8^W = \frac{1}{1-\alpha}\frac{\alpha-2}{1-\alpha}kq^{-\frac{1}{1-\alpha}}\varsigma^{\frac{2\alpha-1}{\alpha(1-\alpha)}}(1-(1-\lambda)N)\widehat{q}_t^2 - 2\frac{1}{1-\alpha}kq^{-\frac{1}{1-\alpha}}\varsigma^{\frac{2\alpha-1}{\alpha(1-\alpha)}}(1-\lambda)\widehat{q}_tN\widehat{N}_{t-1}$$

$$S_9^W = -\frac{\alpha}{1-\alpha}\frac{1}{1-\alpha}q^{-\frac{\alpha}{1-\alpha}}\varsigma^{\frac{\alpha}{1-\alpha}}(1-(1-\lambda)N)\widehat{q}_t^2 - 2\frac{\alpha}{1-\alpha}q^{-\frac{\alpha}{1-\alpha}}\varsigma^{\frac{\alpha}{1-\alpha}}(1-\lambda)\widehat{q}_tN\widehat{N}_{t-1}$$

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