Monetary policy and the adjustment cost between money and assets*

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ABSTRACT

This paper considers monetary policy when an adjustment cost between money and an asset exists. My findings are as follows: First, a positive money growth shock generates a significant decrease in the nominal interest rate through households' portfolio rebalances (the liquidity effect). Second, the determinacy of the model depends on the portfolio adjustment cost of the money and asset. According to the value of the portfolio adjustment cost, a monetary policy must raise the nominal interest rate aggressively in response to a rise in inflation in order to bring the economy to the locally unique equilibrium. Third, a money velocity shock affects the entire economy even though the monetary policy is based on the Taylor rule. Finally, the monetary authority might be able to mitigate the effects of a negative money velocity shock if the monetary authority controls the money growth so as to keep the interest rate fixed. If the money growth rule can be regarded as a strand of a quantitative easing policy, I conclude that the quantitative easing rule might be effective to prevent the economy from the effect of decreasing the money velocity.

Keywords: monetary policy, adjustment cost, liquidity effect, interest rate

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1. Introduction

In theory, a central bank can stimulate the economy by expanding the supply of base money even though the short-term nominal interest rate is close to zero. This is often called *quantitative easing*. The rebalancing of investors' portfolio rebalance is one of the important channels in quantitative easing. According to Bernanke and Reinhart (2004), when the money is an imperfect substitute for other assets, increases in the monetary base can stimulate the economy by encouraging investors' portfolio rebalances and then decreasing the yields of assets. This channel has been analyzed in several papers in the dynamic stochastic general equilibrium (DSGE) literature: Andrés *et al*. (2004) described a model with an imperfect substitution between short-term assets and long-term assets, and they determined the monetary policy channel through the relative price of alternative assets. Chen *et al*. (2012) and Harrison (2012) analyzed the effect of an asset purchase policy on the economy through the portfolio rebalance channel at the zero lower bound. These papers focused mainly on the economic stimulus provided by quantitative easing through an imperfect substitution.

Here, however, I considers the implications of the monetary policy as well as that of stimulating the economy when a strong imperfect substitution between money and assets exists.[1] I introduce the adjustment cost in money and an asset (i.e., a bond) into a household’s preference, which is similar to the specification by Andrés *et al*. (2004). The reasons for this assumption of an adjustment cost in money and assets are (i) it provides a short cut, and (ii) it enables modeling the liquidity of money. The intuition for the second reason is the household's compensation for liquidity. Households perceive the loss of liquidity as they hold more assets. They then hold a liquid asset (i.e. money) to compensate for the loss of liquidity. This set-up leads to the extension of the Euler equation and the money demand equation, and then these equations include the term of marginal disutility of the money-asset ratio. Harrison (2012) employed a specification similar to that described by Andrés *et al*. (2004); he introduced the portfolio adjustment cost of short-term bonds and long-term bonds into the household’s preference. On the other hand, the firm sector is the same as in the standard sticky price model in which the monopolistic competitive firms set their price following the Calvo (1983) pricing rule.

I analyze the behavior of the economy by giving the money growth shock and the money velocity shock in both the model with the adjustment cost in money and asset and the model without. First, I analyze the behavior of the economy in response to a positive money growth shock. The adjustment cost in money and asset amplifies the reduction of the real interest rate in the Euler equation and this reduction dominates the upward pressure by the expected inflation.

Then the nominal interest rate decreases in response to the positive money growth (the liquidity effect). I show next that the liquidity effect is a strand of the portfolio rebalance channel in my model.

Second, I show that monetary policy must raise the nominal interest rate aggressively under the Taylor rule in response to the increase in inflation in order to bring the economy to the local equilibrium. Because of the strong imperfect substitution, the real interest rate fluctuates greatly. This leads the monetary authority to give a stronger response of the nominal interest rate so as not to lower the real interest rate too much. Third, I analyze the economic behavior in response to a money velocity shock under the Taylor rule. I show that the money velocity shock affects the entire economy in a model with the strong imperfect substitution even though the monetary policy is based on the Taylor rule. Since the model without the adjustment cost is the same as the standard sticky price model, money responds to the nominal interest rate passively under the Taylor rule. On the other hand, if a strong imperfect substitution exists, the money velocity affects the entire economy through the marginal disutility of the money-bond ratio in the Euler equation.

Lastly, I consider the monetary policy toward a negative velocity shock under both the money growth rule and the Taylor rule. I show that the monetary policy can mitigate the effects of the velocity by fixing the nominal interest rate under the money growth rule. In contrast, if the interest rate is fixed under the Taylor rule, the money velocity shock amplifies the effect to the real economy. In addition, the effects of the velocity shock are the large under the money growth rule if the nominal interest rate is not fixed.

The remainder of this paper is as follows: I describe the model in Section 2, and show the results of a simulation in Section 3. Section 4 presents my conclusions.

2. The model

Here I describe the model economy. The model is the standard sticky price model except for the adjustment cost in money and asset. Following Andrés *et al*. (2004), I assume an imperfect substitution by introducing the cost of a money-bond ratio into a household's preference.

2.1. Households

The representative household gets utility from consumption C_t and real money m_t and gets disutility from the labor supply N_t and the ratio between real money m_t and real asset b_t .

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{C_t^{1-\sigma}}{1-\sigma} + \frac{(v_t m_t)^{1-\varsigma}}{1-\varsigma} - \frac{N_t^{1+\eta}}{1+\eta} - \frac{\upsilon}{2}\left(\frac{\delta_t}{\delta} - 1\right)^2 \right], \tag{1}$$

where $\beta \in (0,1)$, σ, ς, η, δ and υ are greater than zero, v_t denotes the money demand shock, δ_t denotes the ratio between the money and the bond, m_t/b_t , and δ denotes the steady-state value of δ_t . The last term in the bracket shows the imperfect substitution between the money and the asset. The household pays the costs of changing the ratio between the money and the asset in the form of disutilities. At the steady-state, the costs of the imperfect substitution become zero. The reasons for this assumption are (i) to provide a short cut in the model, and (ii) modelling the liquidity of money is achieved. The intuition for the second reason is the household's compensation for liquidity. As the household hold more bonds, it loses the liquidity. Then the household tries to make up the liquidity by increasing m_t, but the household must pay the costs in the form of disutility for raising the real money. Thus, the marginal disutility of the money-bond ratio describes the value of money liquidity.

C_t is the aggregate consumption expressed by the Dixit-Stiglitz bundle. There is an infinite continuum fo differentiated goods $C_t(i)$ on the $i \in (0,1)$.

$$C_t = \left[\int_0^1 C_t(i)^{\frac{\theta-1}{\theta}} di \right]^{\frac{\theta}{\theta-1}}, \tag{2}$$

where $\theta > 1$ and θ denotes the elasticity of substitution between differentiated goods. The household determines the allocation of differentiated goods given the price $P_t(i)$ for each differentiated goods so that the allocation achieves the minimum cost. This cost minimization leads to the relation as follows:

$$C_t(i) = \left[\frac{P_t(i)}{P_t} \right]^{-\theta} C_t , \tag{3}$$

where aggregate price P_t is

$$P_t = \left[\int_0^1 P_t(i)^{1-\theta} di \right]^{\frac{1}{1-\theta}}, \tag{4}$$

Eq. (3) denotes the household's demand of $C_t(i)$ toward aggregate consumption C_t . Eq. (3) and the definition of the aggregate price yields the following relation:

$$P_t C_t = \int_0^1 P_t(i) C_t(i) di.$$

The household's budget constraint is

$$P_t C_t + M_t + B_t = W_t N_t + R_{t-1} B_{t-1} + M_{t-1} + D_t + T_t , \tag{5}$$

where P_t , R_t , B_t , M_t , W_t , D_t and T_t denote the aggregate price, gross nominal interest rate, nominal bond, nominal money, nominal wage, dividend from the firm sector, and lump sum tax, respectively. Eq. (5) shows that the household allocates the income from wages, bond yields, lump sum tax and a firm's profit to the consumption, money and bond. The household's first-order conditions are as follows:

$$1 = \beta E_t \left[\frac{R_t}{\Pi_{t+1}} \left(\frac{C_{t+1}}{C_t} \right)^{-\sigma} \right] + \frac{\Omega_t \delta_t}{C_t^{-\sigma} b_t} , \tag{6}$$

$$\frac{v_t^{1-\varsigma} m_t^{1-\varsigma}}{C_t^{-\sigma}} = \frac{R_t - 1}{R_t} + \frac{\Omega_t \delta_t}{R_t C_t^{-\sigma} b_t} + \frac{\Omega_t}{C_t^{-\sigma} b_t} , \tag{7}$$

$$\frac{N_t^{\eta}}{C_t^{-\sigma}} = \frac{W_t}{P_t} , \tag{8}$$

where Ω_t denotes the marginal utility of δ_t and Π_t denotes the gross inflation rate:

$$\Omega_t \equiv \left(\frac{\delta_t}{\delta} - 1 \right) \frac{\upsilon}{\delta}, \quad \Pi_t \equiv \frac{P_t}{P_{t-1}} .$$

Eq. (6) denotes the Euler equation which describes a household's intertemporal decision for savings. Since I assume the adjustment cost in money and asset, the marginal cost of the money-bond ratio appears in the last term of the equation. Eq. (7) is the money demand equation. Eq. (7) differs from the standard money demand equation in that the marginal cost of the money-bond ratio tacks on the nominal interest rate. Terms derived from adjustment cost in Eqs. (6) and (7) are key factors contributing to the amplification of an economic disturbance and policy shock.

Finally, Eq. (8) is the labor supply equation; it shows that the opportunity cost of supplying labor equal to the real wage.

2.2. Firms

The final goods sector inputs the differentiated goods $Y_t(i)$ from the intermediate goods sector and produces the final goods Y_t . The final goods sector's profit maximization yields the demand for $Y_t(i)$, $i \in (0, 1)$ toward the aggregate output Y_t :

$$Y_t(i) = \left[\frac{P_t(i)}{P_t} \right]^{-\theta} Y_t , \tag{9}$$

The intermediate goods sector produces the differentiated goods $Y_t(i)$, $i \in (0,1)$ by the product

$Y_t(i) = N_t(i)$.

where $N_t = \int_0^1 N_t(i)\,di$ [2]. By the cost minimization, the real marginal cost equals to the real wage:

$$s_t = \frac{W_t}{P_t}.$$

The monopolistically competitive intermediate goods sector sets the price facing the staggered price. Here I apply the specific model introduced by Calvo (1983). In each period, firms can set the price with probability $1-\alpha$ and cannot change it with probability α. Following Calvo (1983), intermediate goods firms maximize their profits dynamically evaluated by households' marginal utility and set their optimal price considering that they cannot change their price forever with probability α. I define P_t^* as the price which can be set as optimal in the period t. The first-order condition yields

$$P_t^* = \left(\frac{\theta}{\theta-1}\right)\frac{E_t\sum_{k=0}^{\infty}\alpha^k\Lambda_{t,t+k}s_{t+k}Y_{t+k}(i)}{E_t\sum_{k=0}^{\infty}\alpha^k\Lambda_{t,t+k}Y_{t+k}(i)/P_{t+k}}, \qquad (10)$$

where $\Lambda_{t,t+k}$ denotes the stochastic discount factor, $\beta^k\,(C_{t+k}/C_t)^{-\sigma}$.
The definition of the aggregate price index Eq. (4) satisfies the following recursive form.

$$P_t^{1-\theta} = (1-\alpha)(P_t^*)^{1-\theta} + \alpha P_{t-1}^{1-\theta}. \qquad (11)$$

2.3. Fiscal policy

The government's budget constraint is:

$$R_{t-1}B_{t-1} + M_{t-1} + T_t = B_t + M_t.$$

Because $R_t \geq 0$, the government budget constraint might diverge. To prevent the model from this divergence, I assume the taxation policy as follows:

$$\tau_t = -\varphi b_{t-1}, \qquad (12)$$

where $\tau_t = T_t/P_t$ and $\varphi > 0$.

2.4. Equilibrium

The goods market clearing condition is:

$$Y_t = C_t,$$

and I define the money growth as $\mu_t = M_t/M_{t-1}$.

Table 1. Baseline parameter values

β	subjective discount factor	0.99
σ	intertemporal substitution for consumption	2
ς	intertemporal substitution for real money	2
η	Frisch elasticity of labor supply	1
α	price stickiness	0.8
δ	Steady-state ratio between *m* and *b*	0.1
$\tilde{\upsilon}$	adjustment cost	0.045
φ	taxation policy	0.2

3. Simulation

This section derives impulse responses to the money growth shock and money velocity shock. All impulse responses are from a log-linearized model. First, I compare the results from the model with the adjustment cost with the result from the model without the adjustment cost. The money growth shock generates the reduction of the nominal interest rate (the liquidity effect), and the money velocity shock effects the entire economy even though the monetary policy is under the Taylor rule. Second, I derive the impulse responses with the fixed interest rate to the negative money velocity shock and see the effectiveness of the fixed interest rate under both the Taylor rule and the money growth rule on the negative velocity shock when a strong imperfect substitution exists.

3.1. Liquidity effect

First, I derive the impulse response to the positive money growth shock. The money growth rule is given by AR(1) process:

$$\hat{\mu}_t = \rho_\mu \hat{\mu}_{t-1} + \varepsilon_t^\mu$$

where, $\hat{\mu}_t = \ln \mu_t - \ln \mu$ and ε_t^μ , denotes an independently identically distributed (i.i.d.) disturbance term. I set $\rho_\mu = 0.5$ following to Christiano *et al*. (1998) [3]. Table 1 shows the baseline parameters. The value of δ is 0.1 following Woodford (1996). Woodford (1996) used the ratio of monetary base and debt. I set υ so that $\tilde{\upsilon} \equiv \upsilon(1-\beta)/(m-\varsigma b)$ becomes 0.045 following Andrés *et al*. (2004). Setting a value of $\tilde{\upsilon}$, the household's cost of the money-bond ratio, is difficult. Andrés *et al*. (2004) estimated the value υ by the maximum likelihood method with U.S. data, and they indicated 0.045. Harrison (2012) set parameter similar to υ as 0.09. I set φ, the taxation parameter, as 0.2.

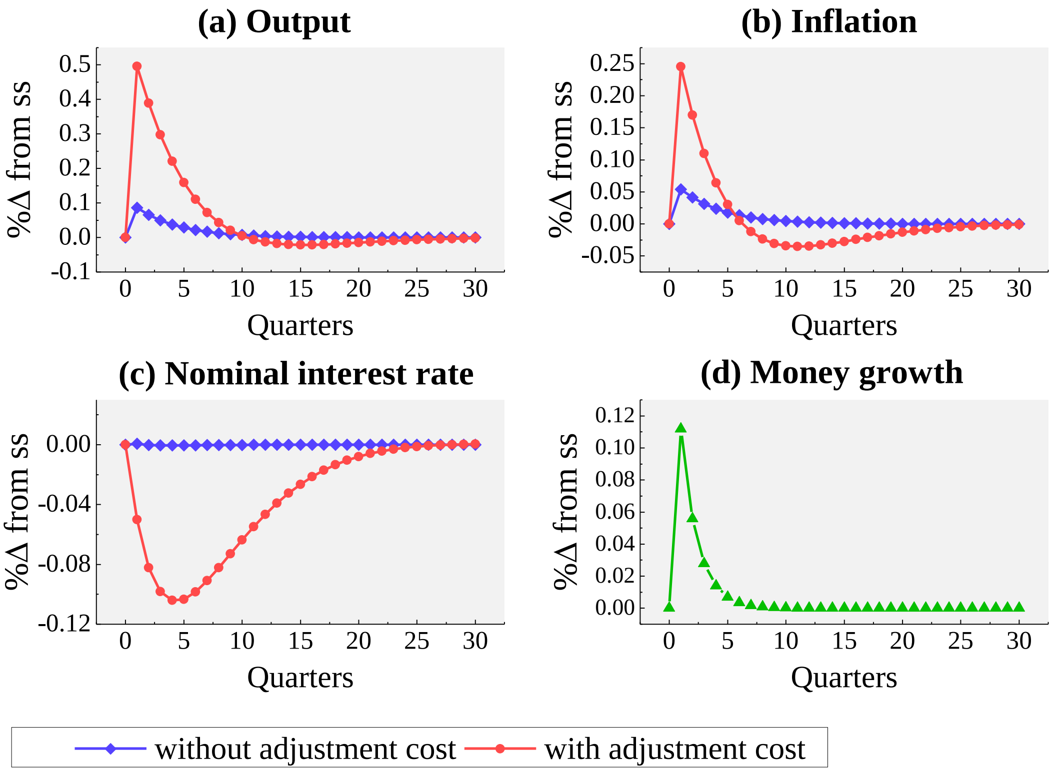

Fig 1. Impulse responses to a positive money growth shock.

Figure 1a-c illustrates the impulse response to the positive money growth shock that is illustrated by Figure 1d.[4] Figure 1a and Figure 1b illustrate the responses of output and inflation, respectively. Since the price responds incompletely, the positive money growth shock raises both output and inflation. However, the strengths are different for the cases with and without adjustment cost. Both variables respond more strongly in the case with adjustment cost.

Figure 1c illustrates the responses of the nominal interest rate. The nominal interest rate shows the negative response in the model with the adjustment cost and it's response is much stronger than in the case without adjustment cost.

The intuition for these results is as follows: Because of the adjustment cost, the imperfect substitution in the money and asset is stronger. The household then pays the costs of changing real money and asset in the form of disutilities. These costs appear as the real interest in the Fisher equation.

$$\hat{r}_t = \left[\sigma(E_t\hat{y}_{t+1} - \hat{y}_t) - \tilde{\upsilon}(\hat{m}_t - \hat{b}_t)\right] + E_t\hat{\pi}_{t+1}. \qquad (13)$$

Eq. (13) is log-linearized form of Eq. (6). Since the term of the real interest rate includes marginal disutilities, the positive response in money and the negative response in real bond affect the nominal interest rate more negatively than the model without the adjustment cost.[5]

Thus, the positive money growth shock lowers the real interest rate significantly through the marginal dis-utilities from the adjustment cost in money and asset. The reduction in the real interest rate dominates the positive pressure of expected inflation and the nominal interest rate decrease (the liquidity effect).

This result is consistent with the quantitative easing effects through the imperfect substitution of the money presented by Bernenke and Reinhart (2004). The adjustment cost denotes the strong imperfect substitution of the money for non-money assets, and then the large increase in money leads to the household's portfolio rebalance. Consequently, the yield of the asset, i.e., the nominal interest rate, decreases. Thus, the liquidity effect can be a strand of the portfolio rebalance effect by the quantitative easing in my model. This implication is somewhat different from the limited participation model presented by Christiano (1991).[6] The limited participation model generates the liquidity effect by the increase in loans from the financial intermediary to the firm. Since the household cannot participate in the asset market after the central bank's cash injection, all of the effect of the cash injection is absorbed by the supply side. This leads to increases in labor, output and loans. The financial intermediary supplies the loan as long as the nominal interest rate is positive, and consequently the nominal interest rate falls.

This mechanism is similar to the portfolio rebalance but it is indirect, and the effect of the cash injection goes through the supply side. However, my model specifies the portfolio rebalance by introducing the cost function into the household's utility directly, and then the effects of the cash injection are absorbed largely by the demand side.

3.2. Determinacy under the Taylor rule and the money velocity shock

In this subsection, I consider a model economy under the Taylor rule when an adjustment cost in money and asset exists. First, I consider the achievement of local uniqueness by a monetary policy. Second, I derive the impulse responses to the negative shock of money velocity under the Taylor rule.

I choose the standard type of the Taylor rule:

$$\hat{r}_t = \psi_\pi \hat{\pi}_t + \psi_y \hat{y}_t .$$

where, $\hat{r}_t$, $\hat{\pi}_t$ and $\hat{y}_t$ denote the percent deviation from the steady state for R_t , Π_t and Y_t .In general, the Taylor rule accommodates the one percent increase in inflation by raising the nominal interest rate more than one percent. If the monetary policy raises the nominal interest rate insufficiently, the economy cannot be stabilized since the increase in expected inflation leads to a large decrease in the real interest rate and the output could increase more. In standard

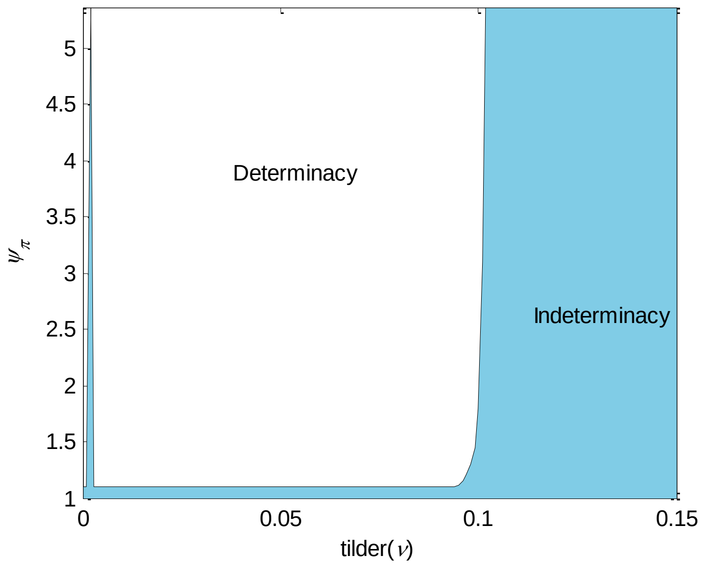

Fig. 2 Determinacy and indeterminacy regions for ψ_π and $\tilde{\upsilon}$.

sticky price models, monetary policy can prevent this stabilization by setting $\psi_\pi > 1$. In theory, $\psi_\pi > 1$ satisfies the Blanchard and Kahn condition.

Analogous to standard sticky price models, setting $\psi_\pi > 1$ satisfies the Blanchard and Kahn condition under baseline parameters. However, the determinacy of the model depends on the value of $\tilde{\upsilon}$ in my model. From Eq. (13), the change in the real interest depends on $\tilde{\upsilon}$. Figure 2 illustrates the areas of the determinacy and indeterminacy on the combination of ψ_π and $\tilde{\upsilon}$.[7] Figure 2 shows that the high $\tilde{\upsilon}$ requires a high response to the inflation, which necessitates an aggressive policy in order to not decrease the real interest too much in response to the inflation. Thus the strong imperfect substitutiability in money and asset might lead to indeterminacy according to the substitution cost in my model.

Now I derive the impulse responses to the money velocity shock. First, I describe the definition of velocity in my model. If $\upsilon = 0$, Eq. (7) becomes:

$$M_t^{\varsigma} V_t = P_t^{\varsigma} Y_t^{\sigma} , \tag{14}$$

where $V_t \equiv v_t^{\varsigma - 1}(1 - R_t^{-1})$. If we regard Eq. (14) as the quantity equation of money, V_t denotes the velocity of money. Then, the household's preference shock on money, v_t , is the part of the money velocity as long as $\varsigma > 1$. Because the reduction in the velocity of money might lead to a recession of the economy, it is valuable to examine how the negative velocity shock affects the economy with the imperfect substitution. The money velocity shock follows the AR(1) process:

$$\hat{v}_t = \rho_\mu \hat{v}_{t-1} + \varepsilon_t^{v} ,$$

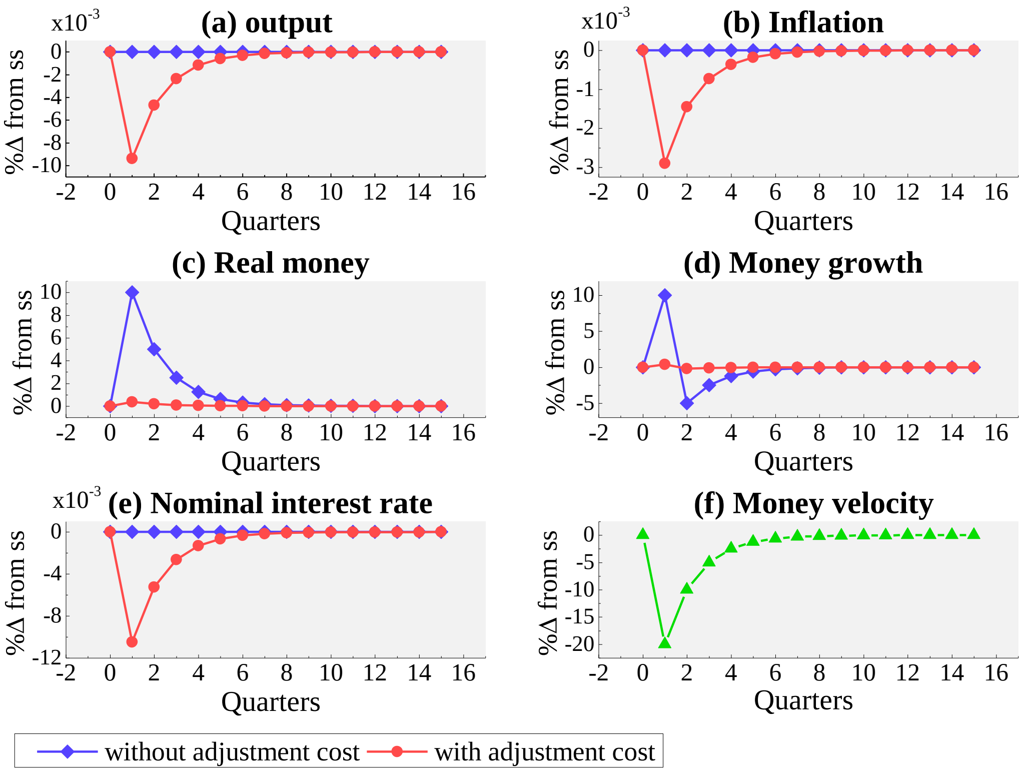

Fig. 3 Responses to a negative velocity shock under the Taylor rule.

where, $\hat{v}_t = \ln v_t - \ln v$ and ε_t^v follows the i.i.d. process, $\rho_v = 0.5$, $\psi_\pi = 2$ and $\psi_y = 0.5$.

Figure 3 illustrates the impulse responses to the negative velocity shock. Only the real money (Fig. 3c) and the money growth (Fig. 3d) respond to the velocity shock in the model without the adjustment cost. Because the model without the adjustment cost is the standard sticky price model, the money responds passively to the nominal interest rate when the monetary policy is the Taylor rule: the shock originating from the money demand equation does not affect the entire economy because output and inflation are determined by only the system (except for the money demand equation in the standard sticky price model). Thus the real money and the money growth absorb the velocity shock completely and then all of the other variables do not respond to the velocity shock.

However, in the model with the adjustment cost, all variables respond to the velocity shock. The strong imperfect substitution in the money and asset allocate the effects of the velocity shock to output, inflation and the nominal interest rate. An intuition for this is as follows: Because the Euler equation includes money, the velocity shock affects the output negatively. The negative response of the output also lowers the inflation through the aggregate supply. The response of the nominal interest rate depends on whether the real interest rate dominates the

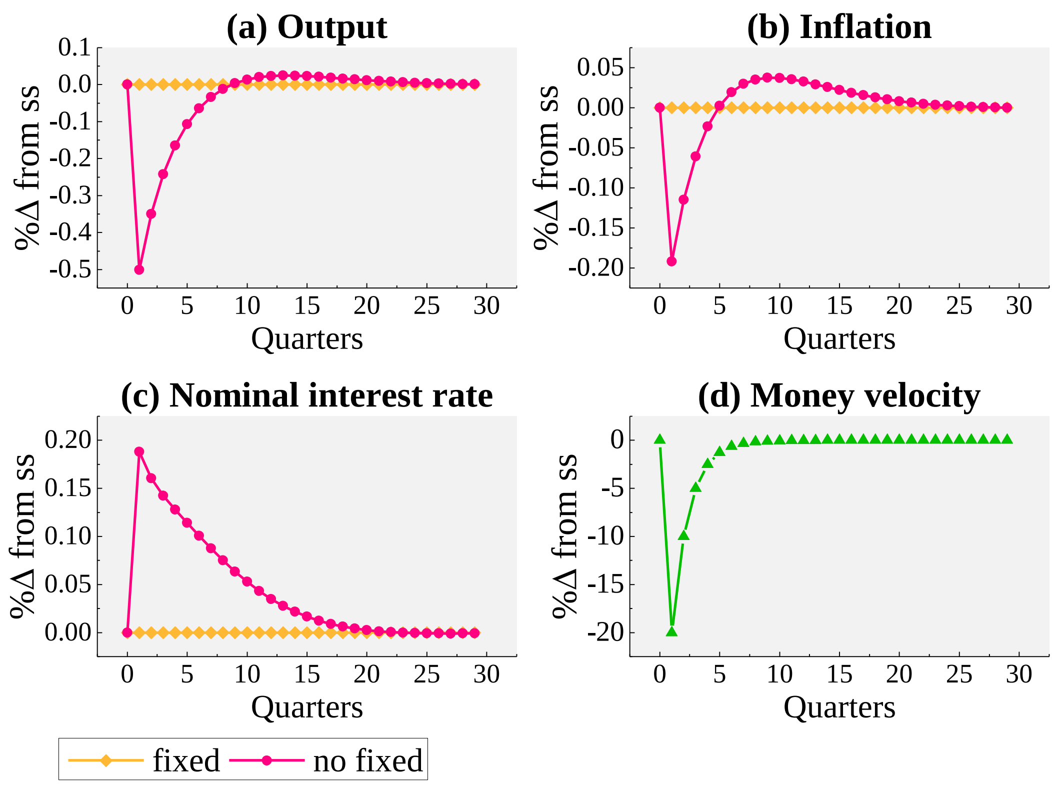

Fig. 4 Responses to a negative velocity shock under the money growth rule with a fixed interest rate.

expected inflation or not. Under the baseline parameter, the nominal interest rate responds negatively to the negative velocity shock.

This is a strand of the portfolio rebalance effect as well as the liquidity effect. Since the negative decrease in the money velocity lowers the liquidity per unit of money, the household must hold more money to keep the liquidity. However, holding more money is costly because of the adjustment cost of the money and asset. This leads to the decrease in output and inflation. Thus, the money velocity shock affects all of the economy when there is a strong imperfect substitution in money and assets even though the monetary policy employs the Taylor rule.

3.3. A negative money velocity shock under the fixed interest rate

In this subsection I derive the impulse responses to a negative money velocity shock and consider the effectiveness of a fixed interest rate under both the Taylor rule and the money growth rule.[8]

Figure 4 illustrates the impulse responses to a negative money velocity shock under the money growth rule.[9] In the model without the fixed interest rate, output and inflation respond negtively to the money velocity shock. This is similar to the result of the Taylor rule, illustrated

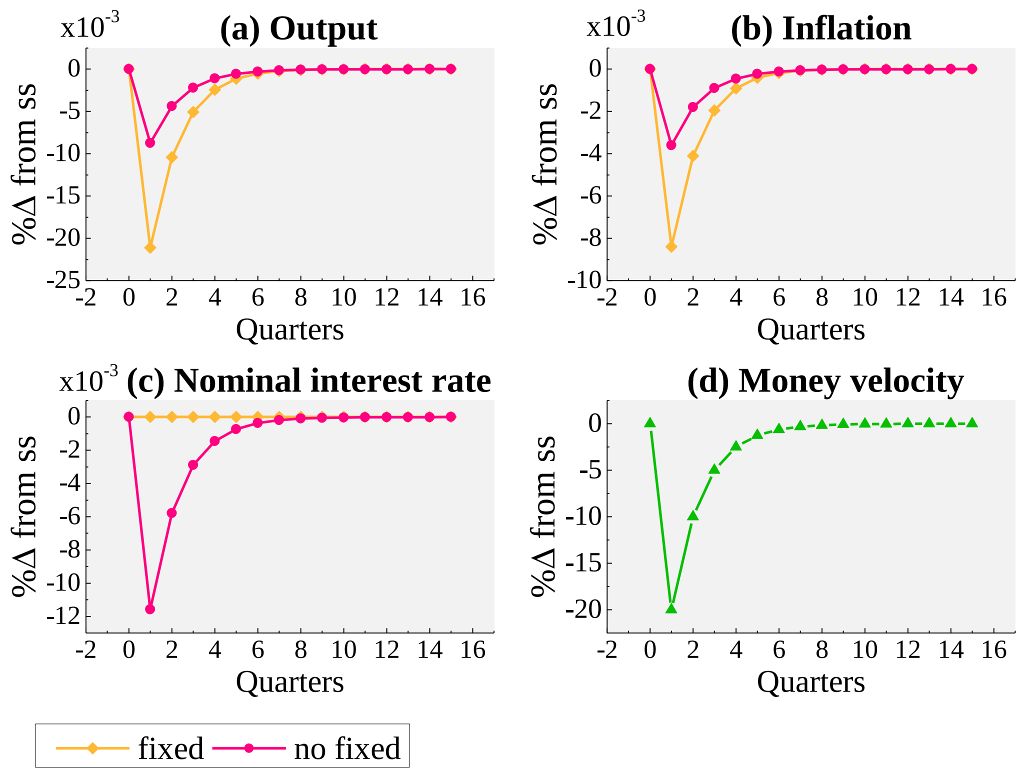

Fig. 5 Responses to a negative money demand shock under the Taylor rule with a fixed interest rate.

by Figure 3. However, the nominal interest responds positively to the negative money velocity shock under the money growth rule. Since the output responds large negatively under the money growth rule, the positive response of the real interest rate dominate the downward pressures of the expected inflation. This leads to a strong positive response of the nominal interest rate.

The result obtained with the fixed interest rate changes dramatically. The fixed interest rate completely mitigates the tightening effects from the negative money velocity shock on the output and inflation under the money growth rule. In other words, the nominal interest rate is the door to the propagation from the money velocity shock to the output and the inflation under the money growth rule. Because the upward pressure works on the nominal interest rate in response to a negative money velocity shock, the fixed interest rate gives easing effects to the economy. This leads to the reduction of the downward pressures on output and inflation. Further, since the nominal interest rate responds strongly under the money growth rule, the fixed interest rate lets the output and the inflation respond positively.

Now I apply the same experiment to the model under the Taylor rule. Figure 5 illustrates the impulse responses to a negative velocity shock under the Taylor rule. Since the model has the

Table 2. Variances for output and inflation

	Money growth rule		Taylor rule	
	Fixed	Not Fixed	Fixed	No Fixed
$\frac{1}{T-1}\sum_{t=0}^{T} y_t^2$	2.3582e-07	35.3554	7.1056	1.4998
$\frac{1}{T-1}\sum_{t=0}^{T} \pi_t^2$	6.5949e-08	2.0385	1.316	0.2842

Variances of output and inflation from the steady state for a simulated period. 'Fixed' denotes the model with a fixed interest rate policy. 'No Fixed' denotes the model without the fixed interest rate policy. I multiplied by 10^4 all of the results and set $T = 15$.

adjustment cost in money and assets, the negative shock of money velocity tightens the entire economy under the Taylor rule.

In the model with the fixed interest rate, the effects of a money velocity shock are amplified. The output and the inflation decrease more than in the case without a fixed interest rate. Since the nominal interest rate moves negatively in response to the negative money velocity shock under the Taylor rule, the fixed interest rate has tightening effects on the economy. Thus, if the monetary authority fixes the interest rate under the Taylor rule, the money velocity shock amplifies the effect on the real economy.

Table 2 shows the variance of the output and the inflation from the steady state for the simulated periods.[10] The column 'Fixed' denotes the model with the fixed interest rate. The column 'not Fixed' denotes the model without the fixed interest rate.

The results show that the fixed interest rate under the money growth rule indicates the smallest value of the variances for both the output and the inflation. The money growth rule also generates the highest variance of the output if the monetary policy does not take the fixed interest rate. On the other hand, if the negative money velocity shock hit an economy under the Taylor rule with a fixed interest rate policy, the recession of the inflation and the output becomes large.

Thus, monetary policy might be able to calm down the fluctuation of the output and the inflation toward a negative money velocity shock by employing the money growth rule rather than the Taylor rule with a fixed nominal interest rate.

4. Conclusion

This paper has analyzed a model with an adjustment cost in money and asset. My findings are as follows: First, a positive money growth shock generates a significant liquidity effect through households' portfolio rebalances. Second, the determinacy of the model depends on the value of portfolio cost between money and assets. According to the value of imperfect substitution in money and assets, monetary policy must raise the nominal interest rate aggressively in response to a rise in inflation in order to bring the economy to the locally unique equilibrium. Third, a money velocity shock affects the entire economy even though the monetary policy is the Taylor rule. Finally, the monetary authority might be able to mitigate the effects of a negative money velocity shock if the monetary policy adopts the money growth rule with a fixed interest rate. If the money growth rule can be regarded as one strand of a quantitative easing policy, I conclude that a quantitative easing policy might be effective in stabilizing the economy toward the reduction of the money velocity even though the economy does not stay near the zero lower bound.

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NOTES

1. I assume the adjustment cost in money and assets. However, money and assets are imperfect substitute to begin with because of the interests on assets. For this reason, I describe the *strong* -imperfect substitution concerning the model with the adjustment costs in money and assets.
2. This assumption leads to $N_t = d_t Y_t \neq Y_t$ where $d_t = \int_0^1 (P_t(i)/P_t)^{-\theta} di$. However, d_t does not appear in the loglinearlized model. For details, see Galí (2008).
3. The higher the persistence in money growth becomes, the more positively the nominal interest rate responds to the positive money growth.
4. I set the positive money growth shock so that the nominal interest rate responds to −0.1 percent at minimum in the imperfect substitution model.
5. The decrease in the real bond is unrealistic. However, since the nominal term of the bond is defined as $P_t b_t$, the price of the bond increase. Since the rise of price is greater, the real bond is decrease.
6. However, since Christiano (1991) generates the liquidity effect with the flexible price model, the result cannot be compared with my model directly.
7. I fix ψ_y at 0.50.
8. I fix the responses of the nominal interest rate at the steady state for all periods of the simulation.
9. I apply the piecewise linear solution to the impulse responses with a fixed nominal interest rate. Guerrieri and Iacoviello (2013) provided the MATLAB codes and details of the algorithm for the piecewise linear solution. See also Bodenstein *et al*. (2009).
10. The order of results does not depend on the length of T.

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