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Monetary Policy and the Financing of Firms

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Abstract

How should monetary policy respond to changes in financial conditions? In this paper we consider a simple model where firms are subject to idiosyncratic shocks which may force them to default on their debt. Firms' assets and liabilities are denominated in nominal terms and predetermined when shocks occur. Monetary policy can therefore affect the real value of funds used to finance production. Furthermore, policy affects the loan and deposit rates. We find that maintaining price stability at all times is not optimal; that the optimal response to adverse financial shocks is to lower interest rates, if not at the zero bound, and engineer a short period of inflation; that the Taylor rule may implement allocations that have opposite cyclical properties to the optimal ones.

Keywords: Financial stability; debt deflation; bankruptcy costs; price level volatility; optimal monetary policy; stabilization policy.

JEL classification: E20, E44, E52

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1 Introduction

During financial crises, credit conditions tend to worsen for all agents in the economy. In the press, there are frequent calls for a looser monetary policy stance, on the grounds that this helps avoid a deep recession and the risks of a credit crunch. The intuitive argument is that lower interest rates tend to make it easier for firms to obtain external finance, thus countering the effects of the tightening of credit standards. Arguments tracing back to Fisher (1933) can also be used to call for some degree of inflation during financial crises, so as to avoid an excessive increase in firms' leverage through a devaluation of their nominal liabilities.

It is less clear, however, whether these arguments would withstand a more formal analysis. In this paper, we present a model that can be used to evaluate them. More specifically, we address the following questions: How should monetary policy respond to financial shocks? How should it respond to real shocks, when financial conditions affect macroeconomic outcomes? Should monetary policy engineer some inflation during recessions? How relevant is the zero bound on the nominal interest rate?

To answer these questions, we use a model where monetary policy has the ability to affect the financing conditions of firms. Our set-up has three distinguishing features. First, firms' internal and external funds are imperfect substitutes. This is due to the presence of information asymmetries, between firms and banks, regarding firms' productivity and to the fact that monitoring is a costly activity for banks. Second, firms' internal and external funds are nominal assets. Third, those funds, both internal and external, as well as the interest rate on bank loans, are predetermined when aggregate shocks occur.

We find that, in our environment, maintaining price stability at all times is not optimal. In response to technology shocks, for example, the price level should move to adjust the real value of total funds. If the shock is negative, the price level increases on impact to lower real funds as well as the real wage. Subsequently, the price level falls in order to increase the real wage at the same pace as productivity, in the convergence back to the steady state. Along the adjustment path, deposit and loan rates, spreads, financial markups, leverage, and bankruptcy rates remain stable. Therefore, under the optimal policy, if technology shocks were the only shocks hitting the economy, bankruptcies would be acyclical.

The optimal response to a financial shock that reduces firms' internal funds, increasing firms' leverage, also involves an increase in the price level on impact, in order to lower real funds and the real wage. The short period of controlled inflation mitigates the adverse consequences of the shock on bankruptcy rates and allows firms to de-leverage more quickly.

We also find that a policy response according to a simple Taylor-type rule can be costly, in the sense of inducing more persistent deviations in real variables from their optimal values and higher bankruptcy rates. In response to technology shocks, bankruptcies become countercyclical under the simple rule. In response to a financial shock that reduces internal funds, there is deflation initially, which increases the real value of total funds and leads to a much larger increase in leverage. The reduction in output is smaller than under the optimal policy and markups decrease, inducing higher bankruptcy rates.

In the baseline version of our model, the optimal deposit rate is zero, corresponding to the Friedman rule. Because assets are nominal and predetermined, for given nominal interest rates, there are many possible equilibrium allocations, and therefore ample room for policy.

To analyze the optimal interest rate reaction to shocks, we introduce government consumption as an exogenous share of production. This assumption generates a rationale for proportionate taxation. The deposit rate acts as a tax on consumption and therefore the optimal steady-state deposit rate becomes positive – the Friedman rule is no longer optimal.

When the optimal average interest rate is away from the lower bound, it may be optimal for the interest rate to respond to shocks. This is indeed the case for financial shocks, but not for technology shocks. In response to technology shocks, it is optimal to keep rates constant even if they could be lowered. For all financial shocks, the flexibility of moving the nominal interest rate downwards allows policy to speed up the adjustment. Moreover, the effect of these shocks on output can be considerably mitigated. For instance, a shock that reduces the availability of internal funds is persistently contractionary when the short term nominal rate is kept fixed at zero, while it is less contractionary and very short-lived when the average interest rate is away from the lower bound and the short term nominal rate is reduced.

In order to understand the mechanisms responsible for these results, we analyze a simplified model in which internal and external funds are perfect substitutes (i.e. monitoring costs are zero). We use this model to illustrate that the two assumptions of nominal denomination and predetermination of the funds used to finance production are sufficient conditions for changes in the price level to affect allocations. For this specific case, we show that, in response to a technology shock, the optimal monetary policy aims at keeping the nominal wage constant. This is achieved by inducing movements in the price level such that the real wage adjusts to productivity. Because, under log-linear preferences, labor does not move either, nominal predetermined funds are ex-post optimal. Finally, we use this model to evaluate the role played by asymmetric information and monitoring costs in explaining business cycle fluctuations. Although these imperfections play a quantitatively minor role in determining the cyclical behavior of non-financial variables, they tend to amplify the reaction of the economy to shocks.

Our paper relates to the literature that analyzes the effect of financial factors on the transmission of shocks. In our model, financial factors play a role because of costly state verification, as in Bernanke et al (1999) and Carlstrom and Fuerst (1997, 1998). We also contribute to the recent literature that analyzes the role of financial factors for optimal monetary policy (see e.g. Curdia and Woodford (2008), De Fiore and Tristani (2008), Ravenna and Walsh (2006), and Faia (2008)). The main differences relative to those models are the nominal denomination of debt, as in Christiano et al (2003) and De Fiore and Tristani (2008), and the assumption that assets are decided before observing the aggregate shocks, as in Svensson (1985). It follows that, in our setup, monetary policy affects allocations by setting the nominal interest rate but also by choosing an appropriate path for prices. This has important implications for the cyclical properties of the economy under the optimal policy.

The paper proceeds as follows. In section 2, we outline the environment and describe the equilibria. Then, we derive implementability conditions and we characterize optimal monetary policy. In section 3, we provide numerical results on the response of the economy to various shocks. We describe results both under the optimal monetary policy and a sub-optimal (Taylor) rule. We compare the case where the level of government consumption is exogenous and the optimal monetary policy is the Friedman rule, to the case where government consumption is a fixed share of output and the optimal average interest rate is away from zero. In section 4, we analyze a simple model in which internal and external funds are perfect substitutes, and use it to provide some intuition on the results obtained for the general model. In section 5, we conclude.

2 Model

We consider a model where firms need internal and external funds to produce and they fail if they are not able to repay their debts. Both internal funds and firm debt are nominal assets.

There is a goods market at the beginning of the period and an assets market at the end, where funds are decided for the following period. Funds are predetermined.

Production uses labor only with a linear technology. Aggregate productivity is stochastic. In addition, each firm faces an idiosyncratic shock whose realization is private information.

The households have preferences over consumption, labor and real money. For convenience we assume separability for the utility in real balances.[1]

Banks are financial intermediaries. They are zero profit, zero risk operations. Banks take deposits from households and allocate them to entrepreneurs on the basis of a debt contract where the entrepreneurs repay their debts if production is sufficient and default otherwise, handing in total production to the banks, provided these pay the monitoring costs. Because there is aggregate uncertainty, we assume that the government can make lump sum transfers between the households and the banks that ensure that banks have zero profits in every state. This way the banks are able to pay a risk free rate on deposits.

Entrepreneurs need to borrow in advance to finance production. The payments on outstanding debt are not state dependent. Entrepreneurs accumulate internal funds indefinitely. A tax on these funds ensures that there is always a need for external funds.

Monetary policy can affect the real value of total funds available for the production of firms, but it can also affect the real value of debt that needs to be repaid. Furthermore, monetary policy also affects the deposit and loan rates.

2.1 Households

At the end of period t in the assets market, households decide on holdings of money M_t that they will be able to use at the beginning of period $t+1$ in the goods market, and on one-period deposits denominated in units of currency D_t that will pay $R_t^d D_t$ in the assets market in period $t+1$. Deposits are riskless, in the sense that banks do not fail. The households also decide on a portfolio of nominal state-contingent bonds A_{t+1} each paying a unit of currency in a particular state in period $t+1$. The state-contingent bonds cost $E_t Q_{t,t+1} A_{t+1}$, where $Q_{t,t+1}$ is the price in units of money at t of each bond normalized by the conditional probability of occurrence of the state at $t+1$.

[1] We also assume a negligible contribution of real balances to welfare. This does not mean that the economy is cashless since firms face a cash-in-advance constraint.

The budget constraint at period t is

$$M_t + E_t Q_{t,t+1} A_{t+1} + D_t \leq A_t + R^d_{t-1} D_{t-1} + M_{t-1} - P_t c_t + W_t n_t - T_t, \tag{1}$$

where c_t is the amount of the final consumption good purchased, P_t is its price, n_t is hours worked, W_t is the nominal wage, and T_t are lump-sum nominal taxes collected by the government.

The household's problem is to maximize utility, defined as

$$E_0 \left\{ \sum_0^\infty \beta^t \left[u\left(c_t, m_t\right) - \alpha n_t \right] \right\}, \tag{2}$$

subject to (1). Here $u_c > 0$, $u_m \geq 0$, $u_{cc} < 0, u_{mm} < 0$, $\alpha > 0$ and $m_t \equiv M_{t-1}/P_t$ denotes real balances. Throughout we will assume that the utility function is separable in real money, m_t, and that the contribution to welfare is negligible.

Optimality requires that the following conditions must hold:

$$\frac{u_c\left(t\right)}{\alpha} = \frac{P_t}{W_t}, \tag{3}$$

$$\frac{u_c\left(t\right)}{\beta u_c\left(t+1\right)} = Q^{-1}_{t,t+1} \frac{P_t}{P_{t+1}}, \tag{4}$$

$$\frac{u_c\left(t\right)}{P_t} = R^d_t E_t \frac{\beta u_c\left(t+1\right)}{P_{t+1}}, \tag{5}$$

$$\frac{E_t u_m\left(t+1\right)}{E_t u_c\left(t+1\right)} = R^d_t - 1. \tag{6}$$

2.2 Production

The production sector is composed of a continuum of firms, indexed by $i \in [0, 1]$. Each firm is endowed with a stochastic technology that transforms $N_{i,t}$ units of labor into $\omega_{i,t} A_t N_{i,t}$ units of output. The random variable $\omega_{i,t}$ is i.i.d. across time and across firms, with distribution Φ, density ϕ and mean one. A_t is an aggregate productivity shock. The shock $\omega_{i,t}$ is private information, but its realization can be observed by the financial intermediary at the cost of a share μ of the firm's output.

The firms decide in the assets market at $t-1$ the amount of internal funds to be available in period t, $B_{i,t-1}$. Lending occurs through the financial intermediary, which is able to obtain a safe return. The existence of aggregate shocks occurring during the duration of the contract implies that the intermediary's return from the lending activity is not safe, regardless of its ability to differentiate across the continuum of firms facing i.i.d. shocks. We assume the existence of a deposit insurance scheme that the government implements by completely taxing away the intermediary's profits whenever the aggregate shock is relatively high, and by providing subsidies up to the point where profits are zero when the aggregate shock is relatively low. Such policy guarantees that the intermediary is always able to repay the safe return to the household, thus insuring households' deposits from aggregate risk.

2.2.1 The financial contract

The firms pay wages in advance of production. Each firm is restricted to hire and pay wages according to

$$W_t N_{i,t} \leq X_{i,t-1}, \tag{7}$$

where $X_{i,t-1}$ are total funds, internal plus external, decided at the assets market in period $t-1$, to be available in period t. The firms have internal funds $B_{i,t-1}$ and borrow $X_{i,t-1} - B_{i,t-1}$.

The loan contract stipulates a payment of $R^l_{i,t-1}\left(X_{i,t-1} - B_{i,t-1}\right)$, where $R^l_{i,t-1}$ is not contingent on the state at t, when the firm is able to meet those payments, i.e. when $\omega_{i,t} \geq \overline{\omega}_{i,t}$, where $\overline{\omega}_{i,t}$ is the minimum productivity level such that the firm is able to pay the fixed return to the bank, so that

$$P_t A_t \overline{\omega}_{i,t} N_{i,t} = R^l_{i,t-1}\left(X_{i,t-1} - B_{i,t-1}\right). \tag{8}$$

Otherwise the firm goes bankrupt, and hands out all the production $P_t A_t \omega_{i,t} N_{i,t}$. In this case, a constant fraction μ_t of the firm's output is destroyed in monitoring, so that the bank gets $\left(1-\mu_t\right) P_t A_t \omega_{i,t} N_{i,t}$.

Define the average share of production accruing to the firms and to the bank, respectively, as

$$f\left(\overline{\omega}_{i,t}\right) = \int_{\overline{\omega}_{i,t}}^{\infty} \left(\omega_{i,t} - \overline{\omega}_{i,t}\right) \Phi\left(d\omega\right). \tag{9}$$

and

$$g\left(\overline{\omega}_{i,t};\mu_t\right) = \int_0^{\overline{\omega}_{i,t}} \left(1-\mu_t\right)\omega_{i,t}\Phi\left(d\omega\right) + \int_{\overline{\omega}_{i,t}}^{\infty} \overline{\omega}_{i,t}\Phi\left(d\omega\right). \tag{10}$$

Total output is split between the firm, the bank, and monitoring costs

$$f\left(\overline{\omega}_{i,t}\right) + g\left(\overline{\omega}_{i,t};\mu_t\right) = 1 - \mu_t G\left(\overline{\omega}_{i,t}\right),$$

where $G\left(\overline{\omega}_{i,t}\right) = \int_0^{\overline{\omega}_{i,t}} \omega_{i,t}\Phi\left(d\omega\right)$. On average, $\mu_t G\left(\overline{\omega}_{i,t}\right)$ of output is lost in monitoring.

The optimal contract is a vector $\left(R^l_{i,t-1}, X_{i,t-1}, \overline{\omega}_{i,t}, N_{i,t}\right)$ that solves the following problem: Maximize the expected production accruing to firms

$$\max \; E_{t-1}\left[f\left(\overline{\omega}_{i,t}\right) P_t A_t N_{i,t}\right]$$

subject to

$$\begin{aligned} W_t N_{i,t} &\leq X_{i,t-1} && (11)\\ E_{t-1}\left[g\left(\overline{\omega}_{i,t};\mu_t\right) P_t A_t N_{i,t}\right] &\geq R^d_{t-1}\left(X_{i,t-1} - B_{i,t-1}\right) && (12)\\ E_{t-1}\left[f\left(\overline{\omega}_{i,t}\right) P_t A_t N_{i,t}\right] &\geq R^d_{t-1} B_{i,t-1} && (13) \end{aligned}$$

where $g\left(\overline{\omega}_{i,t};\mu_t\right)$ and $f\left(\overline{\omega}_{i,t}\right)$ are given by (10) and (9), respectively, and $\overline{\omega}_{i,t}$ is given by (8).[2]

The informational structure in the economy corresponds to a costly state verification (CSV) problem. The optimal contract maximizes the entrepreneur's expected return subject to the borrowing constraint for firms, (11), the financial intermediary receiving an amount not lower on average than the repayment requested by the household (the safe return on deposits), (12), and the entrepreneur being willing to sign the contract, (13).

The decisions on $X_{i,t-1}$ and $B_{i,t-1}$ are made in period $t-1$ at the assets market. We can replace $N_{i,t} = \frac{X_{i,t-1}}{W_t}$ and divide everything by $X_{i,t-1}$ to get

$$\max \; E_{t-1}\left[\frac{P_t A_t}{W_t} X_{i,t-1} f\left(\overline{\omega}_{i,t}\right)\right] \tag{14}$$

subject to

$$\begin{aligned} E_{t-1}\left[\frac{P_t A_t}{W_t} g\left(\overline{\omega}_{i,t};\mu_t\right)\right] &\geq R^d_{t-1}\left(1 - \frac{B_{i,t-1}}{X_{i,t-1}}\right) && (15)\\ E_{t-1}\frac{P_t A_t}{W_t} f\left(\overline{\omega}_{i,t}\right) &\geq R^d_{t-1}\frac{B_{i,t-1}}{X_{i,t-1}} && (16) \end{aligned}$$

where $f\left(\overline{\omega}_{i,t}\right)$ and $g\left(\overline{\omega}_{i,t};\mu_t\right)$ are given by (10) and (9), respectively, and, using (8), which can be rewritten as $\overline{\omega}_{i,t} = \frac{R^l_{i,t-1}}{\frac{P_t A_t}{W_t}}\left(1 - \frac{B_{i,t-1}}{X_{i,t-1}}\right)$.

Given that $B_{i,t-1}$ is exogenous to this problem and is predetermined, we can multiply and divide the objective by $B_{i,t-1}$, so that the problem is written in terms of $\frac{B_{i,t-1}}{X_{i,t-1}}$, $R^l_{i,t-1}$, and

[2] The problem is written under the assumption that it is optimal to produce, rather than just hold the funds. This is true as long as $P_t A_t N_{i,t} \geq X_{i,t-1}$. If it is optimal to produce, then the financial constraint (11) holds with equality, so that it is optimal to produce as long as $\frac{P_t A_t}{W_t} \geq 1$. As long as the economy is sufficiently away from the first best without financial costs, this condition should be satisfied.

$\overline{\omega}_{i,t}$, only. The objective and the constraints of the problem are the same for all firms. The only firm specific variable would be $B_{i,t-1}$ in the objective, but this would be irrelevant for the maximization problem. Hence, the solution for $\frac{B_{i,t-1}}{X_{i,t-1}}$, $R^l_{i,t-1}$, and $\overline{\omega}_{i,t}$ is the same across firms.

Name $b_{t-1} \equiv \frac{B_{i,t-1}}{X_{i,t-1}}$ and $v_t \equiv \frac{P_t A_t}{W_t}$. We can then rewrite $\overline{\omega}_{i,t}$, using (8), as

$$\overline{\omega}_{i,t} \equiv \overline{\omega}_t = \frac{R^l_{t-1}\left(1 - b_{t-1}\right)}{v_t}. \tag{17}$$

This condition, defining the threshold, together with the first-order conditions of the optimal contract problem that can be written as[3]

$$E_{t-1}\left[v_t f\left(\overline{\omega}_t\right)\right] = \frac{R^d_{t-1}}{1 - \frac{E_{t-1}\left[\mu_t \overline{\omega}_t \phi(\overline{\omega}_t)\right]}{E_{t-1}\left[1-\Phi(\overline{\omega}_t)\right]}} b_{t-1} \tag{18}$$

and

$$E_{t-1}\left[v_t g\left(\overline{\omega}_t; \mu_t\right)\right] = R^d_{t-1}\left(1 - b_{t-1}\right) \tag{19}$$

characterize the optimal $\left(R^l_{t-1}, b_{t-1}, \overline{\omega}_t\right)$.

2.3 Entrepreneurial decisions

Entrepreneurs are infinitely lived and have linear preferences over consumption with rate of time preference β^e. We assume β^e sufficiently low so that the return on internal funds is always higher than the preference discount $\frac{1}{\beta^e}$. Entrepreneurs then accumulate their entire share of production as internal funds and never consume. They pay lump-sum taxes which prevents their wealth from growing indefinitely.

The accumulation of internal funds is given by

$$B_t = f\left(\overline{\omega}_t\right) P_t A_t N_t - T_t, \tag{20}$$

The tax revenues are

$$T_t = \gamma_t f\left(\overline{\omega}_t\right) P_t A_t N_t. \tag{21}$$

They are transferred to the households or used for government consumption. The taxes are lump-sum, so that the entrepreneurs do not internalize that they are being taxed at the rate γ_t. The accumulation of funds can then be written as

$$B_t = \left(1 - \gamma_t\right) f\left(\overline{\omega}_t\right) \frac{v_t}{b_{t-1}} B_{t-1}. \tag{22}$$

[3] This is shown in Appendix A.1

We assume that government consumption is a share g of production net of the monitoring costs,

$$G_t = gA_tN_t\left[1 - \mu_t G\left(\overline{\omega}_t\right)\right].$$

The resource constraint is then given by

$$c_t = (1-g)\,A_tN_t\left[1 - \mu_t G\left(\overline{\omega}_t\right)\right]. \tag{23}$$

2.4 Equilibria

The equilibrium conditions are given by equations (3)-(6), (7) holding with equality, (17), (18), (19),

$$B_{i,t} = b_t X_{i,t}, \tag{24}$$

together with (22), (23), and the market clearing conditions

$$M_t + B_t = M_t^s$$

$$D_t = X_t - B_t,$$

$$\int N_{i,t}di = N_t = n_t$$

where $\int B_{i,t}di = B_t$, $\int X_{i,t}di = X_t$, and where $f\left(\overline{\omega}_t\right)$ and $g\left(\overline{\omega}_t;\mu_t\right)$ are given by (9) and (10), respectively, with $\overline{\omega}_t$ replacing $\overline{\omega}_{it}$.

Aggregating across firms and imposing market clearing, we can write conditions (7) and (24) as

$$\frac{B_{t-1}}{P_t} = b_{t-1}\frac{A_t}{v_t}n_t.$$

and

$$b_t = \frac{B_t}{X_t}, \tag{25}$$

The equilibrium conditions are summarized in Appendix A.2, where we also show that, given a set path for the price level, there is a unique equilibrium for all the other variables. We do not need to be explicit about how monetary policy is conducted in order to pin down a unique path for the price level and therefore a unique equilibrium for the real allocations.[4]

[4] That is an issue that is behond the scope of this paper and is present in every monetary model.

2.5 Implementability conditions

We can use the definition of v_t in equation (3), (18) and (19), and combine these last two equations, together with $f(\overline{\omega}_t) = 1 - \mu_t G(\overline{\omega}_t) - g(\overline{\omega}_t; \mu_t)$, to obtain

$$E_{t-1}\left[\frac{u_c(t)A_t}{\alpha}\left[1 - \mu_t G(\overline{\omega}_t) - f(\overline{\omega}_t)\frac{E_{t-1}[\mu_t \overline{\omega}_t \phi(\overline{\omega}_t)]}{E_{t-1}[1 - \Phi(\overline{\omega}_t)]}\right]\right] = R^d_{t-1},\ t \geq 1. \tag{26}$$

Using the definition $b_t = B_t/X_t$, the smallest set of implementability conditions in c_t, N_t, $\overline{\omega}_t$, R^d_{t-1}, b_{t-1}, R^l_{t-1}, $t \geq 1$, is then given by (26), above, together with

$$\frac{E_{t-1}\left[\frac{u_c(t)A_t}{\alpha} g(\overline{\omega}_t; \mu_t)\right]}{E_{t-1}\left[\frac{u_c(t)A_t}{\alpha} f(\overline{\omega}_t)\right]} = \left[1 - \frac{E_{t-1}[\mu_t \overline{\omega}_t \phi(\overline{\omega}_t)]}{E_{t-1}[1 - \Phi(\overline{\omega}_t)]}\right]\frac{(1 - b_{t-1})}{b_{t-1}},\ t \geq 1 \tag{27}$$

$$\overline{\omega}_t = \frac{R^l_{t-1}(1 - b_{t-1})}{\frac{u_c(t)A_t}{\alpha}},\ t \geq 0, \tag{28}$$

$$N_{t-1}\left(1 - \gamma_{t-1}\right) f(\overline{\omega}_{t-1})\frac{u_c(t-1)A_{t-1}}{\alpha} = R^d_{t-1} b_{t-1} \beta E_{t-1} N_t,\ t \geq 1, \tag{29}$$

$$(1 - g_t) A_t N_t [1 - \mu_t G(\overline{\omega}_t)] = c_t,\ t \geq 0. \tag{30}$$

2.6 Optimal policy

We consider two different cases, one where exogenous government consumption is at some level G, and a second case, where government consumption is an exogenous share of production g. The two assumptions have very different implications for the optimal nominal interest rate. In the first case, we can show analytically that the Friedman rule is optimal in the steady state, $R^d = 1$. It is also optimal in response to shocks, in the calibrated version we analyze below. In the second case, it is optimal to distort the consumption-leisure margin, even if lump-sum taxes are available. Since the nominal interest rate acts as a consumption tax, it is optimal to set it higher than zero.

Setting the nominal interest rate does not exhaust monetary policy. Because the funds are nominal and predetermined, there is still a role for policy. For instance, in response to a technology shock, the optimal price level policy is aimed at keeping the nominal wage constant. The price level adjusts so that the real wage moves with productivity. As a result, labor does not move, wages do not move and therefore, nominal predetermined funds are ex-post optimal.

In order to show that, when government consumption is at some exogenous level G, the Friedman rule is optimal in the steady state, we first show that steady-state bankruptcy rates are independent of monetary policy. Using equations (26) and (27), evaluated at the steady state, together with $1-\mu G(\overline{\omega}) = f(\overline{\omega}) + g(\overline{\omega};\mu)$, we get

$$\frac{u_c A}{\alpha} f(\overline{\omega}) = \frac{R^d b}{1 - \frac{\mu\overline{\omega}\phi(\overline{\omega})}{1-\Phi(\overline{\omega})}} \tag{31}$$

which, together with (29), evaluated at the steady state, gives

$$\frac{1-\gamma}{\beta} = 1 - \frac{\mu\overline{\omega}\phi(\overline{\omega})}{1-\Phi(\overline{\omega})}. \tag{32}$$

Equation (32) implies that the steady-state bankruptcy rate is indeed independent of the policy rate R^d or inflation.

The restrictions of the maximization of the steady-state utility $u(c) - \alpha n$, (26) through (30) with $g = 0$, evaluated at the steady state, can be simplified to the implementability condition

$$\frac{u_c A}{\alpha} = \frac{R^d}{1 - \mu G(\overline{\omega}) - f(\overline{\omega}) \frac{\mu\overline{\omega}\phi(\overline{\omega})}{1-\Phi(\overline{\omega})}}, \tag{33}$$

the condition that $\overline{\omega}$ does not depend on policy, (32), and the resource constraint,

$$AN[1 - \mu G(\overline{\omega})] = c + G, \tag{34}$$

together with the implicit restriction that the nominal interest rate cannot be negative, $R^d \geq 1$. The other two conditions determine R^l and b. For an exogenous $\overline{\omega}$ given by (32), suppose we were to maximize utility $u(c) - \alpha n$, subject to the steady-state resource constraint (34) only. Then, optimality would require that

$$\frac{u_c A}{\alpha} = \frac{1}{1 - \mu G(\overline{\omega})}.$$

From (33), this could only be satisfied if either $\mu = 0$ or $\overline{\omega} = 0$, and $R^d = 1$. When credit frictions are present, and $f(\overline{\omega}) \frac{\mu\overline{\omega}\phi(\overline{\omega})}{1-\Phi(\overline{\omega})} \neq 0$, there is a reason to subsidize consumption, which in this economy can only be done by reducing the nominal interest rate. Since $R^d \geq 1$, it is optimal to set $R^d = 1$, as a corner solution. The Friedman rule is optimal.

With $g > 0$, it may be optimal to tax on average. The same argument as above cannot go through. The optimal condition just using the resource constraint would require that

$$\frac{u_c A}{\alpha} = \frac{1}{(1-g)[1 - \mu G(\overline{\omega})]}. \tag{35}$$

In spite of the reason to subsidize, due to $f(\overline{\omega}_t) \frac{\mu\overline{\omega}\phi(\overline{\omega})}{1-\Phi(\overline{\omega})}$, if g is high enough, it is optimal to tax. Then, as we show in the simulations below, it will be optimal to tax at different rates, in response to shocks.

When $g = 0$, in the calibrated version we analyze below, the Friedman rule is optimal also in response to shocks. From condition (26), at the lower bound, we obtain

$$E_{t-1}\left[\frac{u_c(t)\,A_t}{\alpha}\left[1-\mu_t G(\overline{\omega}_t)-f(\overline{\omega}_t)\,\frac{E_{t-1}\left[\mu_t\overline{\omega}_t\phi(\overline{\omega}_t)\right]}{E_{t-1}\left[1-\Phi(\overline{\omega}_t)\right]}\right]\right]=1. \tag{36}$$

This condition provides some intuition on what is at stake for optimal policy. $\frac{u_c(t)A_t}{\alpha}$ is the wedge between the marginal rate of substitution and the marginal rate of transformation if the financial technology is not taken into account. The term $\frac{1}{1-\mu_t G(\overline{\omega}_t)-f(\overline{\omega}_t)\frac{E_{t-1}[\mu_t\overline{\omega}_t\phi(\overline{\omega}_t)]}{E_{t-1}[1-\Phi(\overline{\omega}_t)]}}$ is the financial markup present in models with asymmetric information and bankruptcy costs. The wedge has to be equal to the financial markup, on average, but not always in response to shocks.

As the numerical results will show, for logarithmic preferences, the optimal policy in response to technology shocks is to fully stabilize the financial markup, therefore keeping bankruptcy rates constant, and setting the wedge equal to the constant financial markup. Given that the utility is logarithmic, consumption is proportional to the technology shock, which implies that labor does not move, from (30). From (11), we have that $X_{t-1} = \frac{P_t A_t}{v_t} N_t$. Since $N_t = N$, $v_t = v$, and X_{t-1} does not vary with shocks in t, it must be that the price level is inversely proportional to the technology shock. Since nominal funds are predetermined and labor does not move, the optimal policy is to keep the nominal wage constant and adjust the price level to the movements in the real wage.

3 Numerical results

The model calibration is very standard. We assume utility to be logarithmic in consumption and linear in leisure. Following Carlstrom and Fuerst (1997), we calibrate the volatility of idiosyncratic productivity shocks and the rate of accumulation of internal funds, $1-\gamma_t$, so as to generate an annual steady state credit spread of approximately 2% and a quarterly bankruptcy rate of approximately 1%.[5] The monitoring cost parameter μ is set at 0.15 following Levin *et al.* (2004).

In the rest of this section, we always focus on adverse shocks, i.e. shocks which tend to generate a fall in output. Impulse responses under optimal policy refer to an equilibrium in which policy is described by the first order conditions of a Ramsey planner deciding allocations

[5] The exact values are 1.8% for the annual spread and 1.1% for the bankruptcy rate.

for all times $t \geq 1$, but ignoring the special nature of the initial period $t = 0$. Responses under a Taylor rule refer to an equilibrium in which policy is set according to the following simple interest rate rule:

$$\widehat{i}_t = 1.5 \cdot \widehat{\pi}_t \tag{37}$$

where hats denote logarithmic deviations from the non-stochastic steady state.

In all cases, we only study the log-linear dynamics of the model.

3.1 Impulse responses under optimal policy

Optimal policy in the calibrated version of the model entails setting the nominal interest rate permanently to zero, as long as the level of government consumption is exogenous. This restriction is imposed when computing impulse responses.

3.1.1 Technology shocks: price stability is not optimal

Figure 1 shows the impulse response of selected macroeconomic variables to a negative, 1% technology shock under optimal policy. The variables are production $A_t N_t$ (designated by y_t), real internal funds $\frac{B_{t-1}}{P_t}$ (designated by $\bar{b}_t$), and inflation $\frac{P_t}{P_{t-1}}$ (designated by π_t). Bankruptcy rates, markups, spreads, and leverage are not represented because there is no effect of the shock on those under the optimal policy.

It is important to recall that the model includes many features which could potentially lead to equilibrium allocations that are far from the first best: asymmetric information and monitoring costs; the predetermination of financial decisions; and the nominal denomination of debt contracts. At the same time, the presence of nominal predetermined contracts implies that monetary policy is capable of affecting allocations by choosing appropriate sequences of prices.

Figure 1 illustrates that optimal policy is able to replicate the first-best response of consumption and labor allocations to a technology shock.[6] In response to the negative technology shock, since nominal internal and external funds are predetermined, optimal policy generates inflation for 1 period. As a result, the real value of total funds needed to finance production falls exactly by the amount necessary to generate the correct reduction in output.

In subsequent periods, the real value of total funds is slowly increased through a mild reduction in the price level. Along the adjustment path, leverage remains constant and firms

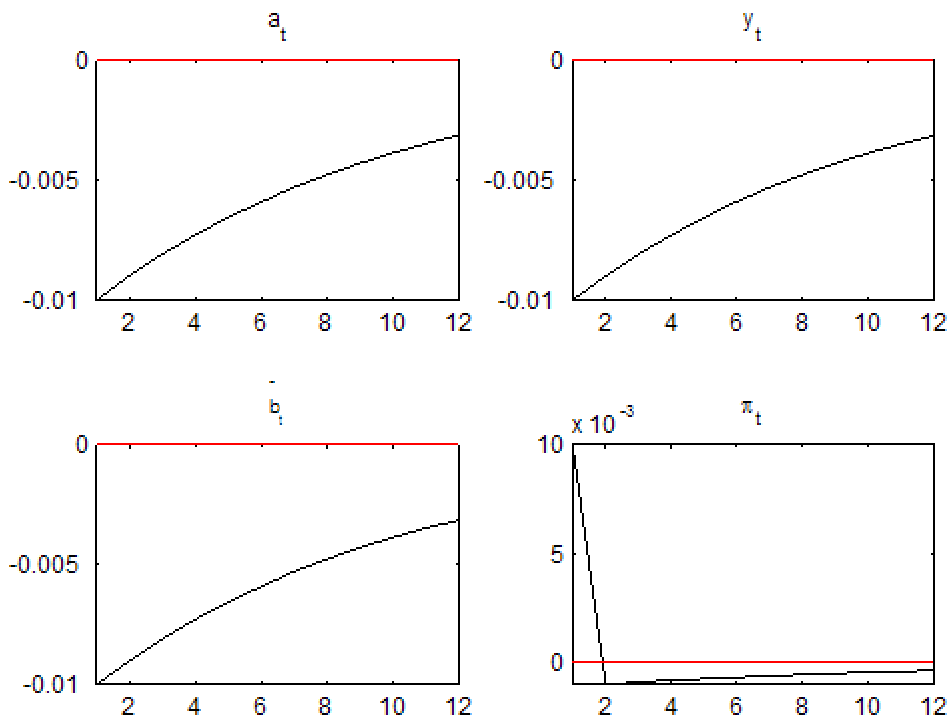
[6] The allocations are distorted, but the responses are as in the first best.

make no losses. Consumption moves one-to-one with technology, while hours worked remain constant. With constant labor and an equilibrium nominal wage that stays constant, the restriction that funds are predetermined is not relevant. The price level adjusts so that the real wage is always equal to productivity. Since total funds are always at the desired level, the accumulation equation for nominal funds never kicks in.

The impulse responses in Figure 1 would obviously be symmetric after a positive technology shock. Hence, perfect price stability – i.e. an equilibrium in which the price level is kept perfectly constant at all points in time – is not optimal in our model (we show below that this is the case for all shocks, not just technology shocks). Short inflationary episodes are useful to help firms adjust their funds, both internal and external, to their production needs. In the case of technology shocks, this policy also prevents any undesirable fluctuations in the economy's bankruptcy rate, financial markup, or the markup resulting from the predetermination of assets.

This result is robust to a number of perturbations of the model. It also holds if there are reasons not to keep the nominal interest rate at zero. And it holds in a model where internal and external funds are perfect substitutes.

Figure 1: Impulse responses to a negative technology shock under optimal policy



Note: Logarithmic deviations from the non-stochastic steady state. Correlation of the shock: 0.9.

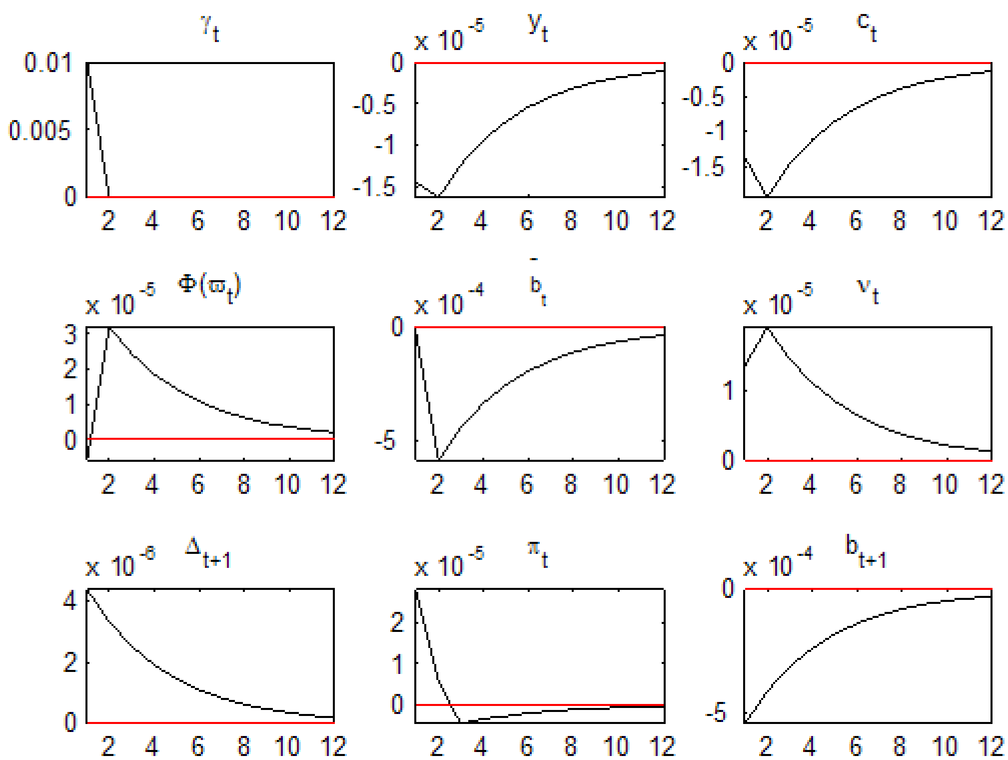
3.1.2 Financial shocks

We can analyze the impulse responses to three types of financial shocks in our economy. The first is an increase in γ_t, namely a shock which generates an exogenous reduction in the level of internal funds. The second one is a shock to the standard deviation of idiosyncratic technology shocks, which amounts to an increase in the uncertainty of the economic environment. The third shock is an increase in the monitoring cost parameter μ_t.

We focus on the first shock. The other two shocks are analyzed in Appendix 3. The impulse responses to γ_t in Figure 2 are interesting because they generate at the same time a reduction in output and an increase in leverage – leverage can be defined as the ratio of external to internal funds used in production, i.e. as $1/b_t - 1$, and it is therefore negatively related to b_t. To highlight the different persistence of the effects of the shock, depending on the prevailing policy rule, we focus on a serially uncorrelated shock. The variables are, in addition to the ones in Figure 1, consumption, c_t, the share of firms that go bankrupt, $\Phi(\overline{\omega}_t)$, the markup,

υ_t, the spread between the lending and the deposit rate, $\Delta_{t+1} \equiv R^l_{t+1} - R^d_{t+1}$, and the ratio of internal to total funds $b_{t+1} = \frac{B_{t+1}}{X_{t+1}}$.

Figure 2: Impulse responses to a fall in the value of internal funds under optimal policy



Note: Logarithmic deviations from the non-stochastic steady state. Serially uncorrelated shock.

The higher γ does not have an effect on funds on impact because of the predetermination of financing decisions, but it represents a fall in internal funds at $t+1$, which leads to an increase in firms' leverage.

We will see below that under a Taylor rule this shock brings about a period of deflation, which would be quite persistent if the original shock were also persistent. The optimal policy response, instead, is to create a short-lived period of inflation. The impact increase in the price level lowers the real value of total funds, so as to decrease labor and production levels. Mark ups increase on impact, as output and consumption decrease, so that the future cut in internal funds can be partially offset. The higher profits allow firms to quickly start rebuilding their internal funds. The adjustment process is essentially complete after 3 years. When consumption starts growing towards the steady state, the real rate must increase. For given nominal interest rate, there must be a period of mild deflation.

3.2 Taylor rule policy

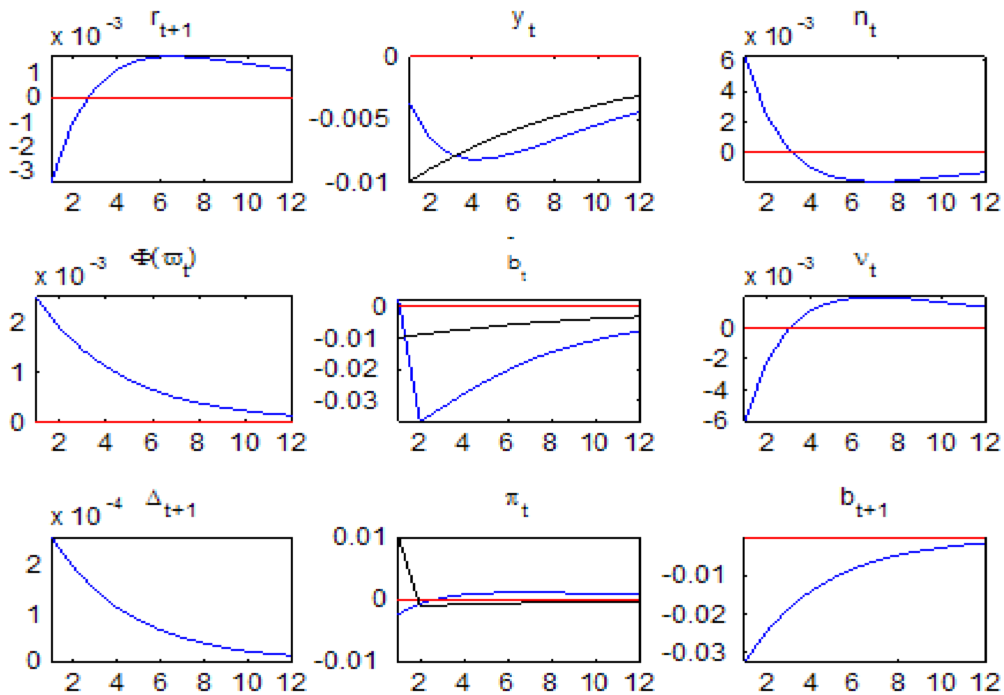
We now compare the impulse responses under optimal policy with those in which policy follows the simple Taylor rule in equation (37).

3.2.1 Technology shocks and the cyclicality of bankruptcies

In response to a negative technology shock, the simple Taylor rule tries to stabilize inflation (see Figure 3). The large amount of nominal funds that firms carry over from the previous period, therefore, has high real value. Given the available funds, firms hire more labor and the output contraction is relatively small, compared to what would be optimal at the new productivity level. As a result, the wage share increases and firms make lower profits, hence they must sharply reduce their internal funds. Leverage goes up, and so do the credit spread and the bankruptcy rate. In the period after the shock, firms start accumulating funds again, but accumulation is slow and output keeps falling for a whole year after the shock. It is only in the second year after the shock that the recovery begins.

Figure 3 illustrates how our model is able to generate realistic, cyclical properties for the credit spread and the bankruptcy ratio. An increase in bankruptcies is almost a definition of recession in the general perception, while the fact that credit spreads are higher during NBER recession dates is documented, for example, in Levin et al. (2004). Generating the correct cyclical relationship between credit spreads, bankruptcies and output is not straightforward in models with financial frictions. For example, spreads are unrealistically procyclical in the Carlstrom and Fuerst (1997, 2000) framework. The reason is that firms' financing decisions are state contingent in those papers. Firms can choose how much to borrow from the banks *after* observing aggregate shocks. Should a negative technology shock occur, they would immediately borrow less and try to cut production. This would avoid large drops in their profits and internal funds, so that their leverage would not increase. As a result, bankruptcy rates and credit spreads could remain constant or decrease during the recession.

Figure 3: Impulse responses to a negative technology shock under a Taylor rule



Note: Logarithmic deviations from the non-stochastic steady state. Correlation of the shock: 0.9. The blue lines indicate impulse responses under the Taylor rule; the black lines report the impulse responses under optimal policy already shown in Figure 1.

In our model, economic outcomes are reversed because of the pre-determination in financial decisions. Firms' loans are no-longer state contingent, hence they cannot be changed after observing aggregate shocks. This assumption implies that firms are constrained in their impact response to disturbances. After a negative technology shock, firms find themselves with excessive funds and their profits will fall because production levels do not fall enough. The reverse would happen during an expansionary shock, when production would initially increase too little and profits would be high.

Our model also generates a realistically hump-shaped impulse response of output and consumption without the need for additional assumptions, such as habit persistence in households' preferences. Once a shock creates the need for changes in internal funds, these changes can only take place slowly. Compared to the habit persistence assumption, our model implies that the hump-shape in impulse responses is policy-dependent. After a technology shock, optimal policy keeps internal funds at their optimal level at any point in time. Firms do not need to accumulate, or decumulate, internal funds, and, as a result, the hump in the response of output and consumption disappears.

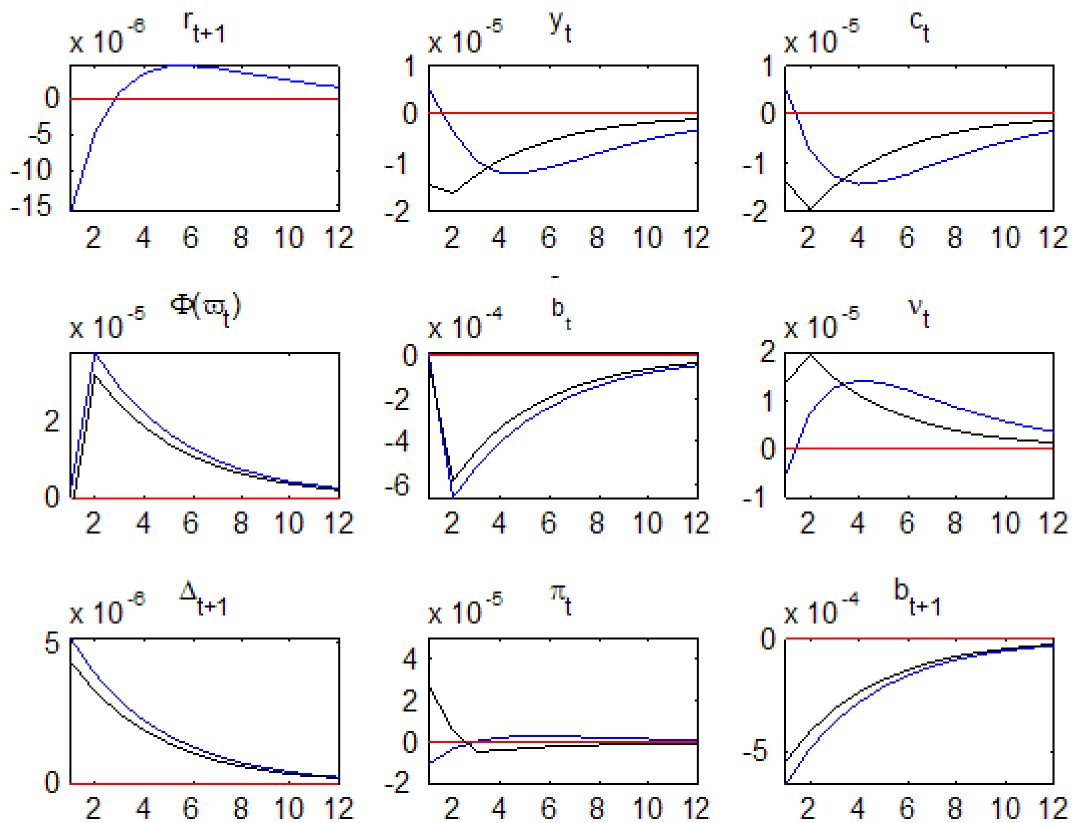
3.2.2 Shocks to the value of internal assets

Contrary to the optimal policy case, under a Taylor rule this shock leads to a fall, rather than an increase, in the price level.

The situation in which firms' leverage increase and deflation ensues is akin to the "initial state of over-indebtedness" described in Fisher (1933). In Fisher's theory, firms try to de-leverage through a fast debt liquidation and the selling tends to drive down prices. If monetary policy accommodates this trend, the price level also falls and the real value of firms liabilities increase further, leading to even higher leverage and further selling.

In our model, over-indebtedness and leverage are also exacerbated by deflation, but the mechanics of the model are different (see Figure 4). The progressive increase in leverage leads to an increase in the economy's bankruptcy rate, and a protracted fall in consumption. This, in turn, is associated with a fall in the real interest rate which, given the policy rule, is implemented through a cut in the nominal rate in spite of a small deflationary period. De-leveraging occurs through an accumulation of assets, rather than a liquidation of debt. However, the de-leveraging process is very slow and consumption is still away from the steady state three years after the shock. Compared to the optimal policy case, the recession is more persistent and it comes at the cost of a higher bankruptcy rate and a higher credit spread.

Figure 4: Impulse responses to a fall in the value of internal assets under a Taylor rule



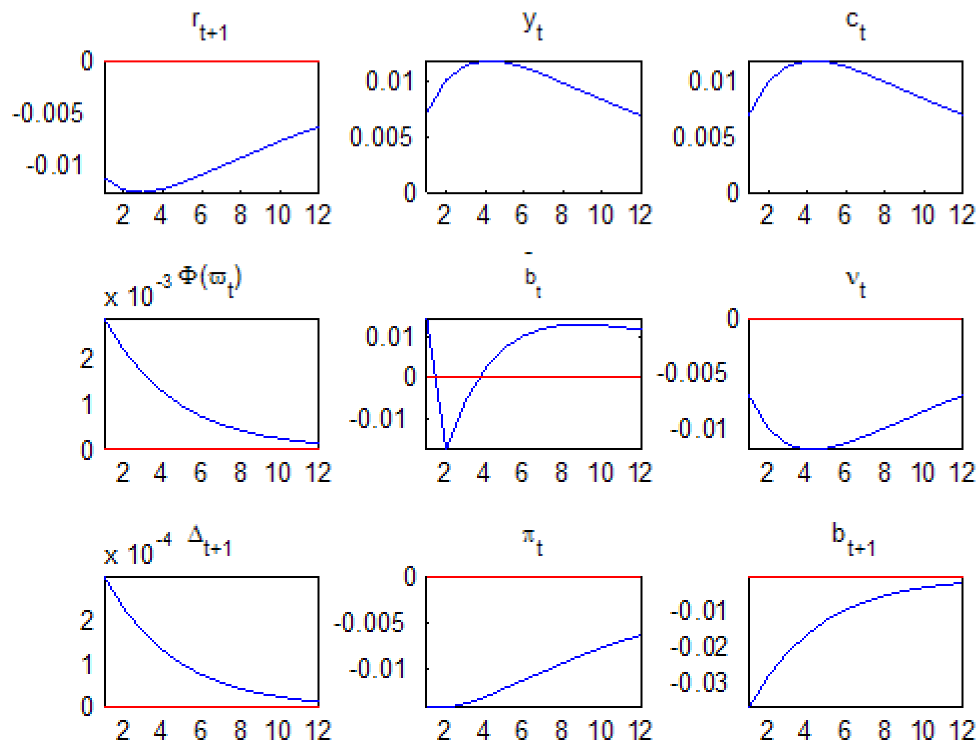
Note: Logarithmic deviations from the non-stochastic steady state. The shock is serially uncorrelated. The blue lines indicate impulse responses under the Taylor rule; the black lines report the impulse responses under optimal policy already shown in Figure 2.

3.2.3 Policy shocks

Figure 5 shows the impulse responses to a serially correlated shock to the Taylor rule, corresponding to a cut in the policy rate.

The shock is useful to illustrate the general features of the "monetary policy transmission mechanism" in this model. These are characterized by the slow mechanism of accumulation of internal funds, which produces very persistent responses in all variables.

Figure 5: Impulse responses to a monetary policy shock



Note: Logarithmic deviations from the non-stochastic steady state. Correlation of the shock: 0.9.

The shock generates an immediate fall in the price level which boosts the real value of firms' nominal funds and induces a boom in production and consumption through an increase in employment higher real wages. Since leverage is predetermined in the first period, the higher production level brings about an increase in the bankruptcy rate. Profits fall and, after one period, firms find themselves short of internal funds and start rebuilding them. The adjustment process is very slow. Three years after the shock, output, consumption and employment are still far away from the steady state.

3.3 Optimal policy when a non-zero interest rate is optimal

In this section, we explore to which extent the optimal policy recommendations described above are affected by the fact that the nominal interest rate is kept constant at zero. In the calibration, we keep all other parameters unchanged, but we assume there is a fixed share of government consumption $g = 0.02$ in the steady state. As discussed above, the optimal steady state level of the nominal interest rate increases proportionately. That is the reason why we consider g to be a small number, because it will correspond to a relatively small nominal interest rate. As a result, there is also an increase in the steady state level of the credit spread and of the bankruptcy rate.[7]

3.3.1 Technology shocks

In spite of the availability of the nominal interest rate as a policy instrument, the optimal response to a technology shock is the same as before. As already discussed, policy is able to replicate the same response of the allocations which would be attained in a frictionless model even when the nominal interest rate must be kept constant (at zero). There are therefore no reasons to deviate from that policy even if the nominal interest rate can be moved.

3.3.2 Financial shocks

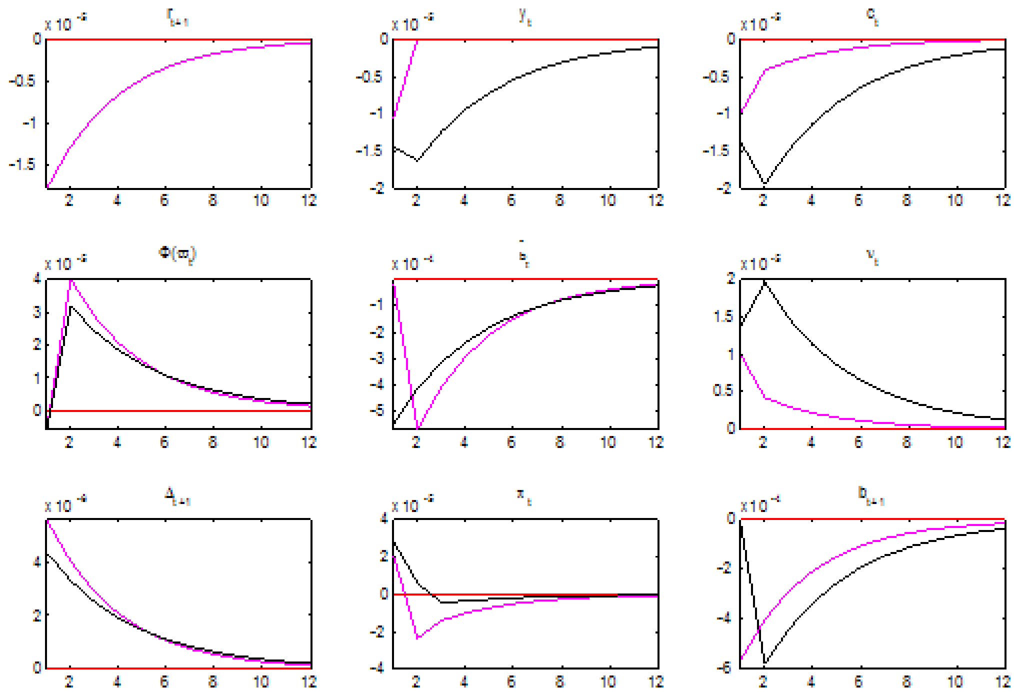
For all financial shocks, the flexibility of using the nominal interest rate allows policy to speed up the adjustment after financial shocks. The effect of these shocks on output is considerably mitigated. We illustrate this general result with a serially uncorrelated shock to γ.

The impulse responses to this shock under the optimal policy are shown in Figure 6, together with the impulse responses in the case where the Friedman rule is optimal. The most striking result is that the impact of this shock on output, which is persistently contractionary when the short term nominal rate is kept fixed at zero, is less contractionary and very short-lived when the interest rate can be reduced.

Given that output is at the steady state after an impact decrease, policy does not need to generate persistent inflation to kick-start the process of accumulation of nominal funds. It can improve credit conditions directly, by reducing the policy interest rate and therefore, loan rates. While the increase in the credit spread is larger here than in the case when the Friedman rule is optimal, the increase is offset by the reduction in the policy rate.

[7] In the steady state, the credit spread increases to 1.27% and the bankruptcy rate to 6.7%.

Figure 6: Impulse responses to a fall in the value of internal assets under optimal policy



Note: Logarithmic deviations from the non-stochastic steady state. Correlation of the shock: 0.9. The violet lines indicate impulse responses under optimal policy when $g > 0$; the black lines report the impulse responses under optimal policy already shown in Figure 2.

The effect on the other variables is comparable to the case in which the Friedman rule is optimal, but the adjustment process is much faster.

4 The case in which internal and external funds are perfect substitutes

In order to better understand the results of our general model, we analyze a simplified case in which assets are predetermined, but internal and external funds are perfect substitutes - i.e. monitoring costs are zero.

Even in the absence of asymmetric information and costly state verification, it is not optimal to maintain price stability at all times. Hence, the predetermination of assets and the nominal denomination of funds are responsible for the deviation from price stability under the optimal policy in the general model.

As before, setting the interest rate does not exhaust the room for policy. Indeed, following a technology shock, the optimal monetary policy induces movements in the price level that are inversely proportional to the shock. The real wage moves with productivity despite nominal wages being constant. Under log-linear preferences, labor does not move either, so that nominal predetermined funds are ex-post optimal.

Finally, we use this model to evaluate the role played by asymmetric information and monitoring costs in explaining business cycle fluctuations. We find that, although these imperfections play a quantitatively minor role in determining the cyclical behavior of non-financial variables, they tend to amplify the reaction of the economy to shocks.

4.1 Price stability is not optimal

We consider the case where $g > 0$, and high enough so that the borrowing constraint of firms is always binding. In the model with financial frictions this was not necessary since positive financial markups guaranteed that the constraint was binding.

The equilibrium conditions in this economy are given by (3)-(6), together with

$$R^l_{t-1} = R^d_{t-1} = R_{t-1},\ t \geq 1 \tag{38}$$

$$E_{t-1}[v_t] = R_{t-1},\ t \geq 1$$

$$N_t = \frac{X_{t-1}}{W_t},\ t \geq 0 \tag{39}$$

$$v_t = \frac{A_t P_t}{W_t},\ t \geq 0 \tag{40}$$

$$c_t = (1-g) A_t N_t,\ t \geq 0. \tag{41}$$

The implementability conditions restricting c_t, N_t, $t \geq 0$, and R_{t-1}, $t \geq 1$, are:

$$E_{t-1}\left[\frac{u_c(t) A_t}{\alpha}\right] = R_{t-1},\ t \geq 1 \tag{42}$$

$$c_t = (1-g) A_t N_t,\ t \geq 0 \tag{43}$$

Every equilibrium sequence for c_t, N_t, $t \geq 0$, and R_{t-1}, $t \geq 1$, in this set can be implemented. The other equilibrium conditions are satisfied by the choice of the remaining variables: (38) determine R^l_{t-1} and R^d_{t-1}, $t \geq 1$. For $t = 0$, given a value X_{-1} and an allocation c_0 and N_0, (39) and (3) are satisfied by the choice of W_0 and P_0. For $t \geq 1$, given an allocation c_t and N_t, and R_{t-1}, conditions (3), (5) and (39) are satisfied by the choice of W_t, P_t and X_{t-1}. There are two contemporaneous conditions and one predetermined condition for two contemporaneous variables and one predetermined variable. (40) determines v_t; (4) determines $Q^{-1}_{t-1,t}$, and (6) restricts m_t.

The restriction that government consumption is a constant share of production is a second-best restriction in this environment, implying the optimal use of proportionate taxation, even if lump-sum taxation is available. The optimal, second-best, allocation maximizes utility subject to the resource constraints

$$c_t \leq (1-g)\, A_t N_t.$$

Optimality requires that

$$\frac{u_c(t)}{\alpha} = \frac{1}{(1-g)\, A_t},\ t \geq 0. \tag{44}$$

This optimal allocation can be implemented in this economy with predetermined assets, since it satisfies the implementability condition (42) when the interest rate is

$$R_{t-1} = E_{t-1}\left[\frac{1}{1-g}\right],\ t \geq 1.$$

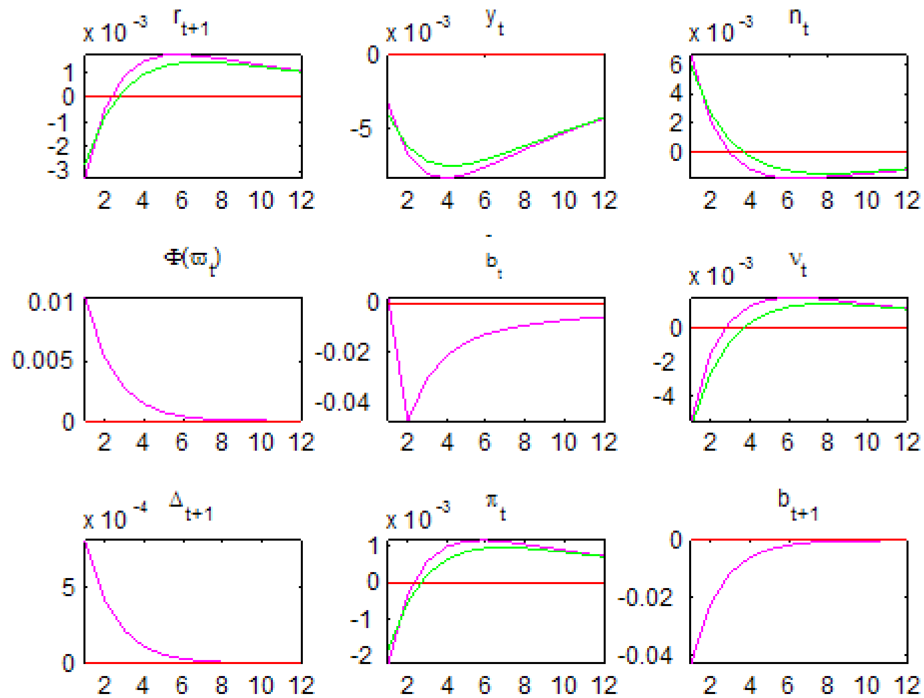
In this economy, monetary policy does much more than just setting the interest rate. Implementing the optimal allocation, requires moving the price level to adjust the real value of funds.

Under log-linear preferences, labor would not move in response to shocks to productivity, A_t. Since funds are predetermined, in (39), the wage rate could not move either and, from (3), the price level would have to be inversely proportional to consumption, or to the shocks to productivity.

4.2 The role of asymmetric information and monitoring costs

Figure 7 compares the reaction to a technology shock under the Taylor rule in the general model of section 2 and in this benchmark model. The figure shows that the differences between the two cases are not overwhelming, but the model with asymmetric information and monitoring costs tends to amplify business cycle fluctuations in response to shocks. Compared to the simple model (the green lines in Figure 7), the recession induced by a negative technology shock is deeper when accompanied by an increase in credit spreads and in the bankruptcy rate (the magenta lines). Employment fluctuations are also more pronounced and so is the volatility of inflation and of the policy interest rate.

Figure 7: Impulse responses to a negative techology shock under a Taylor rule



Note: Logarithmic deviations from the non-stochastic steady state. Correlation of the shock: 0.9. The green lines report the impulse responses in this benchmark model when $g > 0$; the magenta lines indicate impulse responses in our full model when $g > 0$.

5 Conclusions

The model described in this paper represents an attempt to clarify the policy incentives created by the nominal denomination of firms' debt. Our analysis is based on a number of simplifying assumptions and does not aim to provide quantitative policy prescriptions. Nevertheless, we highlight results that may be of relevance also in more general frameworks.

The first result is that maintaining price stability at all times is not optimal when firms' financial positions are denominated in nominal terms and debt contracts are not state-contingent. After a negative technology shock, for example, an impact increase in the price level stabilizes firms' leverage and allows for a more efficient economic response to the shock. This ability of monetary policy to influence the real value of firms' assets and liabilities derives from the assumption that, when shocks occur, financial contracts are predetermined. The policy response through the price level is such that, in response to technology shocks, there is no need for the central bank to adjust the nominal interest rate.

A second result is that the optimal response to an exogenous reduction in internal funds, which amounts to an increase in firms' leverage, is to significantly reduce the nominal interest rate, if the nominal rate is not at its zero bound, and to engineer a short period of controlled inflation. Both policy responses have the advantages of mitigating the adverse consequences of the shock on bankruptcy rates and of allowing firms to quickly de-leverage.

Finally, we show that a simple Taylor-type rule would produce significantly different economic outcomes from those prevailing if policy is set optimally. For example, under a Taylor rule bankruptcy rates would increase during recessions, as it appears to be the case in the empirical evidence. Bankruptcy rates would instead be acyclical under optimal policy.

A Appendix

A.1 The financial contract

Consider the optimal financial contract problem that maximizes (14) subject to (15) and (16), where $g\left(\overline{\omega}_{i,t};\mu_t\right)$ and $f\left(\overline{\omega}_{i,t}\right)$ are given by (10) and (9), respectively, and $\overline{\omega}_{i,t}=\frac{R^l_{i,t-1}}{\frac{P_tA_t}{W_t}}\left(1-\frac{B_{i,t-1}}{X_{i,t-1}}\right)$.

The solution for $\frac{B_{i,t-1}}{X_{i,t-1}}$, $R^l_{i,t-1}$, and $\overline{\omega}_{i,t}$ is the same across firms. Let $b_{t-1}\equiv\frac{B_{i,t-1}}{X_{i,t-1}}$ and $v_t\equiv\frac{P_tA_t}{W_t}$. We can define the function $\overline{\omega}_{i,t}\equiv\overline{\omega}_t=\overline{\omega}\left(R^l_{t-1},b_{t-1};v_t\right)$ as

$$\overline{\omega}_t=\frac{R^l_{t-1}\left(1-b_{t-1}\right)}{v_t}. \tag{45}$$

We can rewrite the problem as

$$\max\ E_{t-1}\left[v_t\frac{1}{b_{t-1}}f\left(\overline{\omega}\left(R^l_{t-1},b_{t-1};v_t\right)\right)\right]$$

subject to

$$E_{t-1}\left[v_tg\left(\overline{\omega}\left(R^l_{t-1},b_{t-1};v_t\right);\mu_t\right)\right]\ \geq\ R^d_{t-1}\left(1-b_{t-1}\right) \tag{46}$$

$$E_{t-1}v_tf\left(\overline{\omega}\left(R^l_{t-1},b_{t-1};v_t\right)\right)\ \geq\ R^d_{t-1}b_{t-1} \tag{47}$$

where the functions $g\left(.;\mu_t\right)$ and $f\left(.\right)$ are given by (10) and (9), respectively.

Define as $\lambda_{1,t-1}$ and $\lambda_{2,t-1}$ the Lagrangean multipliers of (46) and (47) respectively. Conjecturing that $\lambda_{2,t-1} = 0$, the first-order conditions are

$$E_{t-1}\left[-\frac{v_t}{b_{t-1}^2} f\left(\overline{\omega}\left(R_{t-1}^l, b_{t-1}; v_t\right)\right) + \frac{v_t}{b_{t-1}} f_2\left(R_{t-1}^l, b_{t-1}; v_t\right)\right] + \lambda_{1t-1} E_{t-1}\left[v_t g_2\left(R_{t-1}^l, b_{t-1}; v_t, \mu_t\right) + R_{t-1}^d\right] = 0$$

$$E_{t-1}\left[\frac{v_t}{b_{t-1}} f_1\left(R_{t-1}^l, b_{t-1}; v_t\right)\right] + \lambda_{1t-1} E_{t-1}\left[g_1\left(R_{t-1}^l, b_{t-1}; v_t, \mu_t\right) v_t\right] = 0$$

$$E_{t-1} g\left(\overline{\omega}\left(R_{t-1}^l, b_{t-1}; v_t\right); \mu_t\right) v_t = R_{t-1}^d \left(1 - b_{t-1}\right)$$

where f_j and g_j, with $j = 1, 2$, are the derivatives of f and g with respect to the first and second argument of the function $\overline{\omega}\left(R_{t-1}^l, b_{t-1}; v_t\right)$.

Assuming $1 \neq b_t$, we can rewrite these conditions as

$$\lambda_{1t-1} R_{t-1}^d b_{t-1} = E_{t-1}\left[\frac{v_t}{b_{t-1}} f\left(\overline{\omega}\left(R_{t-1}^l, b_{t-1}; v_t\right)\right)\right],$$

$$R_{t-1}^l \left(1 - b_{t-1}\right) \lambda_{1t-1} E_{t-1}\left[\frac{\mu_t}{v_t} \phi\left(\frac{R_{t-1}^l \left(1 - b_{t-1}\right)}{v_t}\right)\right] + \left(\frac{1}{b_{t-1}} - \lambda_{1t-1}\right) E_{t-1}\left[1 - \Phi\left(\frac{R_{t-1}^l \left(1 - b_{t-1}\right)}{v_t}\right)\right] = 0,$$

$$E_{t-1}\left[g\left(\overline{\omega}\left(R_{t-1}^l, b_{t-1}; v_t\right); \mu_t\right) v_t\right] = R_{t-1}^d \left(1 - b_{t-1}\right).$$

From the second condition, since $b_{t-1} < 1$ and $\lambda_{1t-1} > 0$, $R_{t-1}^l \left(1 - b_{t-1}\right) \lambda_{1t-1} E_{t-1}\left[\frac{\mu_t}{v_t} \phi\left(\frac{R_{t-1}^l (1-b_{t-1})}{v_t}\right)\right] > 0$. Moreover, $1 > \Phi\left(\frac{R_{t-1}^l (1-b_{t-1})}{v_t}\right)$ so that $\lambda_{1t-1} - \frac{1}{b_{t-1}} > 0$ and $\lambda_{1t-1} b_{t-1} > 1$. It follows that $R_{t-1}^d b_{t-1} < E_{t-1}\left[v_t f\left(\overline{\omega}\left(R_{t-1}^l, b_{t-1}; v_t\right)\right)\right]$, which verifies the conjecture that $\lambda_{2t-1} = 0$.

Using the definition of the threshold, (45), the first-order conditions can be written as (18) and (19).

A.2 Equilibria

The equilibrium conditions restricting the variables $\left\{c_t, N_t, v_t, P_t, R_t^d, \overline{\omega}_t, b_t, R_t^l, X_t, B_t\right\}$ given b_{-1}, X_{-1}, $B_{-1} = b_{-1} X_{-1}$, and R_{-1}^l, can be summarized by

$$\frac{u_c(t)}{\alpha} = \frac{v_t}{A_t}, \; t \geq 0 \tag{48}$$

$$\frac{u_c(t-1)}{P_{t-1}} = R_{t-1}^d \beta E_{t-1} \frac{u_c(t)}{P_t}, \; t \geq 1 \tag{49}$$

$$E_{t-1}\left[v_t f\left(\overline{\omega}_t\right)\right] = \frac{R^d_{t-1}}{1 - \frac{E_{t-1}\left[\mu_t \overline{\omega}_t \phi\left(\overline{\omega}_t\right)\right]}{E_{t-1}\left[1-\Phi\left(\overline{\omega}_t\right)\right]}} b_{t-1},\ t \geq 1 \tag{50}$$

$$E_{t-1}\left[v_t g\left(\overline{\omega}_t; \mu_t\right)\right] = R^d_{t-1}\left(1 - b_{t-1}\right),\ t \geq 1 \tag{51}$$

$$\overline{\omega}_t = \frac{R^l_{t-1}\left(1 - b_{t-1}\right)}{v_t},\ t \geq 0 \tag{52}$$

$$N_t = \frac{v_t X_{t-1}}{A_t P_t},\ t \geq 0 \tag{53}$$

$$B_{t-1} = b_{t-1} X_{t-1},\ t \geq 1 \tag{54}$$

$$B_{t-1} = \left(1 - \gamma_{t-1}\right) f\left(\overline{\omega}_{t-1}\right) \frac{v_{t-1}}{b_{t-2}} B_{t-2},\ t \geq 1 \tag{55}$$

$$\left(1 - g\right) A_t N_t \left[1 - \mu_t G\left(\overline{\omega}_t\right)\right] = c_t,\ t \geq 0 \tag{56}$$

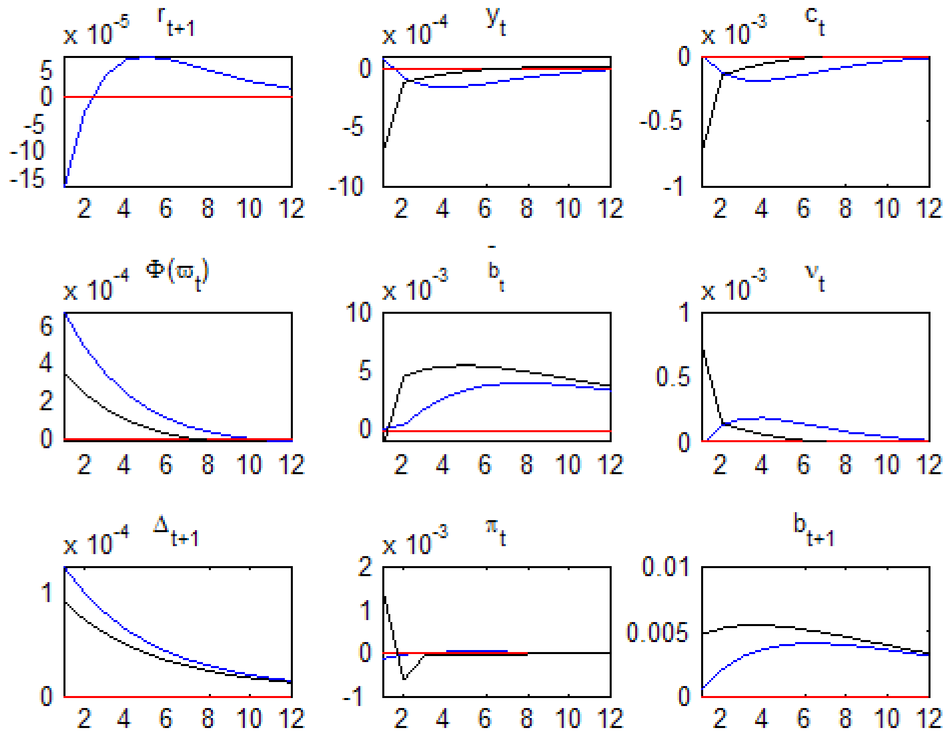
The other equilibrium conditions determine the remaining variables.

Given the path for the price level there is a unique equilibrium for the other variables. To see this, notice that at $t = 0$, given the values of b_{-1}, X_{-1} and R^l_{-1}, the equilibrium for c_0, N_0, v_0, $\overline{\omega}_0$, can be determined using (48), (52), (53), (56)for $t = 0$. Given these variables, $B_{-1} = b_{-1}X_{-1}$, and the path for the price level, P_t, the remaining variables c_t, N_t, v_t, $\overline{\omega}_t$, B_{t-1}, R^d_{t-1}, b_{t-1}, R^l_{t-1}, X_{t-1} for $t \geq 1$, are determined using (48) - (56)for $t \geq 1$. These are 4 contemporaneous variables and 5 predetermined variables, restricted by 4 contemporaneous conditions and 5 predetermined conditions. If P_t are set exogenously, all the other variables have a single solution. Alternatively, we could set exogenously R^d_{t-1}, plus P_t in as many states as $\#S^t - \#S^{t-1}$, and again there would be a unique equilibrium.

A.3 Impulse responses to financial shocks

We present here additional impulse responses to financial shocks in the baseline model where the Friedman rule is optimal. Shocks are serially correlated with a 0.9 correlation coefficient. In all cases, we compare the impulse responses under the optimal policy to those arising under the Taylor rule.

Figure A1: Impulse responses to an increase in σ_{ω_t}

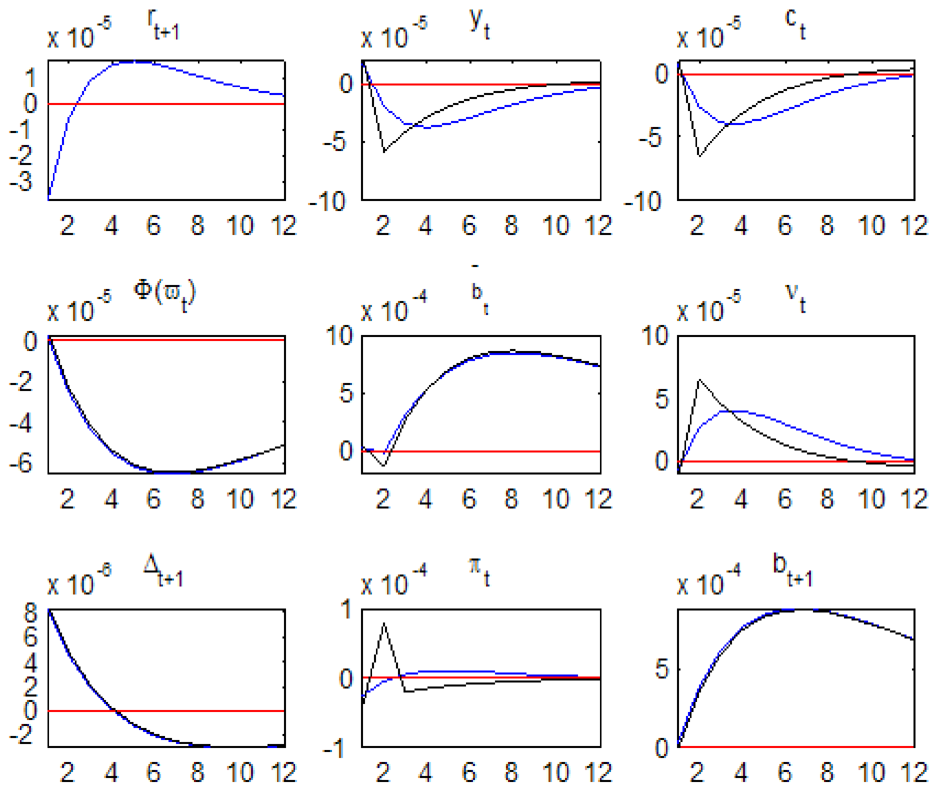


Note: Logarithmic deviations from the non-stochastic steady state. Correlation of the shock: 0.9. The blue lines indicate impulse responses under the Taylor rule; the black lines report the impulse responses under optimal policy.

Figure A1 shows the impulse responses to a persistent increase in the riskiness of the economy, i.e. to an increase in the standard deviation of the idiosyncratic shocks $\omega_{i,t}$. This shock is associated with a prospective worsening of credit conditions and an increase in the bankruptcy rate.

As in the case of the negative technology shock, the optimal monetary policy (black line) engineers on impact an increase in the price level to reduce output. The financing conditions stipulated before the shock are ex-post favorable to firms: on impact, the output contraction enables them to make higher profits, so that they will accumulate more internal funds in the following period. This increase in internal funds allows for a fast economic recovery, in spite of the contemporaneous increase in credit spreads. Even if the shock is serially correlated, output and consumption are back at the steady state after 2 years.

Figure A2: Impulse responses to an increase in μ_t



Note: Logarithmic deviations from the non-stochastic steady state. Correlation of the shock: 0.9. The blue lines indicate impulse responses under the Taylor rule; the black lines report the impulse responses under optimal policy.

Under the Taylor rule (blue line), there is a sharp decrease in the deposit rate that impedes the initial contraction of output and consumption. While under the optimal policy the price level goes up on impact, here it goes down. Leverage, bankruptcy rates, and spreads are higher than under the optimal policy. Internal funds are accumulated at a slower pace and the recession is longer lasting.

Figure A2 plots the responses to an exogenous increase in the proportion of total funds lost in monitoring activities, μ_t. This is different from the shock previously analyzed because it mechanically implies a higher waste of resources per unit of output. The optimal policy response is to reduce output in order to minimize the resource loss. If the shock was not serially correlated, this would once again be achieved through an impact increase in the price level. Since the shock is persistent, however, policy needs to manage a trade-off between immediate and future resource losses. An impact increase in the price level would not only immediately reduce output, but it would also lead to more profits and a faster accumulation of internal funds. As in the case of an increase in the volatility of idiosyncratic shocks, this would imply a quick recovery, hence large future losses in monitoring activity as long as μ_t remains high. Compared to this scenario, future losses would be minimized if the price level were instead cut on impact, so that firms' leverage would increase and the accumulation of internal funds would be especially slow. At the same time, however, an impact fall in the price level would increase the real value of firms' funds which, in turn, would allow them to expand production with an ensuing amplification of the impact resource loss due to the higher μ_t. It turns out that the optimal response is to do almost nothing on impact, allowing for a very mild fall in the price level. As a result, output does not fall – it actually increases slightly – and the bankruptcy rate stays almost unchanged. It is only after one period that production falls, due to an increase in both the credit spreads and the price level. Firms start from scratch their slow process of accumulation of internal funds and the shock is reabsorbed very slowly.

In reaction to a shock to μ_t, the Taylor rule generates small differences relative to the optimal policy case. The dynamics of the credit spread, of internal funds and of the bankruptcy rate are almost identical. The resource loss in monitoring, however, is higher under the Taylor rule, because output falls less in the few quarters after the shock, when μ_t is highest, and more after 1 year, when μ_t is returning to its steady state level.

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