Credit Risks and Monetary Policy Trade-Offs*

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Abstract

Financial frictions and financial shocks can affect the trade-off between inflation stabilization and output-gap stabilization faced by a central bank. Financial frictions lead to a greater response in output following any deviation of inflation from target and thus lead to an increase in the sacrifice ratio. As a result, optimal monetary policy in the face of credit frictions is to allow greater output gap instability in return for greater inflation stability. Such a shift in optimal monetary policy can be mimicked in a Taylor-type interest rate feedback rule that shifts weight to inflation and the lagged interest rate and away from output. However, the ability of the conventional Taylor rule to mimic optimal policy gets worse as credit market frictions and shocks intensify. By including a financial variable like the lending spread in the monetary policy rule, the central bank can partially reverse this worsening output-inflation trade-off brought about by financial frictions and partially undo the effects of credit market frictions and shocks. Thus the central bank may want to include lending spreads in the policy rule even when financial distortions are not explicitly part of the central bank's objective function.

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1 Introduction

The recent financial crisis and ensuing recession have spurred a surged interest in the implications of credit risk for monetary policy. Much of the inquiry is revolved around the question of whether monetary policy deliberations should take account of financial frictions or shocks. A popular view is that the central bank should include credit spreads in a Taylor type monetary policy rule. In his testimony on February 26, 2008 before the Committee on Financial Services of the U.S. House of Representatives, John B. Taylor argued that the intercept term in a Taylor type rule for monetary policy, that is, the natural rate of interest, should be adjusted downward in proportion to observed increase in the spread between the term Libor rate at three month maturity and an index of overnight federal funds rates expected for the same period. Similar views have been expressed by others, including Goodfriend and McCallum (2007), De Fiore and Tristani (2007), McCulley and Toloui (2008), Meyer and Sack (2008), Curdia and Woodford (2009 and 2010), Woodford (2010), and Mishkin (2010a and 2010b).

Many of these suggestions that there be an explicit role for financial market conditions in the central bank's policy rule are predicated on idea that financial stability should be another goal of monetary policy, on top of the traditional inflation and output-gap stabilization objectives. There are, however, concerns about assigning monetary policy this additional goal. As Philadelphia Fed President Charles Plosser argued at the 2013 American Economic Association Annual Meeting, "Financial stability should not be an explicit objective of monetary policy per se...we need to resist the temptation of adding the financial stability goal to the burdens of monetary policy..."

We make two contributions to this inquiry by establishing two main results. First, even when monetary policy goals are confined to stabilizing just inflation and output-gap, credit frictions and shocks can exacerbate tensions between the two conventional objectives. Specifically, credit frictions and shocks change the trade-off between inflation and the output gap that can be achieved through monetary policy. For a given deviation of inflation from its target, the resulting deviation of output from its potential level will be more severe in the presence of credit frictions.[1] As a result, deviations in inflation from target become very costly in terms of the associated deviation of output

[1] One way to think of this is that financial frictions flatten the Phillips curve.

from potential. The loss in output required to reduce inflation (the sacrifice ratio) is larger in an environment with credit frictions and credit shocks. Given the higher cost of correcting deviations of inflation from target, in the face of credit frictions and credit shocks, the focus of monetary policy will shift towards ensuring that inflation never strays too far from target in the first place.

Thus the first key finding of this paper is that the presence of financial frictions or financial shocks changes the trade-off between inflation and output faced by the central bank, and the central bank responds by shifting weight to inflation stabilization. Our model takes its root in the classic financial accelerator literature pioneered by Gertler (1988), Bernanke and Gertler (1989), Carlstrom and Fuerst (1997), Kiyotaki and Moore (1997), and Bernanke, Gertler, and Gilchrist (1999), among others. These models incorporate financial frictions, which through balance sheet effects lead to a greater response of output following a shock like an unexpected increase in inflation. This financial accelerator framework is incorporated into an otherwise standard New Keynesian framework with both staggered wage and price setting. The presence of nominal rigidities in both price and wage setting gives rise to a non-trivial trade-off between inflation stability and output gap stability.[2] In addition to financial frictions that enhance an otherwise ordinary shock, we consider financial shocks themselves. This type of shock was shown to be an important independent cause of business cycle fluctuations in models like Christiano, Motto, and Rostagno (2003 and 2009), among others.[3]

Simulations of the model show that under Ramsey optimal monetary policy, credit frictions and shocks lead to a shift in optimal policy away from output-gap stabilization towards inflation stabilization. Furthermore, such shift in the conduct of monetary policy can be implemented by modifying a Taylor-type interest-rate feedback rule. The modifications entail making the risk-free policy rate respond relatively more aggressively to deviations of inflation from target, and the policy rate should be set more in line with its own lags. Thus in the face of credit frictions that worsen the trade-off between inflation and output, the central bank should reduce the variability

[2] For standard New Keynesian models with staggered price and wage settings, but without financial frictions and shocks, see, among others, Huang and Liu (2002), Huang, Liu, and Phaneuf (2004), and Christiano, Eichenbaum, and Evans (2005).

[3] This type of shock is documented by Taylor and Williams (2009a) who describe the sudden increase in interbank lending spreads at the beginning of the financial crisis in August 2007. Bordo and Haubrich (2010) document historical instances of these credit market shocks going back to 1875. Helbling et al. (2010) and Gilchrist, Yankov and Zakrajsek (2009) single out these credit shocks and demonstrate their importance in explaining the fluctuations in broader macro aggregates. Within the framework of a financial accelerator model, a number of recent papers, like Attah-Mensah and Dib (2008), Nolan and Thoenissen (2009), Jermann and Quadrini (2012), and Gilchrist, Ortiz, and Zakrajsek (2009) have introduced credit shocks into a DSGE model.

of monetary policy and how it responds to current economic conditions. However, these changes in the parameters of the central bank's optimal simple rule are at best a poor substitute for the optimal monetary response to credit frictions and shocks; the performance of the optimal simple rule relative to that of Ramsey optimal monetary policy gets worse in a model where credit supply shocks are major drivers of business cycle fluctuations.

The second major result of this paper is that by including credit spreads in its Taylor-type monetary policy rule, the central bank can partially reverse the change in the output-inflation trade-off brought about by financial frictions. This is especially true when fluctuations in the spread are driven primarily by exogenous credit supply shocks. When the central bank cannot include financial variables in its Taylor-type monetary policy rule, it responds to credit frictions and shocks by shifting the focus of policy towards inflation stabilization. However, if the central bank can also include a financial variable like the lending spread in the Taylor-type monetary policy rule, it shifts less weight towards inflation stabilization, implying that the addition of a financial variable in the monetary policy rule can help the central bank partially reverse the change in the output-inflation trade-off brought about by financial frictions. It is also interesting to note that when the central bank responds to credit frictions and shocks by shifting weight towards inflation stabilization, price stability is only achieved at the cost of higher output gap instability. But when the central bank responds to credit frictions and shocks by putting more weight on a financial variable like the lending spread, both inflation variability and output gap variability are reduced. Thus the central bank may want to include a financial variable like lending spreads in the policy rule even when financial distortions are not explicitly part of the central bank's objective function.

This paper will proceed as follows. Section 2 presents the model that will be used to derive these results. The model is a new Keynesian model with financial frictions, which enable the model to move away from the irrelevance of balance sheets implied by the Modigliani and Miller (1958) theorem. Then the calibration of the model is discussed in section 3. The optimal parameters in the Taylor rule as derived from simulations of the model are presented in section 4. First we discuss how the presence of financial frictions in the model changes the central bank's inflation-output trade-off, and induces the central bank to shift the parameters of their policy rule towards inflation stabilization. Then we discuss whether or not the central bank will want to directly target a financial variable like the lending spread. Finally, section 5 concludes and offers some suggestions for further research.

2 Model

In the model there are four types of agents: firms, entrepreneurs, capital builders and households. There is also a central bank that sets the risk free nominal rate of interest.

Firms use capital and labor inputs to produce tradeable output that is used for consumption and investment. Each firm produces a differentiated good and sets prices according to a Calvo (1983) style price setting framework, thus giving rise to nominal price rigidity.

Entrepreneurs own physical capital and rent it to firms. This physical capital is financed partially through debt and partially through equity. In every period, an individual entrepreneur faces an idiosyncratic shock to the value of their physical capital assets. While these shocks have no direct aggregate effects, they introduce heterogeneity among entrepreneurs. The shock is uninsurable, and a fraction of entrepreneurs may experience an abnormally large shock to the value of their physical capital stock and be pushed into bankruptcy, while most will not. The uncertainty over which entrepreneurs will be pushed into bankruptcy and which will not is a type of financial friction in the entrepreneurial sector. The ratio of debt to equity on an entrepreneur's balance sheet determines their ability to withstand a shock to the value of their capital stock. Creditors use the entrepreneur's debt-equity ratio to determine the riskiness of lending to the entrepreneurial sector, giving rise to a default risk interest premium that depends on the debt-equity ratio.[4]

Capital builders purchase final goods from firms for physical capital investment. There are diminishing marginal returns to physical capital investment. In periods when investment is high, the marginal return of that investment in producing new physical capital is low, and vice versa. This gives rise to a procyclical relative value of physical capital.

Households supply labor to firms and consume final output. Furthermore they supply a differentiated type of labor and set wages according to a Calvo-style wage setting process, giving rise to nominal wage rigidity.

Finally, the central bank tries to stabilize output and prices by controlling the risk-free nominal rate of interest. The central bank sets policy using a Taylor rule function combining the current

[4] The fact that this idiosyncratic shock is uninsurable provides the necessary violation of the complete markets assumption necessary to overcome the implications of the Miller and Modigliani (1958) theorem.

period's inflation rate, output gap, and the lagged risk free nominal interest rate. We will also consider the case where lending spreads are part of the Taylor rule.

2.1 Firms

Goods producing firms, indexed $i \in [0\ 1]$, combine capital and labor, $k_t(i)$ and $h_t(i)$ to produce a unique intermediate good $y_t(i)$. The firm's production function is:

$$y_t(i) = A_t h_t(i)^{1-\alpha} k_t(i)^{\alpha} - \phi \tag{1}$$

where A_t is an exogenous stochastic TFP parameter that is common to all firms and ϕ is a fixed cost parameter that is calibrated to ensure that firms earn zero profit in the steady state.

Intermediate goods are then combined into one aggregate final good with the following Dixit and Stiglitz (1977) aggregator function:

$$y_t = \left(\int_0^1 y_t(i)^{\frac{\sigma-1}{\sigma}} di \right)^{\frac{\sigma}{\sigma-1}} \tag{2}$$

where σ is the elasticity of substitution between intermediate goods from different firms. The aggregate final good is allocated to consumption by households, C_t, and investment by capital builders, I_t, $y_t = C_t + I_t$.

From this aggregator function the demand for the intermediate good from firm i as a function of aggregate demand is:

$$y_t(i) = \left(\frac{P_t(i)}{P_t} \right)^{-\sigma} y_t \tag{3}$$

where $P_t(i)$ is the price of the good from firm i, $P_t = \left(\int_0^1 (P_t(i))^{1-\sigma} di \right)^{\frac{1}{1-\sigma}}$ is the price index of final demand.

In period t, the firm will be able to change its price with probability $1 - \xi_p$. If the firm cannot change prices then they are reset automatically according to $P_t(i) = \pi_{t-1} P_{t-1}(i)$, where $\pi_{t-1} = \frac{P_{t-1}}{P_{t-2}}$.

Thus if allowed to change their price in period t, the firm will set a price to maximize:

$$\max_{P_t(i)} E_t \sum_{\tau=0}^{\infty} \beta^{\tau} \left(\xi_p\right)^{\tau} \lambda_{t+\tau} \left\{\Pi_{t,t+\tau} P_t\left(i\right) y_{t+\tau}\left(i\right) - MC_{t+\tau} y_{t+\tau}\left(i\right)\right\}$$

where λ_t is the marginal utility of income in period t. As discussed in this paper's technical appendix, the firm that is able to change its price in period t will set its price to:

$$P_t\left(i\right) = \frac{\sigma}{\sigma-1} \frac{E_t \sum\limits_{\tau=0}^{\infty} \beta^{\tau} \left(\xi_p\right)^{\tau} \lambda_{t+\tau} MC_{t+\tau} \left(\frac{\Pi_{t,t+\tau}}{P_{t+\tau}}\right)^{-\sigma} y_{t+\tau}}{E_t \sum\limits_{\tau=0}^{\infty} \beta^{\tau} \left(\xi_p\right)^{\tau} \lambda_{t+\tau} \Pi_{t,t+\tau} \left(\frac{\Pi_{t,t+\tau}}{P_{t+\tau}}\right)^{-\sigma} y_{t+\tau}}$$

If prices are flexible, and thus $\xi_p = 0$, then this expression reduces to:

$$P_t\left(i\right) = \frac{\sigma}{\sigma-1} MC_t$$

which says that the firm will set a price equal to a constant mark-up over marginal cost.

Write the price set by the firm that can reset prices in period t as $\tilde{P}_t\left(i\right)$ to denote that it is an optimal price. Firms that can reset prices in period t will all reset to the same level, so $\tilde{P}_t\left(i\right) = \tilde{P}_t$. Substitute this optimal price into the price index $P_t = \left(\int_0^1 \left(P_t\left(i\right)\right)^{1-\sigma} di\right)^{\frac{1}{1-\sigma}}$. Since a firm has a probability of $1-\xi_p$ of being able to change their price, then by the law of large numbers in any period $1-\xi_p$ percent of firms will reoptimize prices, and the prices of ξ_p percent of firms will be automatically reset using the previous periods inflation rate. Thus the price index, P_t, can be written as:

$$P_t = \left(\xi_p \left(\Pi_{t-1,t} P_{t-1}\right)^{1-\sigma} + \left(1-\xi_p\right) \left(\tilde{P}_t\right)^{1-\sigma}\right)^{\frac{1}{1-\sigma}}$$

The full details of this derivation are located in the appendix.

The firm hires labor and capital inputs, where W_t is the wage rate paid for labor input and R_t is the capital rental rate, both of which the firm takes as given. Furthermore the firm must pay their wage bill at the beginning of the period, prior to production. To do so they borrow $b_t^{wc}\left(i\right) = W_t h_t\left(i\right)$. The firm's income after paying for capital and labor inputs is:

$$d_t^f\left(i\right) = P_t\left(i\right) y_t\left(i\right) - W_t h_t\left(i\right) - R_t k_t\left(i\right) - r_t^{wc} b_t^{wc}\left(i\right) \tag{4}$$

where r_t^{wc} is the interest rate on working capital loans. Since there is no default risk from lending working capital to firms, the interest rate on working capital loans is simply equal to the nominal risk-free rate, $r_t^{wc} = i_t$.

The aggregate income from all firms is returned to households as a lump sum payment, $d_t^f = \int_0^n d_t^f(i)\, di$.

The firm will choose $h_t(i)$ and $k_t(i)$ to maximize profit in (4) subject to the production function in (1). The working capital requirement implies that the cost of the labor input is $W_t(1 + r_t^{wc})$ and the cost of the physical capital input is R_t. Given these prices, the firm's demand for labor and capital inputs are:

$$\begin{aligned} h_t(i) &= (1-\alpha)\frac{MC_t}{W_t(1+r_t^{wc})} y_t(i) \\ k_t(i) &= \alpha \frac{MC_t}{R_t} y_t(i) \end{aligned} \tag{5}$$

where $MC_t = \frac{1}{A_t}\left(\frac{W_t(1+r_t^{wc})}{1-\alpha}\right)^{1-\alpha}\left(\frac{R_t}{\alpha}\right)^{\alpha}$.

2.2 Entrepreneurs

Entrepreneurs, indexed $j \in [0\ 1]$, buy capital from capital builders and rent it to firms. At the beginning of period t, entrepreneur j has a stock of capital, $K_t(j)$, that he will rent to firms in period t at a rental rate R_t. In equilibrium, the aggregate stock of capital supplied by all entrepreneurs j is equal to the aggregate stock of capital demanded by all firms i, $\int_0^1 K_t(j)\, dj = \int_0^1 k_t(i)\, di$.

Entrepreneurs finance this stock of capital partially through debt. The entrepreneur borrows $b_t(j)$ to finance their capital stock $K_t(j)$. Thus the market value of the assets and liabilities for entrepreneur j at the beginning of period t are:

$$\begin{aligned} \text{Assets:} &\quad P_t^K K_t(j) \\ \text{Liabilities:} &\quad b_t(j) \end{aligned} \tag{6}$$

where P_t^K is the price of existing capital.

The end of the period the value of the non-depreciated capital stock for the average entrepreneur is $P_t^K(1-\delta)K_t$. However during the period, the individual entrepreneur j receives an idiosyncratic draw that affects the relative price of their existing capital, so for entrepreneur j the end of period value of their non-depreciated capital stock is:

$$\omega_t(j)\,P_t^K(1-\delta)\,K_t(j)$$

where $\omega_t(j)$ is a i.i.d. draw from a lognormal distribution on the interval $[0\ \infty)$ with mean 1 and standard deviation σ_t.

Since this draw has a mean 1, it has no effect on the aggregate capital stock. It simply introduces heterogeneity among entrepreneurs, and in any given period a fraction of entrepreneurs receive a draw that has a large adverse effect on the value of their existing capital (a small $\omega_t(j)$) and thus at the end of the period, the value of their liabilities exceeds the value of their assets.

During the period the entrepreneur rents his capital stock to firms for a rental rate of R_t. The entrepreneur finances this capital stock by borrowing with an interest rate r_t. Thus at the end of the period, after the realization of $\omega_t(j)$, the nominal market value of entrepreneur j's assets is $\omega_t(j)\,P_t^K(1-\delta)\,K_t(j)+R_tK_t(j)$. At the end of the period the nominal value of the entrepreneur's liabilities is $(1+r_t)\,b_t(j)$.

Thus, after the realization of $\omega_t(j)$, entrepreneur j is bankrupt if:

$$\omega_t(j)\,P_t^K(1-\delta)\,K_t(j)+R_tK_t(j)<(1+r_t)\,b_t(j) \tag{7}$$

Thus the threshold value of $\omega_t(j)$ below which the entrepreneur goes bankrupt in period t and above which they continue operations is:

$$\bar{\omega}_t=\frac{(1+r_t)\,\frac{b_t(j)}{K_t(j)}-R_t}{P_t^K(1-\delta)} \tag{8}$$

where $DA_t(j)=\frac{b_t(j)}{K_t(j)}$ is the ratio of the book value of debt to the book value of assets on an entrepreneur's balance sheet. The history of individual entrepreneur j will influence the level of $b_t(j)$ and $K_t(j)$, but the ratio $DA_t(j)=\frac{b_t(j)}{K_t(j)}$ is equal across all entrepreneurs. This is a key result for aggregation, for it implies that the bankruptcy cutoff value $\bar{\omega}_t$ does not depend on an entrepreneur's history. More intuition behind this result is presented at the end of this section and a formal proof is presented in the appendix.

When deciding how much to lend to entrepreneurs going into next period and at what rate, creditors factor in the fact that if entrepreneur j does not default in period $t+1$, they receive a return of r_{t+1}. If the entrepreneur defaults, creditors receive a share of the entrepreneur's remaining assets, less the bankruptcy cost μ. The threshold value $\bar{\omega}_{t+1}$ in equation (8) determines whether or not an entrepreneur goes into default next period. Thus the payoff to creditors conditional of the realization of the draw $\omega_{t+1}(j)$ is:

$$\begin{array}{cl} (1+r_{t+1})(b_{t+1}(j)) & \text{if } \omega_{t+1}(j) \geq \bar{\omega}_{t+1} \\ (1-\mu)\left[\omega_{t+1}(j)(1-\delta)P^K_{t+1}K_{t+1}(j) + R_{t+1}K_{t+1}(j)\right] & \text{if } \omega_{t+1}(j) < \bar{\omega}_{t+1} \end{array} \tag{9}$$

Perfect competition among creditors implies that the lending rate, r_{t+1}, is set such that the expected return, after factoring in the cost of bankruptcy, is equal to the risk-free rate, i_{t+1}:

$$\begin{aligned} (1+i_{t+1})\, b_{t+1}(j) \quad = \quad & \int_0^{\bar{\omega}_{t+1}} (1-\mu)\left(\omega_{t+1}(j)(1-\delta)P^K_{t+1}K_{t+1}(j) + R_{t+1}K_{t+1}(j)\right) dF(\omega_{t+1};\sigma_t) \\ & + \int_{\bar{\omega}_{t+1}}^{\infty} (1+r_{t+1})\, b_{t+1}(j)\, dF(\omega_{t+1};\sigma_t) \end{aligned}$$

where $F(\omega_{t+1};\sigma_t)$ is the c.d.f. of the lognormal distribution of ω_{t+1}, and thus the fraction of entrepreneurs that are forced to declare bankruptcy in period $t+1$.

Thus the lending rate is:

$$1+r_{t+1} = \frac{(1+i_{t+1})}{1-F(\bar{\omega}_{t+1};\sigma_t)} - \frac{(1-\mu)\left[R_{t+1}F(\bar{\omega}_{t+1};\sigma_t) + (1-\delta)P^K_{t+1}\int_0^{\bar{\omega}_{t+1}} \omega_{t+1}dF(\omega_{t+1};\sigma_t)\right]}{(1-F(\bar{\omega}_{t+1};\sigma_t))\frac{b_{t+1}(j)}{K_{t+1}(j)}} \tag{10}$$

Holding all else equal, this interest rate, r_{t+1}, is increasing in $F(\bar{\omega}_{t+1};\sigma_t)$. $F(\bar{\omega}_{t+1};\sigma_t)$ is increasing in $\bar{\omega}_{t+1}$. $\bar{\omega}_{t+1}$ is increasing in the entrepreneur's debt-asset ratio. Thus when there are financial frictions in the entrepreneurial sector, the lending rate is increasing in the level of debt on an entrepreneur's balance sheet.

The cutoff value of $\omega_{t+1}(j)$ in equation (8) combined with the interest rate expression in (10) demonstrates the feedback loop associated with financial frictions in the entrepreneurial sector.

When the price of existing capital, P_{t+1}^{K} falls, the cutoff value $\bar{\omega}_{t+1}$ rises. This implies that more firms will receive draws of $\omega_{t+1}(j)$ below this cutoff value and be forced into bankruptcy. When more firms go into bankruptcy, $F(\bar{\omega}_{t+1};\sigma_t)$ increases, and r_{t+1} increases as creditors now demand a higher interest rate to compensate for the increased bankruptcy risk. This higher r_{t+1} means higher interest expenses and lower profit for the entrepreneur, which leads to a further increase in the cutoff value $\bar{\omega}_{t+1}$.

The end of period net worth for the entrepreneur that survives is the entrepreneur's profit in time t plus the value of their non-depreciated capital stock:

$$\tilde{N}_t(j) = R_t K_t(j) - (1+r_t)\, b_t(j) + \omega_t(j)\, P_t^K (1-\delta)\, K_t(j)$$

The entrepreneur will pay a dividend to shareholders of $d_t^e(j)$ and begin the next period with net worth $N_{t+1}(j) = \tilde{N}_t(j) - d_t^e(j)$. Entrepreneurs that declare bankruptcy in period t pay no dividend and drop out of the market, they are replaced with new entrepreneurs, which are endowed with start up capital of $\bar{N}$. Thus the net worth of the entrepreneurial sector at the beginning of next period is:

$$\begin{aligned} N_{t+1} &= \int_0^{\bar{\omega}_t} N_{t+1}(j)\, dF(\bar{\omega}_t;\sigma_t) + \int_{\bar{\omega}_t}^{\infty} N_{t+1}(i)\, dF(\bar{\omega}_t;\sigma_t) \qquad (11) \\ &= \bar{N} F(\bar{\omega}_t;\sigma_t) + \left(r_t^k K_t - (1+r_t)\, b_t - d_t^e\right)(1 - F(\bar{\omega}_t;\sigma_t)) + P_t^K (1-\delta) K_t \int_{\bar{\omega}_t}^{\infty} \omega_t dF(\bar{\omega}_t;\sigma_t) \end{aligned}$$

At the beginning of any period, entrepreneurs have different levels of net worth $N_{t+1}(j)$ that will depend on the entrepreneur's history of idiosyncratic shocks $\omega_t(j)$.

The entrepreneur will acquire capital up to the point where the lending rate is equal to the expected return to holding a unit of capital:

$$r_{t+1} = E_t \left(\frac{R_{t+1} + \omega_{t+1}(j)(1-\delta)\, P_{t+1}^K}{P_t^K} \right)$$

Since $\omega_{t+1}(j)$ is i.i.d. and $E_t(\omega_{t+1}(j)) = 1$, the left hand side of the above expression is the same across all entrepreneurs j, which implies that r_{t+1} is the same across all entrepreneurs.

2.3 Capital Builders

The representative capital builder converts final goods, given by equation (2), into the physical capital purchased by entrepreneurs. At the end of period t, the non-depreciated physical capital stock is $(1-\delta)\,K_t$, and the physical capital stock at the beginning of the next period is K_{t+1}. The evolution of the physical capital stock is given by:

$$K_{t+1}-(1-\delta)\,K_t=\phi\left(\frac{I_t}{K_t}\right)K_t$$

where $\phi'>0$ and $\phi''<0$ implying that there are diminishing marginal returns to physical capital investment. Capital builders purchase final goods for investment at a price P_t and sell existing capital to entrepreneurs at a price P_t^K. Thus the profits of the representative capital builder are given by:

$$d_t^c=P_t^K\left(K_{t+1}-(1-\delta)\,K_t\right)-P_tI_t$$

In a competitive capital building sector, profit maximization implies that the relative price of existing capital is:

$$\frac{P_t^K}{P_t}=\left[\phi'\left(\frac{I_t}{K_t}\right)\right]^{-1}$$

Since $\phi''<0$, when $\frac{I_t}{K_t}$ is high, $\phi'\left(\frac{I_t}{K_t}\right)$ is low, so $\frac{P_t^K}{P_t}$ is high. This implies that during times of high physical capital investment, when the ratio of investment to the existing capital stock is high, the relative price of existing capital is high. Since investment is highly procyclical, capital adjustment costs imply that the relative price of capital is highly procyclical as well.

2.4 Households

Households, indexed $l\in[0\ 1]$, supply heterogeneous labor to firms and consume from their labor income, interest on savings, and profit income from firms, entrepreneurs, and capital builders.

The household maximizes their utility function:

$$\max \sum_{t=0}^{\infty} \beta^t \left[\ln (C_t(l)) - \psi (H_t(l))^{\frac{1+\sigma_H}{\sigma_H}} \right] \tag{12}$$

subject to their budget constraint:

$$\begin{aligned} &P_t C_t(l) + B_{t+1}(l) + F(\bar{\omega}_t; \sigma_t) \bar{N} = \\ &W_t(l) H_t(l) + d_t^f(l) + d_t^e(l) + d_t^c(l) + (1-\zeta_t)(1+r_t) B_t(l) + \zeta_t^e \end{aligned} \tag{13}$$

where $C_t(l)$ is consumption by household l in period t, $H_t(l)$ is the household's labor effort in the period, $B_t(l)$ is the household's stock of lending to entrepreneurs at the beginning of the period, $W_t(l)$ is the wage paid for the household's heterogenous labor supply, ζ_t represents the share of loans to the entrepreneurial sector that are lost to bankruptcy and liquidation costs, and $d_t^f(l)$, $d_t^e(l)$, and $d_t^c(l)$ are the household's share of period t profits from firms, entrepreneurs, and capital builders, respectively.[5]

Each household supplies a differentiated type of labor. The function to aggregate the labor supplied by each household into the aggregate stock of labor employed by firms is:

$$H_t = \left(\int_0^1 H_t(l)^{\frac{\theta-1}{\theta}} dl \right)^{\frac{\theta}{\theta-1}} \tag{14}$$

where $H_t = \int_0^1 h_t(i)\, di$. Since the household supplies a differentiated type of labor, it faces a downward sloping labor demand function:

$$H_t(l) = \left(\frac{W_t(l)}{W_t} \right)^{-\theta} H_t$$

In any given period, household j faces a probability of $1-\xi_w$ of being able to reset their wage, otherwise it is reset automatically according to $W_t(l) = \pi_{t-1} W_{t-1}(l)$.

If household j is allowed to reset their wages in period t they will set a wage to maximize the expected present value of utility from consumption minus the disutility of labor.

[5] Market clearing in the bond market implies that the sum of lending across households l is equal to the sum of borrowing across entrepreneurs j, $\int_0^1 B_t(l)\, dl = \int_0^1 b_t(j)\, dj$.

$$E_t \sum_{\tau=0}^{\infty} \beta^{\tau} (\xi_w)^{\tau} \left\{ \lambda_{t+\tau} \Pi_{t,t+\tau} W_t (l) H_{t+\tau} (l) - \psi (H_{t+\tau} (l))^{\frac{1+\sigma_H}{\sigma_H}} \right\}$$

Thus after technical details which are located in the appendix, the household that can reset wages in period t will choose a wage:

$$W_t (l)^{\frac{\theta}{\sigma_H}+1} = \frac{\theta}{\theta-1} \frac{1+\sigma_H}{\sigma_H} \psi (W_t)^{\frac{\theta}{\sigma_H}} \frac{E_t \sum_{\tau=0}^{\infty} \beta^{\tau} (\xi_w)^{\tau} \left(\frac{W_{t+\tau}}{\Pi_{t,t+\tau} W_t}\right)^{\frac{\theta}{\sigma_H}+\theta} (H_{t+\tau})^{\frac{1+\sigma_H}{\sigma_H}}}{E_t \sum_{\tau=0}^{\infty} \beta^{\tau} (\xi_w)^{\tau} \lambda_{t+\tau} \Pi_{t,t+\tau} \left(\frac{W_{t+\tau}}{\Pi_{t,t+\tau} W_t}\right)^{\theta} H_{t+\tau}}$$

If wages are flexible, and thus $\xi_w = 0$, this expression reduces to:

$$W_t (l) = \frac{\theta}{\theta-1} \frac{\frac{1+\sigma_H}{\sigma_H} \psi (H_t)^{\frac{1}{\sigma_H}}}{\lambda_t}$$

Thus when wages are flexible the wage rate is equal to a mark-up, $\frac{\theta}{\theta-1}$, multiplied by the marginal disutility of labor, $\frac{1+\sigma_H}{\sigma_H} \psi (H_t)^{\frac{1}{\sigma_H}}$, divided by the marginal utility of consumption, λ_t.

Write the wage rate for the household that can reset wages in period t, $W_t (l)$, as $\tilde{W}_t (l)$ to denote it as an optimal wage. Also note that all households that can reset wages in period t will reset to the same wage rate, so $\tilde{W}_t (l) = \tilde{W}_t$.

All households face a probability of $(1 - \xi_w)$ of being able to reset their wages in a given period, so by the law of large numbers $(1 - \xi_w)$ of households can reset their wages in a given period. The wages of the other ξ_w will automatically reset by the previous periods inflation rate.

Substitute $\tilde{W}_t$ into the expression for the average wage rate $W_t = \left(\int_0^n W_t (l)^{1-\theta} dl\right)^{\frac{1}{1-\theta}}$, to derive an expression for the evolution of the average wage:

$$W_t = \left(\xi_w (\Pi_{t-1,t} W_{t-1})^{1-\theta} + (1 - \xi_w) \left(\tilde{W}_t\right)^{1-\theta} \right)^{\frac{1}{1-\theta}}$$

2.5 Monetary Policy

The monetary policy instrument is the risk-free rate, i_t, which is determined by the central bank's Taylor rule function:

$$i_{t+1} = i_{ss} + \theta_i (i_t - i_{ss}) + (1 - \theta_i) (\theta_p \pi_t + \theta_y \hat{y}_t - \theta_r r\hat{p}_t) \tag{15}$$

where $\pi_t = \frac{P_t}{P_{t-1}} - 1$, and $\hat{y}_t = \frac{GDP_t}{G\tilde{D}P_t} - 1$, and $r\hat{p}_t = r_{t+1} - i_{t+1}$. $G\tilde{D}P_t$ is the level of GDP at time t in an economy with the same structure as the one just described and subject to the same shocks, only there are no price or wage frictions, $\xi_p = \xi_w = 0$, and there are no financial frictions, $\sigma_t = 0$.

When $\theta_r = 0$, the central bank does not place any weight the spread between the lending rate and the risk-free rate and the Taylor rule is simply the conventional Taylor rule with smoothing.

3 Parameter Values

The model in the previous section is solved with a first-order approximation and the results are found from simulations of the calibrated model. This section will begin by presenting the basic parameter values used in this calibration. Then we will describe the various types of exogenous shocks that will drive the simulations of the model and the estimation of these different shock processes.

The full list of the model's parameters and their values is found in table 1.

The first six parameters: the discount factor, the capital depreciation rate, capital's share of income, the labor supply elasticity, the elasticity of substitution between goods from different firms, and the elasticity of substitution between labor from different households are all set to values that are commonly found in the literature.

The capital adjustment cost parameter, κ, describes the curvature of the capital adjustment function $\phi\left(\frac{I_t}{K_t}\right)$. It is the elasticity of the relative price of capital with respect to changes in the investment-capital ratio. This parameter preforms the important functions of lowering the relative volatility of investment and ensuring the procyclicality of the price of capital. Empirical estimates of this parameter vary, but the value of 0.125 is in the middle of the range of empirical estimates and ensures that the relative volatility of investment in the model is near what we see in the data.

The next two parameters in the table are the Calvo price and wage stickiness parameters. The wage stickiness parameter is chosen such that on average a household adjusts their wages once a year. The price stickiness parameter implies that prices are a little more flexible than wages and is taken from the DSGE estimation literature (see e.g. Christiano et al. 2005).

The next two parameters are all determined so that the steady state of the model is able to match certain features of the data; ϕ and ψ are the fixed cost in the production of intermediate goods and the weight on the disutility from labor in the household's utility function, respectively. These are set to ensure that in the steady state, intermediate goods firms earn zero economic profit and the household's labor supply is unity.

Finally the last two parameters in the table relate to the risk of bankruptcy and liquidation costs in the entrepreneurial sector. The cost of liquidation and the idiosyncratic bankruptcy risk in the entrepreneurial sector, μ^e and σ_e are jointly determined. These parameters ensure that in the steady state of the model, when firms in the entrepreneurial sector have a debt-asset ratio of 0.5, an entrepreneur faces a 2% probability of bankruptcy and the steady state spread between the lending rate and the risk-free rate is approximately 70 basis points.[6]

3.1 Exogenous Shock Processes

In this model there are two types of shocks. The first shock is simply a shock to total factor productivity (TFP) in (1). The second shock is a credit supply shock. In terms of the model this is a shock to the uncertainty about asset values for an individual entrepreneur, σ_t, more generally it can be thought of as a shock to the intermediation process that causes the supply curve in the credit market to shift to the left.

Since TFP shocks are not the primary focus of the study, we set the exogenous process that governs TFP shocks to a simple process that is familiar in the business cycle literature. Shocks to TFP, $\hat{A}_t$, follow an AR(1) process with an autoregressive coefficient of 0.9. Since the model is solved using a first-order approximation, we simply normalize the variance of the shocks to TFP to one.

Alternatively we can consider shocks to credit market uncertainty, σ_t. Equation (10) describes how the default rate among entrepreneurs, $F\left(\bar{\omega}_{t+1};\sigma_{t+1}\right)$ drives fluctuations in the spread between the lending rate and the risk-free rate, $r\hat{p}_t$. Fluctuations in the default rate can be broken down into two components, one due to fluctuations in the endogenous cutoff value $\bar{\omega}_{t+1}$, and one due to exogenous fluctuations in credit market uncertainty, σ_{t+1}.

$$F\left(\bar{\omega}_{t+1};\sigma_{t+1}\right) \approx f_1\left(\frac{\bar{\omega}_{t+1}-\bar{\omega}_{ss}}{\bar{\omega}_{ss}}\right) + f_2\left(\frac{\sigma_{t+1}-\sigma_{ss}}{\sigma_{ss}}\right) \tag{16}$$

[6] The calibration that entrepreneurs have a steady state debt-asset ratio of about 0.5 is based on the historical average debt-asset ratios for U.S. non-financial firms as reported in the Federal Reserve's Flow of Funds Accounts.

Due to the financial frictions in the model, movements in $\bar{\omega}_{t+1}$ will cause movements in $F(\bar{\omega}_{t+1}; \sigma_{t+1})$, and thus the lending spread even when the TFP shock is the only shock in the model. If we calculate the spread between Baa rated corporate bonds and Aaa rated corporates (the Baa-Aaa spread) from U.S. data from the first quarter of 1984 to the fourth quarter of 2011, the spread has a first order autocorrelation coefficient of 0.81, and the ratio of the standard deviation of the spread to the standard deviation of GDP over the same period is 0.36 (if we instead calculate these statistics over the 1984-2007 period the autocorrelation coefficient is 0.87 and the relative standard deviation is 0.27).

In the model with only TFP shocks, the first order autocorrelation of $r\hat{p}_t$ is 0.97 and the volatility of $r\hat{p}_t^b$ relative to the volatility of the GDP is 0.03. If we assume that σ_{t+1} follows an AR(1) process with autoregressive coefficient of 0.8 then as the variance of the financial shock increases, the autoregressive coefficient of $r\hat{p}_t$ approaches 0.81. In the next section we will present the results from finding the optimal Taylor rule coefficients in the model under different assumptions about the volatility of the exogenous process for the credit supply shocks σ_{t+1}. Under each of these different assumptions about the strength of the shocks, we will report the volatility of $r\hat{p}_t$ relative to the volatility of the GDP. In the different cases we consider, this relative volatility varies from about 3% under no financial shocks to as high as 40%.

4 Results

To identify optimal monetary policy in this model with credit frictions and shocks and to see how optimal policy changes as the degree of credit risk increases, we first have to define the loss function that the central bank will attempt to minimize. In order to ensure that the changes in optimal policy are due to changes in the endogenous structure of the economy and the transmission mechanism and not due to changes in the central bank's preferences, this loss function should remain the same regardless of the degree of credit market risk in the economy.

When finding the optimal coefficients in the Taylor rule, the central bank will attempt to minimize:

$$\mathcal{L} = var(\pi_t) + \Lambda var(\hat{y}_t)$$

4.1 Credit frictions and the stance of monetary policy

4.1.1 The conventional Taylor rule parameters

To evaluate how monetary policy should respond to credit risk, we first identify the optimal weights on inflation, the output gap, and the lagged interest rate in the Taylor rule function in the model where business cycles are driven by productivity shocks. We find these optimal parameters twice, in a model with and without a financial accelerator, setting $\Lambda = 0.5$, a value commonly used in similar studies.

We find these parameters through a grid search. We vary θ_p, θ_y, and θ_i until we find the combination of the three terms in the central bank's Taylor rule function that minimizes the central bank's loss function. The results from this search are presented in table 2.

The table presents three rows of results. In the first row, there is no financial accelerator in the model and the central bank finds chooses the optimal combination of θ_p, θ_y, and θ_i to minimize its loss function. In the second row, the model does have a financial accelerator, but the central bank cannot re-optimize its choices of θ_p, θ_y, and θ_i. The addition of a financial accelerator in the model raises both the variance of inflation and the variance of the output gap.

In the third row, the model has a financial accelerator, but the central bank is able to re-optimize its choice of coefficients in the Taylor rule. In deciding a new optimal policy, the central bank faces a trade-off between inflation stability and output gap stability. The central bank chooses in favor of inflation stability by increasing the relative weights it places on the lagged interest rate and on current inflation.[7]

The results in table 2 were found under the assumption that the central bank will choose its optimal combination of parameters to minimize a loss function consisting of the variance of the inflation rate and one half the variance of the output gap. In table 3 we repeat the same exercise, but assume than in its loss function the central bank places equal weight on both inflation stabilization and output gap stabilization.

Under this different loss function the Taylor rule coefficient on the output gap will increase and the coefficients on the inflation rate and the lagged inflation rate will fall. This is to be expected from a new loss function where there is a greater weight on output gap stabilization, and under

[7] The relative weight it places on inflation, $\frac{\theta_p}{\theta_p+\theta_y} = 0.77$ before the re-optimization and 0.82 after.

optimal policy, the variance of inflation is higher and the variance of the output gap is lower than it was under the old loss function.

However, the same results hold as before; the addition of the financial accelerator to the model without allowing the central bank to re-optimize will lead to higher volatilities of inflation and the output gap, as shown in the second row of the table. However, the third row of the table shows that when the central bank is able to re-optimize in the model that now contains a financial accelerator, the central bank will still re-optimize in favor of inflation stabilization at the expense of greater output gap variability. The central bank will increase the relative weight on inflation in its Taylor rule, and thus by re-optimizing it will favor inflation stability over output gap stability, even when the two have equal weights in the central bank's loss function.

In tables 2 and 3, financial frictions lead to endogenous changes in lending spreads in response to fluctuations in balance sheets and asset prices that are ultimately caused by exogenous productivity shocks. Many recent papers have also considered the role of exogenous financial shocks. As described in equation (16), fluctuations in the lending spread are driven by fluctuations in $\bar{\omega}_t^b$, which is determined by endogenous variables like the price of capital and debt-asset ratios, and also by exogenous fluctuations in σ_t, credit supply shocks.

Define Σ as the standard deviation of the exogenous fluctuations in the lending spread. The standard deviation of exogenous TFP fluctuations is normalized to one, so Σ measures the ratio of the standard deviations of the two shocks in the model, the exogenous credit supply shocks and the exogenous shocks to TFP.

$$\Sigma^2 = \frac{var\left[f_2\left(\frac{\sigma_{t+1}-\sigma_{ss}}{\sigma_{ss}}\right)\right]}{var\left[A_t\right]}$$

The performance of the Taylor rule as Σ increases is presented in table 4. This table considers the effect of increasing Σ while not allowing the central bank to reoptimize. Thus the table measures the optimality of the simple Taylor rule when the coefficients θ_p, θ_y, and θ_i were optimal when there were no credit market shocks in the model, $\Sigma = 0$, but may not be optimal when there are credit market shocks in the model.

As Σ increases, credit market shocks become more important in driving business cycle fluctuations. The fourth column of the table reports the volatility of fluctuations in the lending spread relative to the volatility of fluctuations in GDP in simulations of the model. When $\Sigma = 0$, and there are no exogenous credit market shocks, the relative volatility of the lending spread is about 0.03. As Σ increases, the relative volatility of the lending spread increases. In the U.S., the relative volatility of the Baa-Aaa spread is 0.27 over the period 1984-2007 and 0.36 over the period 1984-2011.

The fifth column of the table reports the performance of the conventional Taylor rule compared with Ramsey optimal monetary policy. Specifically the statistics in the last column of the table measure the value of the loss function under the Taylor rule over the value of the loss function under Ramsey optimal policy. When $\Sigma = 0$, the Taylor rule returns a value of the loss function that is 9.45% higher than under Ramsey policy. As Σ increases, the performance of this Taylor rule gets worse. When Σ is high enough so that the model is able to match the relative volatility of lending spreads that are observed in the data, the value of the loss function is 25% higher under the conventional Taylor rule than it would be under Ramsey policy.

The variances of inflation and the output gap under Ramsey optimal policy as well as the various Taylor rule specifications we consider in this paper are presented in table 5. In the specification where the parameters of the central bank's Taylor rule function are held fixed (in the table this is listed as "Taylor rule (1)"), both the variance of inflation and the variance of the output gap increase as Σ increases. Under Ramsey policy, as credit supply shocks become more important for driving business cycle fluctuations, the stance of monetary policy shifts towards inflation stabilization, and the variance of inflation remains relatively constant while the variance of the output gap increases. Thus as the degree of credit market risk increases, the stance of monetary policy wants to shift towards inflation stabilization.

The results in table 4 are found when the central bank is not able to reoptimize, and must use the same parameters θ_p, θ_y, and θ_i that were optimal when $\Sigma = 0$. As Σ increases, the variances of both inflation and the output gap increase. A credit market shock leads to a decline in output and an increase in inflation. The central bank then faces a trade-off between using monetary policy to stabilize inflation or using it to stabilize the output gap. This trade-off is shown in the last two columns of the table. This table shows the effect on the variances of inflation and the output gap of increasing the coefficient on the lagged interest rate, θ_i. When $\Sigma = 0$, increasing the coefficient on the lagged interest rate from 0.791 to 0.801 will reduce the volatility of inflation by 0.5% but will increase the volatility of the output gap by 1%. Given the weights of 1 and 0.5 in the loss function, the optimal vale of θ_i will be at the point where the ratio of the benefit in terms of increased inflation stability divided the cost in terms of increased output instability is equal to -0.5. If the ratio is less than -0.5 then the central bank should increase the coefficient on the lagged interest rate. Thus the value of 0.791 is optimal when $\Sigma = 0$, as credit market shocks become more important, the benefit of increasing θ_i in terms of inflation stability increases and the cost in terms of output gap instability falls. When Σ is at levels that we would expect to see in the data, the benefit of increasing θ_i is much greater and the cost is much less, implying that the ratio of the two is less than -0.5, so as credit market shocks become more important in driving business cycle fluctuations, the central bank should increase the coefficient on the lagged interest rate.

In table 3, the central bank is able to reoptimize and assign new values to the parameters θ_p, θ_y, and θ_i as Σ, the variability of exogenous credit market shocks, increases. The results in the last column of the table show that when the central bank is able to reoptimize and place, the performance of the Taylor rule relative to Ramsey optimal policy is vastly improved. As discussed in the earlier results when the central bank could not reoptimize, when $\Sigma = 0$ and there are no credit market shocks, the value of the loss function under the Taylor rule is about 10% higher than its value under Ramsey policy, but when the model includes credit market shocks akin to those that we see in the data, the value of the loss function under the same Taylor rule is nearly 25% high than under Ramsey policy. Now when the central bank is able to reoptimize, the loss function under the new reoptimized Taylor rule is only about 18% above Ramsey policy, a significant improvement.

Returning to table 5 we see that by shifting the parameters in the Taylor rule towards inflation stabilization, the central bank using a Taylor-type feedback rule is able to get much closer to true optimal policy. The table shows that by placing more weight on the inflation terms and the lagged interest rate, the central bank is able to mimic the fact that true optimal policy keeps inflation variability relatively constant as Σ increases. However, the central bank using the Taylor-type feedback rule cannot perfectly mimic true optimal policy, and this greater inflation stability only comes at the cost of more output instability. Comparing the results under the "Taylor rule (1)" and the "Taylor rule (2)" specifications, when the central bank is able to reoptimize their choice of parameters, they achieve a much better result in stabilizing inflation, but this is only achieved by allowing greater output instability.

4.1.2 The optimal weight on lending spreads

The last two columns of table 3 shows the benefits and costs of adding lending spreads to the central bank's Taylor rule function. If the central bank were to put a positive coefficient θ_r on the spread $r\hat{p}_t$ in equation (15) then it would be using a stimulative monetary policy following a shock that has a negative effect on output and a positive effect on inflation. Such a stimulative policy would mitigate the fall in output, but exacerbate the increase in inflation. Thus the final two columns of table 3 show that when the central bank increases the coefficient on the lending spread, the volatility of the output gap falls but the volatility of inflation rises. Specifically, for higher values of Σ, which correspond to the level of variability of credit market shocks that we observe in the data, if the central bank were to raise the coefficient on the lending spread from 0 to 0.01, the volatility of inflation would rise by 0.04% and the volatility of the output gap would fall by 0.13%. Given this ratio of the costs to the benefits, the central bank should increase the coefficient on the lending spread.[8]

The results from allowing the central bank to reoptimize and find the optimal combination of the coefficients θ_p, θ_y, θ_i, and θ_r is shown in table 7. It should be noted how for small values of Σ, the central bank will not assign any weight to the lending spread. This is due to the fact that for small values of Σ, fluctuations in the lending spread are so small that the central bank can safely ignore them. However this model specification leads to a counterfactually small relative volatility of the lending spread. To have the model reproduce a relative volatility of the lending spread that is similar to that which we observe in the data, we need a higher value of Σ, and at these more realistic values, the clearly it is optimal to place a positive coefficient on the lending spread.

A comparison of the sixth column in table 7 with the fifth column in table 3 shows that by including lending spreads in its Taylor rule, the central bank can attain a slightly lower value of the loss function and can slightly improve the performance of its Taylor rule relative to Ramsey optimal monetary policy. Recall from the fifth column of table 3 that when the central bank does not include the lending spread in its optimal Taylor rule, the Taylor rule yields a value of the loss

[8] The partial derivative of the central bank's loss function is: $\frac{\partial \mathcal{L}(\theta_r)}{\partial \theta_r} = \frac{\partial var(\pi_t(\theta_r))}{\partial \theta_r} + \frac{1}{2}\frac{\partial var(\hat{y}_t(\theta_r))}{\partial \theta_r}$. Thus the optimal value of θ_r is the point where $\frac{\frac{\partial var(\hat{y}_t(\theta_r))}{\partial \theta_r}}{\frac{\partial var(\pi_t(\theta_r))}{\partial \theta_r}} = -\frac{1}{2}$. Since $\frac{\partial var(\pi_t(\theta_r))}{\partial \theta_r} < 0$, the central bank should increase the coefficient θ_r if $\frac{\frac{\partial var(\hat{y}_t(\theta_r))}{\partial \theta_r}}{\frac{\partial var(\pi_t(\theta_r))}{\partial \theta_r}} > -\frac{1}{2}$.

function that is about 18% higher than under Ramsey policy. When the central bank can include the lending spread in the rule, the value of the loss function if now about 16% higher than under Ramsey policy.

Returning to table 5 we see that by including the lending spread in the Taylor-type feedback rule, the central bank is able to reduce the variability of both inflation and the output gap. Quantitatively the effect is small, although it is enough to get the Taylor rule policy 2% closer to the true optimal, but qualitatively it is significant since it implies that the central bank can reduce the variability of inflation without sacrificing output, and vice versa. In the earlier results where the central bank could adjust only the conventional Taylor rule parameters, greater inflation stability was only achieved by allowing greater output instability. By including the spread in its feedback rule, the central bank is able to change its very trade-off between output and inflation.

4.2 Impulse responses to a credit supply shock

In the previous section we show how including spreads in the Taylor rule can numerically bring us closer to true optimal policy. In this section we will instead consider impulse responses to see the path of the output gap, inflation and other macro variables following a shock and show how including spreads in the Taylor rule can make the path of these variables following a shock closer to the true optimal path.

Figure 1 presents the responses of the output gap, inflation, investment, consumption, the nominal risk free rate, and the lending spread following an exogenous credit supply shock. The responses are plotted under three assumptions for monetary policy. The solid line represents Ramsey optimal monetary policy, the dashed line is the path when policy is determined by a Taylor rule function of the output gap, inflation, and the lagged interest rate, and the line with stars is the path when monetary policy is determined by a Taylor rule function of the output gap, inflation, the lagged interest rate, and the lending spread.[9]

The entire process is driven by an exogenous 250 basis point increase in the lending spread, as shown in the lower right-hand diagram. When monetary policy is determined by a conventional Taylor rule without interbank lending spreads, this exogenous increase in the spread leads to a 3

[9] In the case of the optimally chosen conventional Taylor rule without spreads, we use the coefficients from the $\Sigma = 0.175$ line of table 6. The parameters for the optimally chosen modified Taylor rule are taken from the $\Sigma = 0.175$ line of table 7.

percent fall in output, and under the conventional Taylor rule the central bank barely cuts the risk-free rate. However, under Ramsey optimal monetary policy, the central bank cuts the nominal risk-free rate by over 100 basis points immediately after the shock, and as a result, there is not the same sharp drop in output and the output gap is actually slightly positive following the shock.

When spreads are included in the Taylor rule, the path of the risk free rate following the shock is closer to the path determined by Ramsey optimal policy. When spreads are included in the Taylor rule, the central bank cuts the risk-free rate slightly in the immediate aftermath of the credit supply shock, and as a result, instead of falling by 3 percent, output falls by only 1 percent.

It should be noted however that the policy of including spreads in the Taylor rule, while closer to true optimal policy than when spreads are ignored, is not costless. The exogenous credit supply shock is a shock to the efficiency of financial intermediation. Specifically it represents a shift in the supply curve in the credit market. The central bank can cut the risk free rate to accommodate the shock, but it cannot reverse the shock. The cost of accommodation is higher inflation, as shown in the top row in the figure. Specifically, when monetary policy is determined by a Taylor rule with spreads, accommodating the exogenous 250 basis point increase in the interbank lending spread results in a $50-60$ basis point increase in inflation. Under the optimal Taylor rule that did not include spreads, inflation would only rise by 40 basis points.

5 Conclusion

Credit market risks can change the output-inflation trade-off faced by the central bank by increasing the response of the output gap to a given deviation of inflation from target. This implies that the credit frictions and credit shocks lead to a higher sacrifice ratio, and thus a greater cost of inflation. Thus in the face of credit market frictions or even credit supply shocks, the central bank will place greater weight on inflation stabilization.

This is true of the Ramsey optimal monetary response. In addition, a simple Taylor-type interest rate feedback rule can mimic optimal policy. As credit frictions and credit supply shocks become more severe, the central bank will respond by putting relatively more weight on inflation and the lagged interest rate. While this shift towards inflation stabilization in the Taylor rule helps the central bank get closer to optimal policy, it doesn't nullify the effect of the credit supply frictions or shocks. Credit frictions change the trade-off between inflation and output and using the conventional Taylor rule, the central bank responds by stabilizing inflation but only at the cost of greater output instability. Although, when the central bank is able to include a financial variable like lending spreads in its Taylor rule, it is able to partially reverse this change in the trade-off between inflation and output and the central bank doesn't lean as heavily towards inflation stabilization. As a result, the Taylor rule with a role for financial variables like lending spreads can mimic Ramsey optimal policy better than the conventional Taylor rule. These results have important implications for the conduct of monetary policy in the face of varying financial market conditions, for the central bank may want to include lending spreads in the policy rule even when financial distortions are not explicitly part of the central bank's objective function.

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A Technical Appendix

This appendix will present some of the more technical derivations in the paper related to the nominal rigidities and financial frictions present in the model. The first part of the appendix, section A.1 presents the derivations involved with the Calvo style wage and price equations. The second part of this appendix, section A.2 presents the proofs necessary for aggregation in the presence of financial frictions.

A.1 Nominal Rigidities

A.1.1 Sticky Wages

In any given period, household j faces a probability of $1-\xi_w$ of being able to reset their wage, otherwise it is reset automatically according to $W_t(l) = \pi_{t-1} W_{t-1}(l)$, where $\pi_{t-1} = \frac{P_{t-1}}{P_{t-2}}$.

If household j is allowed to reset their wages in period t they will set a wage to maximize the expected present value of utility from consumption minus the disutility of labor.

$$E_t \sum_{\tau=0}^{\infty} \beta^{\tau} (\xi_w)^{\tau} \left\{ \lambda_{t+\tau} \Pi_{t,t+\tau} W_t(l) H_{t+\tau}(l) - \psi \left(H_{t+\tau}(l) \right)^{\frac{1+\sigma_H}{\sigma_H}} \right\} \tag{17}$$

where $\lambda_{t+\tau}$ is the marginal utility of consumption in period $t+\tau$.[10]

$$\Pi_{t,t+\tau} = \begin{cases} 1 & \text{if } \tau = 0 \\ \pi_{t+\tau-1} \Pi_{t,t+\tau-1} & \text{if } \tau > 0 \end{cases}$$

The imperfect combination of labor from different households is described in (14). Use this function to derive the demand function for labor from a specific household:

$$H_t(l) = \left(\frac{W_t(l)}{W_t} \right)^{-\theta} H_t \tag{18}$$

where $W_t = \left(\int_0^n W_t(l)^{1-\theta} dl \right)^{\frac{1}{1-\theta}}$ is the average wage across households, and H_t is aggregate labor supplied by all households.

[10] We assume complete contingent claims markets among households within a country. This implies that the marginal utility of consumption is the same across all households within a country, regardless of their income. Therefore the total utility from the consumption of labor income in any period is simply the country specific marginal utility of comsumption, λ_t, multiplied by the household's labor income, $W_t(l) N_t(l)$.

Substitute the labor demand function into the maximization problem to express the maximization problem as a function of one choice variable, the wage rate, $W_t(l)$:

$$E_t \sum_{\tau=0}^{\infty} \beta^{\tau} (\xi_w)^{\tau} \left\{ \lambda_{t+\tau} \Pi_{t,t+\tau} W_t(l) \left(\frac{\Pi_{t,t+\tau} W_t(l)}{W_{t+\tau}} \right)^{-\theta} H_{t+\tau} - \psi \left(\left(\frac{\Pi_{t,t+\tau} W_t(l)}{W_{t+\tau}} \right)^{-\theta} H_{t+\tau} \right)^{\frac{1+\sigma_H}{\sigma_H}} \right\}$$

After some rearranging, the first order condition of this problem is:

$$W_t(l)^{\frac{\theta}{\sigma_N}+1} = \frac{\theta}{\theta-1} \frac{1+\sigma_H}{\sigma_H} \psi (W_t)^{\frac{\theta}{\sigma_H}} \frac{E_t \sum_{\tau=0}^{\infty} \beta^{\tau} (\xi_w)^{\tau} \left(\frac{W_{t+\tau}}{\Pi_{t,t+\tau} W_t} \right)^{\frac{\theta}{\sigma_H}+\theta} (H_{t+\tau})^{\frac{1+\sigma_H}{\sigma_H}}}{E_t \sum_{\tau=0}^{\infty} \beta^{\tau} (\xi_w)^{\tau} \lambda_{t+\tau} \Pi_{t,t+\tau} \left(\frac{W_{t+\tau}}{\Pi_{t,t+\tau} W_t} \right)^{\theta} H_{t+\tau}}$$

If wages are flexible, and thus $\xi_w = 0$, this expression reduces to:

$$W_t(l) = \frac{\theta}{\theta-1} \frac{\frac{1+\sigma_H}{\sigma_H} \psi (H_t)^{\frac{1}{\sigma_H}}}{\lambda_t}$$

Thus when wages are flexible the wage rate is equal to a mark-up, $\frac{\theta}{(\theta-1)}$, multiplied by the marginal disutility of labor, $\frac{1+\sigma_H}{\sigma_H} \psi (H_t)^{\frac{1}{\sigma_H}}$, divided by the marginal utility of consumption, λ_t.

Write the wage rate for the household that can reset wages in period t, $W_t(l)$, as $\tilde{W}_t(l)$ to denote it as an optimal wage. Also note that all households that can reset wages in period t will reset to the same wage rate, so $\tilde{W}_t(l) = \tilde{W}_t$.

All households face a probability of $(1-\xi_w)$ of being able to reset their wages in a given period, so by the law of large numbers $(1-\xi_w)$ of households can reset their wages in a given period. The wages of the other ξ_w will automatically reset by the previous periods inflation rate.

So substitute $\tilde{W}_t$ into the expression for the average wage rate $W_t = \left(\int_0^n W_t(l)^{1-\theta} dl \right)^{\frac{1}{1-\theta}}$, to derive an expression for the evolution of the average wage:

$$W_t = \left(\xi_w (\Pi_{t-1,t} W_{t-1})^{1-\theta} + (1-\xi_w) \left(\tilde{W}_t \right)^{1-\theta} \right)^{\frac{1}{1-\theta}}$$

A.1.2 Sticky Output Prices

In period t, the firm will be able to change it's price with probability $1-\xi_p$. If the firm cannot change prices then they are reset automatically according to $P_t(i) = \pi_{t-1} P_{t-1}(i)$.

The firm that can reset prices in period t will choose $P_t(i)$ to maximize discounted future profits:

$$\max_{P_t(i)} E_t \sum_{\tau=0}^{\infty} \beta^{\tau} \left(\xi_p\right)^{\tau} \lambda_{t+\tau} \left\{\Pi_{t,t+\tau} P_t(i)\, y_{t+\tau}(i) - MC_{t+\tau} y_{t+\tau}(i)\right\}$$

where $MC_{t+\tau}$ is marginal cost of production in period $t+\tau$.

The firm's demand is given in (3). Substitute this demand function into the maximization problem to express this problem as a function of one choice variable, $P_t(i)$:

$$\max_{P_t(i)} E_t \sum_{\tau=0}^{\infty} \beta^{\tau} \left(\xi_p\right)^{\tau} \lambda_{t+\tau} \left\{ \begin{array}{c} \Pi_{t,t+\tau} P_t(i)\, \gamma(n)^{\frac{1-\rho}{1-\sigma}-1} \left(\frac{\Pi_{t,t+\tau} P_t(i)}{P_{t+\tau}}\right)^{-\sigma} y_{t+\tau} \\ -MC_{t+\tau} \gamma(n)^{\frac{1-\rho}{1-\sigma}-1} \left(\frac{\Pi_{t,t+\tau} P_t(i)}{P_{t+\tau}}\right)^{-\sigma} y_{t+\tau} \end{array} \right\}$$

After some rearranging, the first order condition with respect to $P_t(i)$ is:

$$P_t(i) = \frac{\sigma}{\sigma-1} \frac{E_t \sum_{\tau=0}^{\infty} \beta^{\tau} \left(\xi_p\right)^{\tau} \lambda_{t+\tau} MC_{t+\tau} \left(\frac{\Pi_{t,t+\tau}}{P_{t+\tau}}\right)^{-\sigma} y_{t+\tau}}{E_t \sum_{\tau=0}^{\infty} \beta^{\tau} \left(\xi_p\right)^{\tau} \lambda_{t+\tau} \Pi_{t,t+\tau} \left(\frac{\Pi_{t,t+\tau}}{P_{t+\tau}}\right)^{-\sigma} y_{t+\tau}}$$

If prices are flexible, and thus $\xi_p = 0$, then this expression reduces to:

$$P_t(i) = \frac{\sigma}{\sigma-1} MC_t$$

which says that the firm will set a price equal to a constant mark-up over marginal cost.

Write the price set by the firm that can reset prices in period t as $\tilde{P}_t(i)$ to denote that it is an optimal price. Firms that can reset prices in period t will all reset to the same level, so $\tilde{P}_t(i) = \tilde{P}_t$. Substitute this optimal price into the price index $P_t = \left(\frac{1}{n}\int_0^n \left(P_t(i)\right)^{1-\sigma} di\right)^{\frac{1}{1-\sigma}}$ and use the fact that in any period $1-\xi_p$ percent of firms will reoptimize prices, and the prices of ξ_p percent of firms will be automatically reset using the previous periods inflation rate, to derive an expression for the price index, P_t:

$$P_t = \left(\xi_p \left(\Pi_{t-1,t} P_{t-1}\right)^{1-\sigma} + \left(1-\xi_p\right) \left(\tilde{P}_t\right)^{1-\sigma}\right)^{\frac{1}{1-\sigma}}$$

A.2 Financial Frictions

In this model, aggregation amont the continuum of atomistic entrepreneurs was only possible because at the beginning of the period, entrepreneur j's debt-asset ratio, $DA_t(j) = \frac{b_t(j)}{K_t(j)}$, was equal across all entrepreneurs. This section of the appendix will present the formal proof to both of these claims.

A.2.1 Entrepreneurial sector

Prove: $DA_{t+1}(i) = DA_{t+1}(j)$:

Entrepreneur i will purchase capital up to the point where:

$$1 + r_{t+1}(i) = E_t\left(\frac{R_{t+1} + \omega_{t+1}(i) P^K_{t+1}(1-\delta) K_{t+1}}{P^K_t}\right)$$

Since $E_t(\omega_{t+1}(i)) = 1$ and $cov\left(\omega_{t+1}(i), P^K_{t+1}(1-\delta)K_{t+1}\right) = 0$, $E_t\left(\frac{R_{t+1}+\omega_{t+1}(i)P^K_{t+1}(1-\delta)K_{t+1}}{P^K_t}\right) = E_t\left(\frac{R_{t+1}+P^K_{t+1}(1-\delta)K_{t+1}}{P^K_t}\right)$

Since $E_t\left(\frac{R_{t+1}+P^K_{t+1}(1-\delta)K_{t+1}}{P^K_t}\right)$ does not depend on any characteristics that are specific to entrepreneur i, in equilibrium $r_{t+1}(i) = r_{t+1}(j)$ for any two entrepreneurs i and j.

Proof by contradiction:

Suppose $DA_{t+1}(i) < DA_{t+1}(j)$

From the bank's loan supply schedule:

$$1 + r_{t+1}(j) = \frac{(1+i_{t+1})}{1 - F(\bar{\omega}_{t+1}(j))} - \frac{(1-\mu)\left[R_{t+1}F(\bar{\omega}_{t+1}(j)) + (1-\delta)P^K_t \int_0^{\bar{\omega}_{t+1}(j)} \omega_{t+1} dF(\omega_{t+1})\right]}{(1 - F(\bar{\omega}_{t+1}(j)))\frac{b_{t+1}(j)}{K_{t+1}(j)}}$$

where

$$\bar{\omega}_{t+1}(j) = \frac{(1+r_{t+1})\frac{b_{t+1}(j)}{K_{t+1}(j)} - R_{t+1}}{P^K_{t+1}(1-\delta)}$$

If $DA_{t+1}(i) < DA_{t+1}(j)$, then $\frac{b_t(i)}{K_t(i)} < \frac{b_t(j)}{K_t(j)}$, so $\bar{\omega}_t(i) < \bar{\omega}_t(j)$ and $r_t(i) < r_t(j)$.

This contradicts with the earlier equilibrium condition that $r_{t+1}(i) = r_{t+1}(j)$, thus $DA_{t+1}(i) \nless DA_{t+1}(j)$ and since the choice of i and j where arbitrary the only possible equilibrium is one where $DA_{t+1}(i) = DA_{t+1}(j)$.

Table 1: Benchmark Parameter Values

Symbol	Value	Description
β	0.99	discount factor
δ	0.025	depreciation rate
α	0.36	capital's share of income
σ_n	1	labor supply elasticity
σ	10	substitution elasticity across goods from different firms
θ	21	substitution elasticity across differentiated labor inputs
κ	0.125	capital adjustment cost parameter
ξ_p	0.62	probability that a firm cannot change prices in the current period
ξ_w	0.75	probability that a worker cannot change wages in the current period
ϕ	0.271	fixed cost in production
ψ	0.021	coefficient on labor effort in the utility function
μ	0.134	cost of liquidation
σ	0.370	standard deviation of idiosyncratic entrepreneur shocks

Table 2: The optimal coefficients on inflation, the output gap, and the lagged interest rate in the central bank's Taylor rule in the model with and the model without a financial accelerator.

	θ_p	θ_y	θ_i	$var(\pi_t)$	$var(\hat{y}_t)$
$\sigma_t = 0$	1.838	0.525	0.797	3.34%	8.26%
$\sigma_t > 0$	1.838	0.525	0.797	3.60%	8.61%
$\sigma_t > 0$	1.660	0.360	0.791	3.17%	9.44%

Table 3: The optimal coefficients on inflation, the output gap, and the lagged interest rate in the central bank's Taylor rule in the model with and the model without a financial accelerator. These results are calculated assuming that the central bank places equal weight on the volatilities of inflation and the output gap in their loss function

	θ_p	θ_y	θ_i	$var(\pi_t)$	$var(\hat{y}_t)$
$\sigma_t = 0$	1.642	0.710	0.686	5.76%	4.86%
$\sigma_t > 0$	1.642	0.710	0.686	6.47%	5.24%
$\sigma_t > 0$	1.519	0.493	0.683	5.62%	6.02%

Table 4: The preformance of the conventional Taylor rule as credit supply shocks become more important.

	θ_p	θ_y	θ_i	$\sqrt{\frac{var(rp_t)}{var(GDP_t)}}$	Rel. Loss	$\frac{\partial var(\pi_t(\theta_i))}{\partial \theta_i}$	$\frac{\partial var(\hat{y}_t(\theta_i))}{\partial \theta_i}$
$\Sigma = 0$	1.660	0.360	0.791	2.71%	9.45%	−0.50%	1.00%
$\Sigma = 0.025$	1.660	0.360	0.791	8.70%	10.04%	−0.50%	0.99%
$\Sigma = 0.050$	1.660	0.360	0.791	16.12%	11.68%	−0.51%	0.96%
$\Sigma = 0.075$	1.660	0.360	0.791	22.58%	14.04%	−0.52%	0.92%
$\Sigma = 0.100$	1.660	0.360	0.791	27.88%	16.74%	−0.54%	0.85%
$\Sigma = 0.125$	1.660	0.360	0.791	32.06%	19.46%	−0.56%	0.76%
$\Sigma = 0.150$	1.660	0.360	0.791	35.33%	22.01%	−0.59%	0.66%
$\Sigma = 0.175$	1.660	0.360	0.791	37.85%	24.29%	−0.63%	0.54%

Table 5: The variance of inflation and the output gap under optimal monetary policy and three Taylor rule specifications.

	Ramsey		Taylor rule (1)		Taylor Rule (2)		Taylor rule (3)	
	$var\ (\pi_t)$	$var\ (\hat{y}_t)$	$var\ (\pi_t)$	$var\ (\hat{y}_t)$	$var\ (\pi_t)$	$var\ (\hat{y}_t)$	$var\ (\pi_t)$	$var\ (\hat{y}_t)$
$\Sigma = 0$	3.35%	7.72%	3.17%	9.44%	3.17%	9.44%	3.17%	9.44%
$\Sigma = 0.025$	3.36%	7.99%	3.24%	9.72%	3.19%	9.82%	3.19%	9.82%
$\Sigma = 0.050$	3.41%	8.78%	3.44%	10.54%	3.21%	10.97%	3.21%	10.97%
$\Sigma = 0.075$	3.47%	10.11%	3.77%	11.91%	3.31%	12.69%	3.31%	12.69%
$\Sigma = 0.100$	3.57%	11.96%	4.24%	13.82%	3.34%	15.30%	3.32%	15.28%
$\Sigma = 0.125$	3.69%	14.34%	4.84%	16.29%	3.48%	18.33%	3.43%	18.28%
$\Sigma = 0.150$	3.84%	17.26%	5.57%	19.30%	3.68%	21.89%	3.57%	21.85%
$\Sigma = 0.175$	4.02%	20.70%	6.43%	22.86%	3.90%	26.06%	3.73%	25.90%

Note: Taylor rule (1) refers to the outcome under the conventional Taylor rule where the central bank cannot reoptimize as Σ increases, as in table 4. Taylor rule (2) refers to the conventional Taylor rule where the central bank can reoptimize as Σ increases, as in table 6. Taylor rule (3) refers to the outcome under the Taylor rule where the central bank can also target lending spreads, as in table 7.

Table 6: The preformance of the conventional Taylor rule as credit supply shocks become more important when the central bank is able to reoptimize.

	θ_p	θ_y	θ_i	$\sqrt{\frac{var(rp_t)}{var(GDP_t)}}$	Rel. Loss	$\frac{\partial var(\pi_t(\theta_r))}{\partial \theta_r}$	$\frac{\partial var(\hat{y}_t(\theta_r))}{\partial \theta_r}$
$\Sigma = 0$	1.660	0.360	0.791	2.71%	9.45%	0.00%	0.03%
$\Sigma = 0.025$	1.668	0.359	0.794	8.66%	10.02%	0.00%	0.02%
$\Sigma = 0.050$	1.690	0.353	0.802	15.79%	11.53%	0.01%	−0.01%
$\Sigma = 0.075$	1.814	0.401	0.825	21.88%	13.32%	0.01%	−0.04%
$\Sigma = 0.100$	1.950	0.429	0.847	26.50%	15.06%	0.02%	−0.07%
$\Sigma = 0.125$	2.187	0.505	0.873	30.25%	16.35%	0.03%	−0.11%
$\Sigma = 0.150$	2.447	0.581	0.894	33.20%	17.27%	0.03%	−0.12%
$\Sigma = 0.175$	2.805	0.684	0.914	35.50%	17.78%	0.04%	−0.13%

Table 7: The optimal Taylor rule coefficients when the central bank also targets the lending spread.

	θ_p	θ_y	θ_i	θ_r	$\sqrt{\frac{var(rp_t)}{var(GDP_t)}}$	Rel. Loss
$\Sigma = 0$	1.660	0.360	0.791	0.000	2.71%	9.45%
$\Sigma = 0.025$	1.668	0.359	0.794	0.000	8.66%	10.02%
$\Sigma = 0.050$	1.690	0.353	0.802	0.000	15.79%	11.53%
$\Sigma = 0.075$	1.814	0.401	0.825	0.000	21.88%	13.32%
$\Sigma = 0.100$	1.887	0.387	0.844	0.374	26.56%	14.73%
$\Sigma = 0.125$	1.985	0.390	0.863	0.534	30.34%	15.73%
$\Sigma = 0.150$	2.123	0.406	0.883	0.658	33.31%	16.27%
$\Sigma = 0.175$	1.732	0.226	0.862	0.711	35.77%	16.04%

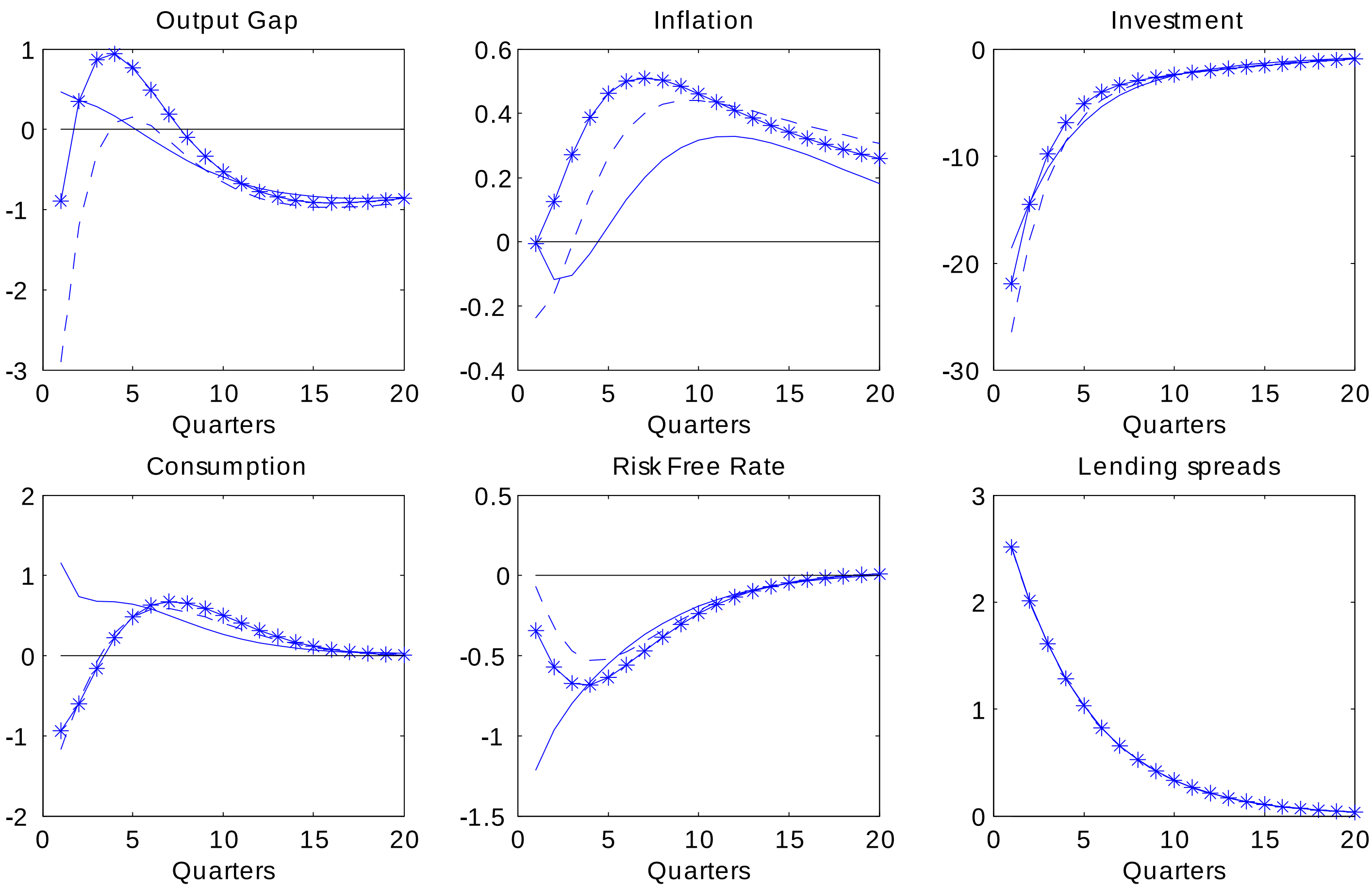

Figure 1: Responses to financial sector uncertainty shock. Calculated under three assumptions for monetary policy, Ramsey optimal policy (solid line), the conventional Taylor rule (dashed line), and the modified Taylor rule that is a function of interbank lending spreads (line with stars).