The interaction of monetary and macroprudential policies in economic stabilisation

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Abstract

I analyse the dynamics of a New Keynesian DSGE model where the financing of investments is affected by a moral hazard problem. I solve for jointly Ramsey-optimal monetary and macroprudential policies. I find that when economic fluctuations are caused by real supply or demand shocks, conventional monetary policy alone is enough to stabilise the economy, and active macroprudential policy can make the output gap more volatile. On the other hand, when the shocks arise in the financial sector, macroprudential policy is helpful in stabilising the economy. The source of fluctuations is highly relevant for the choice of the appropriate policy mix.

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1 Introduction

The global financial crisis that erupted in 2007 in the U.S. has highlighted the importance of aggregate balance sheet conditions of banks for economic cycles. As a response to the crisis, policymakers have emphasised the importance of *macroprudential* regulation, as opposed to and in addition of reforms to the regulation and supervision of individual institutions (see, for

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example, the policy reports by the Bank of England (2009) and the Bank of International Settlements (2011)).

Macroprudential policy refers to policy measures that aim at mitigating the risks and imbalances of the financial system as a whole, while conventional microprudential banking regulation has focused on single institutions. The mitigation of credit cycles, which tend to be much more volatile than real output cycles, has been seen as a key policy goal for the new macroprudential framework. This regulatory response stems from the widespread view that a build-up of system-wide risks and imbalances was at the heart of the collapse of the financial system in 2007. In this view, mitigating credit cycles and supporting financial stability are important policy goals in themselves, but also essential for the stability of the economy as a whole, as banking crises tend to have long-lasting consequences for real economic activity.

Suggested new macroprudential policy tools include countercyclical and risk-weighted capital buffers for banks, that depend not only on the banks' own balance sheet conditions, but on aggregate credit and other economic conditions. This new policy framework was internationally adopted in the Basel III agreement in 2010 (Basel Committee on Banking Supervision 2010).

As the crisis unfolded, many banks both in the U.S. and in Europe were bailed out or recapitalised by governments. In the Euro Area, a new regulatory framework (the "banking union") was set up. It includes both common supervision of individual financial institutions, as well as a common bank resolution mechanism, which entered into force in 2014. This Single Resolution Mechanism will be funded by contributions from the financial institutions themselves, in proportion to the size of their balance sheet, with the purpose of minimising the costs of future bank failures on the real economy (see European Commission 2012).

Most theoretical macroeconomic models that deal with policy issues, however, do not take the capital position of the financial sector into account, even though there is ample empirical evidence of bank capital affecting economic activity. Even many of the recent dynamic stochastic general equilibrium (DSGE) models of financial frictions abstract from banks' balance sheets. Examples of such studies include Iacovello (2005), Monacelli (2006), Faia and Monacelli (2007), and Adrian and Shin (2010). All of these articles consider shocks to asset prices and the net worth of the borrower. However, none of them discuss or analyse an explicit financial sector; instead, lending is done directly between lender and borrower without intermediation.

Some more recent research do consider the role of credit intermediation in business cycles. Many of them concentrate on "unconventional" monetary policy tools, in contrast to conventional interest rate policies, such as expanding the balance sheet of the monetary authority (quantitative easing) or direct lending to the private sector by the central bank. Cúrdia and Woodford (2010a, b, 2011) model balance sheets of both the central bank and private banks in a framework of costly financial intermediation. Their results suggest that in a deep enough financial crisis, such unconventional monetary policy measures can be efficient.

Canzoneri et al. (2011) suggest, building on Cúrdia and Woodford (2010a, b, 2011), that financial market frictions can be strongly countercyclical and have amplification effects on business cycles and fiscal multipliers. This finding supports the view that mitigating credit cycles has important consequences for general economic conditions.

Gertler and Kiyotaki (2010) and Gertler and Karadi (2011) also study unconventional monetary policies and find that direct lending by the central bank is an efficient monetary policy tool in mitigating financial turmoil. Gertler and Kiyotaki (2010, 2013) extend the model of Gertler and Karadi (2011) to include interbank credit markets. In these models, the moral hazard is generally between the bank and its depositors, affecting the supply side of credit intermediation.

Another strand of literature uses the Holmström–Tirole (1997) double moral hazard framework to explicitly model frictions on both the demand and the supply side of credit intermediation. This approach to modelling agency costs has been used by Chen (2001), Meh and Moran (2010), Christensen et al. (2011), and Faia (2010), and most recently by Haavio et al. (2014), on which the present paper builds.

It is not evident how monetary policy should react to financial imbalances – if at all – and how the new macroprudential policy measures should be coordinated with monetary policy over the business cycle. As an example, in an economic upturn, the monetary authority typically wishes to raise interest rates. This will on the one hand increase banks' cost of lending, reining in credit intermediation. On the other hand, high interest rates could have adverse incentive effects, for example by encouraging excessive risk taking. According to the Tinbergen principle, a policymaker should have as many policy instruments as there are policy objectives, and each instrument should be assigned to one objective. In light of this view, then, a separate macroprudential tool could be useful if stabilising credit cycles is an objective of the policymaker. Following the introduction of the Basel III regulatory framework, some focus has shifted on analysing the impacts of countercyclical capital buffers for banks on cyclical fluctuations.

The literature on jointly optimising monetary and macroprudential policies is not large. Angeloni and Faia (2013) study jointly optimal rule-based monetary policies and capital regulation using a model of bank runs. Christensen et al. (2011) investigate optimal rule-based capital ratio regulation and monetary policy. With regard to jointly optimal Ramsey policies, Collard et al. (2012) study jointly optimal monetary and macroprudential policies in a model setting where limited liability and deposit insurance cause excess risk-taking in the financial sector. The closest work to the present paper is Christensen et al. (2011); the findings of this paper are in line with theirs, but provide a different formulation for the macroprudential policy and an analysis of fully optimal policies in contrast to rule-based ones.

In this paper, I analyse the interaction of interest-rate-based monetary policy with macroprudential regulation in the stabilisation of economic cycles. I formulate a DSGE model where the banks' balance sheets play a key role in financial intermediation, which in turn has an important effect on economic cycles. These dynamics arise because of informational frictions in credit intermediation caused by a particular agency problem, as formulated by Holmström and Tirole (1997).

The main contribution of the present research is to solve for the Ramsey-optimal mix of monetary and macroprudential policies in response to various economic and financial disturbances, and to analyse the welfare effects of jointly setting these policies. I also compare the performance of rule-based policies to the optimal policies.

Specifically, I model macroprudential policy as a proportional and procyclical tax on banks' total assets, which restrains their leverage in upswings, and subsidises bank lending in downturns.

The choice of such a fiscal policy tool is motivated firstly by its interpretation as a bank resolution mechanism, similar to the Single Resolution Mechanism (SRM) adopted in the Euro Area banking union. Under the balanced-budget assumption, the tax can be seen as a contribution that banks pay in expansions, proportional to their total assets, and that is used to smooth out credit intermediation and maintain financial stability in contractions. In addition, the leverage tax is analytically more tractable than capital ratio regulations, as it does not create a binding constraint on the banks' decisions (such as in the models of Christensen et al. (2011) and Faia (2010)).

I find that there are clear benefits from a separate macroprudential policy tool in stabilising the effects of financial disturbances. By controlling the aggregate leverage of the banking sector and smoothing out the credit cycle, the macroprudential policy can effectively prevent the financial shock from propagating to the real economy.

In contrast, when the disturbances arise from real supply or demand side shocks and not from the financial sector, the macroprudential tax can be counterproductive as it tends to hinder proper economic adjustment by creating an additional friction on the adjustment of investments. This result highlights the importance of the health of the financial system, which is an important channel of adjustment for the economy.

The remainder of the paper is organised as follows. First, section 2 outlines the theoretical framework and describes the macroprudential leverage tax in detail. Next, section 3 discusses the implications of the frictions in the financial sector to the aggregate economy. Section 4 presents the calibration and discusses the empirical fit of the model. Section 5 presents the contribution of the paper. It analyses the aggregate dynamics of the model economy under various disturbances and discusses the welfare implications of different policy regimes. Finally, Section 6 concludes.

2 The model

The model presented in this section builds on the recent work by Haavio, Ripatti, and Takalo (2014). It incorporates into an otherwise fairly standard New Keynesian setup a financial sector afflicted by double moral hazard of the Holmström and Tirole (1997) type, whereby a moral hazard problem exists both between the bank and its depositors, and the bank and its borrowers. This allows for a friction to exist both on the supply and the demand side of credit.

2.1 Structure of the economy

The economy consists of atomistic households, a production sector, a financial sector, and a government. The total mass of households is one. Each household has three members with distinct roles: an entrepreneur, a banker, and a worker-consumer[1]. Each banker manages a bank, each entrepreneur undertakes risky projects to produce new capital goods, and each worker supplies labour to firms, consumes final goods, and saves. Intertemporal savings can be invested in riskless government bonds or in productive capital. There is perfect insurance between the family members within a household, so that the model can be described with a representative household.

The production sector is standard to New Keynesian models, except for capital production. There are intermediate good firms and final good firms. Monopolistically competitive intermediate good firms employ capital and labour to produce goods, which are then bundled into final goods by perfectly competitive final good firms.

Capital is produced by entrepreneurs, who undertake risky projects to do so. The financial sector takes deposits from households, and issues loans to entrepreneurs, who need funding for their projects. The banks also monitor the entrepreneurs' projects to guarantee efficient use of the funds.

The government issues riskless nominal bonds and conducts monetary and macroprudential policy.

[1]The terms "worker-consumer", "worker" and "depositor" will be used interchangeably to denote the family member who is not an entrepreneur or a banker, depending on the specific context.

2.2 Households

In each period, part of the economy's entrepreneurs and bankers exit. An entrepreneur survives to the next period with a constant probability $\lambda^e \in (0, 1)$, and exits with probability $1 - \lambda^e$. A banker's survival probability is, similarly, $\lambda^b \in (0, 1)$. New entrepreneurs and bankers are born in every period to replace the exiting ones, such that the shares of entrepreneurs and bankers in the economy remain constant over time. Consequently, also the fraction of worker-consumers in the economy stays constant.

While a banker or an entrepreneur is active, they do not consume; they merely engage in their banking or entrepreneurial activities and accumulate net worth. The assumption of finite lives for bankers and entrepreneurs is needed to ensure that they cannot accumulate wealth infinitely. When they exit, their net worth is transferred to their household (to be consumed or saved). A small start-up fund is allocated to each new-born banker and entrepreneur.

The working member of the household consumes, makes saving decisions and portfolio choices, and supplies labour in each period in a standard manner.

The representative household maximises its utility:

$$\max_{\{C_t, B_{t+1}, I_t, L_t\}_{t=0}^{\infty}} E_0 \sum_{t=0}^{\infty} \beta^t U(C_t, L_t), \quad 0 < \beta < 1, \tag{1}$$

subject to a budget constraint:

$$P_t C_t + P_t q_t K_{t+1} + B_t = W_t L_t + P_t r_t^K K_t + (1 + r_{t-1}) B_{t-1} + P_t \Pi_t, \tag{2}$$

where C_t is real consumption, B_t are nominal bonds issued by the government, L_t is labour supply, K_t is the real capital stock, and Π_t are real lump sum transfers received by the household (net lump-sum transfers or taxes from the government, profits from the monopolistically competitive firms owned by the household, and net returns from banking and entrepreneurial activities). P_t is the price index, q_t is the real value of capital, W_t is the nominal wage rate, r_t^K is the real rental rate of capital, and r_t is the nominal short-term interest rate.

I specify a standard CES utility function for the household:

$$U(C_t, L_t) = Z_t^c \frac{C_t^{1-\sigma}}{1-\sigma} - \frac{\chi L_t^{1+\theta}}{1+\theta}.$$

Here $\sigma > 0$ is the risk aversion parameter, $\theta > 0$ is the inverse of the Frisch elasticity of labour subsitution, and $\chi > 0$ is the labour disutility coefficient. Z_t^c is an exogenous preference shock, which captures real demand-side disturbances.

This household problem leads to the following optimality condition for labour supply and two Euler equations for bond and capital holdings:

$$w_t = -\frac{U_L(C_t, L_t)}{U_C(C_t, L_t)} \tag{3}$$

$$1 = \beta E_t \left[\lambda_{t,t+1} (1 + r_t) \frac{P_t}{P_{t+1}} \right] \tag{4}$$

$$q_t = \beta E_t \left[\lambda_{t,t+1} (r_{t+1}^K + (1-\delta) q_{t+1}) \right], \tag{5}$$

where $\lambda_{t,t+1} = \frac{U_C(C_{t+1}, L_{t+1})}{U_C(C_t, L_t)}$ is the marginal rate of intertemporal substitution, and $w_t = \frac{W_t}{P_t}$ is the real wage.

The parameter $\beta \in (0, 1)$ denotes the discount factor of the household, σ is the elasticity of consumption, ϕ is the Frisch elasticity of labour supply, and $\chi > 0$ is a scaling factor for the disutility of labour supply.

2.3 Final good production

Final good producers bundle the intermediate goods $Y_t(i)$ into final goods Y_t using a standard aggregation technology

$$Y_t = \left(\int_0^1 Y_t(i)^{\frac{\varepsilon-1}{\varepsilon}} di \right)^{\frac{\varepsilon}{\varepsilon-1}}, \quad \varepsilon > 0. \tag{6}$$

There is free entry and exit in the final good sector, and the firms are perfectly competitive.

The maximisation problem of the final good producers, combined with the zero-profit condition, yields the standard expressions for the demand schedule of intermediate good $Y_t(i)$ and the aggregate price level P_t:

$$Y_t(i) = \left(\frac{P_t(i)}{P_t}\right)^{-\varepsilon} Y_t \tag{7}$$

$$P_t = \left(\int_0^1 P_t(i)^{1-\varepsilon} di\right)^{\frac{1}{1-\varepsilon}}. \tag{8}$$

2.4 Intermediate good production

There is a continuum of intermediate good producers of mass one, indexed by i. At the beginning of each period, the intermediate firm i rents capital $K_t(i)$ from the household at price r_t^K, and employs labour $L_t(i)$ at a nominal wage rate W_t.

Each intermediate firm uses a Cobb-Douglas production technology

$$Y_t(i) = Z_t K_t(i)^{\alpha} (L_t(i))^{1-\alpha}, \tag{9}$$

where Z_t is an exogenous total factor productivity shock.

Cost minimisation by the intermediate firm yields the standard optimality conditions for the capital and labour demand given the relative factor prices, and a condition for the real marginal cost ψ_t:

$$\frac{r_t^K}{w_t} = \frac{\alpha L_t(i)}{(1-\alpha)K_t(i)}, \tag{10}$$

$$\psi_t = \left(\frac{r_t^K}{\alpha}\right)^{\alpha} \left(\frac{w_t}{1-\alpha}\right)^{(1-\alpha)} Z_t^{-1}. \tag{11}$$

Each firm is able to set its price in a staggered manner à la Calvo (1983). In any given period, the constant probability of being able to reset the price is $1-\omega$, with $0 < \omega < 1$. The profit maximisation problem of the intermediate firm i who is able to reset the price in period t is:

$$\max_{P_t(i)} E_t \left[\sum_{k=0}^{\infty} \omega^k Q_{t,t+k} \left(\frac{P_t(i)}{P_{t+k}} - \Psi_{t+k|t}\right) Y_{t+k|t}(i)\right], \tag{12}$$

subject to the demand condition

$$Y_{t+k|t}(i) = \left(\frac{P_t(i)}{P_{t+k}}\right)^{-\varepsilon} Y_{t+k}.$$

$Q_{t,t+k} = \beta^k \lambda_{t,t+k} \frac{P_t}{P_{t+k}}$ denotes the stochastic discount factor that is obtained from the household's optimality conditions. Ψ_t denotes the nominal marginal cost.

Focusing on the symmetric equilibrium where all intermediate firms choose the price $P_t(i) = P_t^*$ yields the expression for the optimal price:

$$P_t^* = \frac{\varepsilon}{\varepsilon - 1} \frac{E_t \sum_{k=0}^{\infty} \omega^k \, Q_{t,t+k} \, \psi_{t+k|t} \, Y_{t+k|t} \, P_{t+k}^{\varepsilon+1}}{E_t \sum_{k=0}^{\infty} \omega^k \, Q_{t,t+k} \, Y_{t+k|t} \, P_{t+k}^{\varepsilon}}. \tag{13}$$

In this equilibrium, the aggregate price index (8) can be written as:

$$P_t = \left[\omega P_{t-1}^{1-\epsilon} + (1-\omega)(P_t^*)^{1-\epsilon}\right]^{\frac{1}{1-\epsilon}}, \tag{14}$$

and the gross inflation rate between periods t and $t-1$ as:

$$\Pi_t = \left[\omega + (1-\omega)\left(\frac{P_t^*}{P_{t-1}}\right)^{1-\epsilon}\right]^{\frac{1}{1-\epsilon}}. \tag{15}$$

2.5 Capital good production

Capital needed in the production of intermediate good is produced by the entrepreneurs. Entrepreneurs can acquire external funding for the investment projects from banks. The banks, on the other hand, invest both their own funds and the deposits of workers into the project. The details of this three-party financing contract are given in the next section. The financial sector is affected by agency costs created by a double moral hazard problem as formulated by Holmström and Tirole (1997) in a partial equilibrium setting.

2.5.1 The financing contract

This section describes the partial equilibrium in the financial market. In what follows, small letters denote individual-level variables, whereas capital letters denote aggregate variables.

The financial sector consists of banks that channel funds from the workers to the entrepreneurs. Workers can choose to deposit their savings at a bank[2]; to attract deposits, the return on the risky investment has to be high enough for the depositor. In this sense, the deposit is not a safe bank deposit, but rather has to be understood as a short-term risky investment. The deposit and the financing contract are intra-period.[3] The exact timing of the events is detailed in a later section.

An entrepreneur can borrow money from the bank in order to lever the return to her project. However, she can choose to neglect the investment project to obtain a private benefit. The depositor nor the banker cannot observe whether the project was neglected or not. If the entrepreneur chooses to neglect the project in favour of her private benefit, the productive investment project is less likely to succeed. This presents the first form of moral hazard in the financial sector and creates a friction to the *demand side* of funds, restricting the ability of the entrepreneur to get external funding for her project.

In order to mitigate this moral hazard problem, the banker needs to monitor the entrepreneur. But this has a non-verifiable cost to the banker; because of this, he might want to forgo the monitoring. The worker observes whether the project succeeds or not but cannot verify whether the banker properly monitored the entrepreneur. This is the second form of moral hazard in the financial sector, which creates a friction to the *supply side* of funds. To mitigate this second moral hazard problem, and to be able to attract deposits from the worker, the banker needs to invest some of his own funds to be properly incentivised to monitor the project, i.e., he must have some "skin in the game".

[2]To make the financial sector non-trivial, I assume that a worker cannot deposit his savings in the bank managed by the banker in the same household; nor can the banker lend funds to the entrepreneur in the same household.

[3]This is also why the deposit does not appear in the budget constraint of the household.

Formally, if i_t is the size of an individual investment project, n_t is the net worth of the entrepreneur, a_t is the net worth of the banker, κ_t is the unit cost of monitoring the investment project, and d_t is the deposit of the worker in period t, then:

$$i_t - n_t \leq a_t + d_t - \kappa_t i_t \tag{16}$$

gives the maximum amount of external funding an entrepreneur can get for her project, given her own net worth.

A successful project turns i_t final goods into Ri_t capital goods with $R > 1$. A failed project yields zero. The one-period contract specifies how the returns of the project are divided between the worker (R_t^w), the banker (R_t^b) and the entrepreneur (R_t^e):

$$R \geq R_t^w + R_t^b + R_t^e. \tag{17}$$

There are two types of projects: "good" and "bad" ones (or non-neglected and neglected ones). The project succeeds with probability $p \in \{p_H, p_L\}$, with $\Delta p = p_H - p_L > 0$ and $1 > p_H > p_L > 0$. If the entrepreneur chooses the good project, the success probability is p_H, but there is no private benefit to her. There is also a continuum of bad projects, each with the same success probability p_L, but with an associated positive non-verifiable private benefit b with $0 < b \leq \bar{b}$, proportional to the size of the project.

By choosing a monitoring intensity κ_t, the banker can prevent the entrepreneur from choosing any of the bad projects with $b \geq b(\kappa_t)$. I assume $b'(\kappa) \leq 0$, $b''(\kappa) \geq 0$ and $\lim_{c\to\infty} b'(\kappa) = 0$. Because monitoring is costly, it is never possible for the banker to monitor at a level that completely eliminates all bad projects.

In order for the three parties to be willing to participate in the contract, the following incentive and participation constraints must be met:

$$q_t p_H R_t^w i_t \geq (1 + r_t) d_t \tag{18}$$

$$q_t p_H R_t^b i_t \geq (1 + r_t^a) a_t \tag{19}$$

$$q_t p_H R_t^b i_t - \kappa_t i_t \geq q_t p_L R_t^b i_t \tag{20}$$

$$q_t p_H R_t^e i_t \geq q_t p_L R_t^e i_t + b(\kappa_t) i_t \tag{21}$$

Equations (16) – (21) define the financial contract. (18) is the participation constraint of the depositor, which tells that the depositor must obtain a gross return at least as high from participating in the project, as she would get on the deposit otherwise; r_t is the net outside return on the deposit, which is equal to the short-term market interest rate. Similarly, (19) is the participation constraint of the banker, where r_t^a is the outside return on bank capital.

(20) and (21) are the incentive constraints of the banker and the entrepreneur, respectively. In order for the banker to be willing to monitor the entrepreneur, the return from the good project, net of monitoring cost, must be at least as much than the return from the bad project. The entrepreneur, in turn, must get at least as much from the good project as she would get from the bad project together with the private benefit.

In equilibrium, all constraints bind.[4] It is easy to see why: first, the two resource constraints (16) and (17) are trivially binding at optimum. Second, the compensations R_t^e and R_t^b must be high enough to properly incentivise the entrepreneur and banker to behave; but by the pie-sharing constraint (17), the more is allocated to them, the less is left for the depositor, who is the residual claimant of the project return. Thus, the depositor will not participate unless the minimum possible shares that satisfy the incentive and participation constraints are allocated to the entrepreneur and the banker.

As a consequence, in each period, the entrepreneur and the banker invest their whole net worth (net of monitoring cost), as well as the whole deposit of the worker, into the investment project, and the entrepreneur always undertakes the good project.

In order to guarantee that the good investment project is desirable compared to the bad projects from the household's point of view, I further assume that $q_t p_H R > \max\{1 + r_t,\, q_t p_L R + \bar{b}\}$. This assumption also guarantees that the project has a positive rate of return (and positive pledgeable income).

2.5.2 Optimal investment and leverage

In this section, I solve for the optimal leverage ratio of the entrepreneur, and the corresponding optimal size i_t of an investment project. From the

[4] See Holmström and Tirole (1997) for a detailed discussion.

incentive constraints (20) and (21), the banker and the entrepreneur must get at least

$$R_t^b = \frac{\kappa_t}{q_t \Delta p} \tag{22}$$

$$R_t^e = \frac{b(\kappa_t)}{q_t \Delta p} \tag{23}$$

to be properly incentivised in equilibrium. In other words, the more severe the moral hazard of the entrepreneur at any given monitoring level, the more she must be compensated for undertaking the good project instead of the bad one; and the costlier monitoring is, the more the banker has to be compensated.

The depositor is the residual claimant of the return, who can then get at most

$$R_t^w = R - R_t^b - R_t^e = R - \frac{b(\kappa_t) + \kappa_t}{q_t \Delta p}. \tag{24}$$

Therefore it is in the best interest of the depositor that the project is properly monitored to guarantee that the good project is chosen. In equilibrium, the entrepreneur and the banker get the minimum return that satisfies their incentive constraints, and the depositor gets the maximum residual return.

From the participation constraints (18) and (19) it follows:

$$R_t^w = \frac{(1 + r_t)d_t}{q_t p_H i_t} \tag{25}$$

$$R_t^b = \frac{(1 + r_t^a)a_t}{q_t p_H it}. \tag{26}$$

Combining (22) with (26) yields:

$$\frac{a_t}{i_t} = \frac{p_H}{\Delta p} \frac{\kappa_t}{1 + r_t^a}. \tag{27}$$

Further, combining (24) with (25) yields:

$$\frac{d_t}{i_t} = \frac{q_t p_H R}{1 + r_t} - \frac{p_H}{\Delta p} \frac{\kappa_t + b(\kappa_t)}{1 + r_t}. \tag{28}$$

Equations (27) and (28) indicate that the greater is the cost of monitoring, κ_t, the less deposits can be attracted from the worker, as the worker cannot be convinced as easily that the project is properly monitored. The amount of deposits is also decreasing in the severity of the moral hazard, $b(\kappa_t)$. On the other hand, it is increasing in the total expected return of the project, $q_t p_H R$.

Substituting (27) and (28) into the resource constraint (16) gives, after some manipulation, the optimal investment as a function of the inverse leverage g_t:

$$i_t = \frac{n_t}{g_t}, \tag{29}$$

where the inverse leverage $g_t \equiv g(r_t, r_t^a, q_t, \kappa_t)$ is given by:

$$g_t = 1 - \frac{q_t p_H R}{1+r_t} + \frac{p_H}{\Delta p}\frac{b(\kappa_t)}{1+r_t} + \left(1 + \frac{p_H}{\Delta p}\left(\frac{1}{1+r_t} - \frac{1}{1+r_t^a}\right)\right)\kappa_t. \tag{30}$$

Notice that $\frac{q_t p_H R}{1+r_t} - 1 \equiv \rho_t$ is the net pledgeable income of the project, i.e. maximum net excess return that the entrepreneur can promise to the investors. Equation (30) tells that the worse the moral hazard of the entrepreneur, the costlier monitoring, the smaller the net pledgeable income, or the lower the real value of capital q_t is, the less the entrepreneur can attract external funding (or lever the investment size).

Now, the problem of the entrepreneur is to choose i_t to maximise her expected profit, given her net worth n_t and the inverse leverage g_t. As the profits are proportional to the investment size, expected profit is maximised when i_t is maximised, or in other words, when the leverage ratio $\frac{1}{g_t}$ is maximised. Given prices, g_t is fully determined by the monitoring intensity κ_t.

Let κ_t^* denote the monitoring intensity that maximises the entrepreneurs profit. Using (21) and (29), the entrepreneur's expected profit in terms of κ_t^* can be expressed as (taking as given the prices q_t, r_t and r_t^a):

$$q_t p_H R_t^e i_t = \frac{p_H}{\Delta p}\frac{b(\kappa_t^*) n_t}{g(\kappa_t^*)}. \tag{31}$$

Thus, the monitoring intensity that maximises the entrepreneur's profit is found by solving:

$$\kappa_t^* = \arg\max_{\kappa_t} \frac{b(\kappa_t)}{g(\kappa_t)}. \tag{32}$$

In order to solve this problem, let us assume the following functional relationship between the monitoring intensity and the size of the private benefit:

$$b(\kappa_t) = \begin{cases} \Gamma \kappa_t^{-\frac{\gamma}{1-\gamma}} & \text{if } \kappa_t > \underline{\kappa} \\ \bar{b} & \text{if } \kappa_t \leq \underline{\kappa}. \end{cases} \tag{33}$$

where $0 < \gamma < 1$, $\Gamma > 0$, $\bar{b} > 0$, and $\bar{c} \geq 1$. In other words, there is a lower bound for the efficiency of monitoring under which the maximum private benefit is always feasible. When $\kappa_t > \underline{\kappa}$, the amount of private benefit is a strictly convex function of the monitoring intensity, increasing in Γ, and decreasing in γ.

This specification of the monitoring technology yields the following interior solution to the problem (40):

$$\kappa_t^* = \frac{\gamma \rho_t}{1 + \frac{p_H}{\Delta p} \left(\frac{1}{1+r_t} - \frac{1}{1+r_t^a} \right)}, \tag{34}$$

which, when substituted into equation (30), yields the following equilibrium degree of inverse leverage:

$$g(\kappa_t^*) = \frac{p_H}{\Delta p} \frac{b(\kappa_t^*)}{1 + r_t} - (1 - \gamma) \rho_t, \tag{35}$$

which in turn determines the equilibrium investment size.

The endogenous monitoring intensity κ_t^* plays a key role in the dynamics of the financial sector. If κ_t^* were constant, the monitoring intensity would not react to any disturbances in the economy. Because of this, also the private benefit, and thus the incentives of the entpreneur, would not change. As a result, because the ability of the banker to attract deposits depends on the monitoring of the project, any shock that would reduce the banker's own capital available for investments would just be replaced by increased deposits, and the total amount of loans would not be affected.

In contrast, when κ_t^* is endogenous, it reacts to developments in the financial markets. If the banker's net worth deteriorates, he has less resources to monitor the entrepreneur's project, and thus the moral hazard problem is exacerbated. As a consequence, less deposits can be attracted, and less loanable funds are available. Endogenous monitoring is the key driver behind the financial dynamics of this model, and it is what makes bank capital fundamentally different from entrepreneurial capital or deposits. The aggregate implications of this mechanism are discussed in more detail in Section 5.

2.6 A leverage tax on banks

Let us now introduce a tax on banks. The financial regulator cares about mitigating fluctuations in the financial market, and in particular in credit intermediation. To achieve this goal, the regulator imposes a time-varying tax on bank leverage. In an upturn, when credit intermediation is above its long-run trend, banks have to pay a fraction of their total assets to the government. Conversely, in a downturn, and particularly if the economy is hit by a credit crunch, the government subsidises bank lending. The exact policy rule is specified below in section 2.8.

Formally, bank leverage is defined as the ratio of total assets to net worth. Bank net worth is equal to the bank's own capital a_t, and the total liabilities of the banking sector are composed of bank capital and deposits, $a_t + d_t$. As an accounting identity, total assets are equal in size to total liabilities. Then, bank leverage can be defined as:

$$\mathcal{B} = \frac{a_t + d_t}{a_t}. \tag{36}$$

The financial regulator imposes a time-varying tax τ_t on bank leverage, or equivalently, on the bank's total assets. Then, the after-tax net leverage is:

$$\bar{\mathcal{B}}_t = (1 - \tau_t)\mathcal{B}_t = (1 - \tau_t)\frac{a_t + d_t}{a_t}. \tag{37}$$

When $\tau_t > 0$, the financial regulator imposes a tax on the bank's total assets that restricts bank leverage. When $\tau_t < 0$, the regulator subsidizes bank leverage, which stimulates bank lending.

The funding constraint of the bank under this tax is:

$$i_t - n_t + \kappa_t I_t \leq (1 - \tau_t)(a_t + d_t). \tag{38}$$

The bank now has to use its own capital and the deposits to finance both the loan to the entrepreneur and the monitoring of the project, as well as to pay for the tax.

The variables net of tax can be derived exactly as presented in the previous sections. The variables net of the tax are denoted by an upper bar.

Pledgeable income after tax is:

$$\bar{\rho}_t = (1 - \tau_t)\frac{q_t p_H R}{1 + r_t} - 1. \tag{39}$$

The optimal level of monitoring, net of the tax, is:

$$\bar{\kappa}_t^* = \frac{\gamma \bar{\rho}_t}{1 + (1 - \tau_t)\frac{p_H}{\Delta p}\left(\frac{1}{1+r_t} - \frac{1}{1+\bar{r}_t^a}\right)}. \tag{40}$$

The after-tax inverse leverage of the entrepreneur is:

$$\bar{g}_t = (1 - \tau_t)\frac{p_H}{\Delta p}\frac{b(\bar{\kappa}_t^*)}{1 + r_t} - (1 - \gamma)\bar{\rho}_t. \tag{41}$$

Then, the level of investment is determined by:

$$\bar{i}_t = \frac{\bar{n}_t}{\bar{g}_t} \tag{42}$$

The after-tax return on bank capital is:

$$1 + \bar{r}_t^{a*} = \frac{p_H}{\Delta p}\frac{\bar{i}_t}{\bar{a}_t}\bar{\kappa}_t^*. \tag{43}$$

The return on bank capital is affected through the effect of the tax on the level of monitoring and entrepreneur leverage. Similarly, also return on entrepreneurial capital, and consequently also the net worth of the entrepreneur, is affected only indirectly through the effect on g_t. I denote the level of return and the entrepreneurial net worth consistent with the after-tax investment by $\bar{r}_t^e$ and $\bar{n}_t$, respectively.

2.7 Aggregation

I focus on the symmetric equilibrium where all projects are monitored at the same intensity $\bar{\kappa}_t^*$ given by (40), and the capital structure, given by the ratios of own and external funds to total investment ($\frac{\bar{n}_t}{\bar{i}_t}$, $\frac{\bar{a}_t}{\bar{i}_t}$ and $\frac{\bar{d}_t}{\bar{i}_t}$), is equal across entrepreneurs, bankers and depositors, respectively. Notice the size of the project i_t may vary.

Then, the corresponding after-tax aggregate ratios are simply given by

$$\frac{N_t}{I_t} = \frac{\bar{n}_t}{\bar{i}_t}, \quad \frac{A_t}{I_t} = \frac{\bar{a}_t}{\bar{i}_t}, \quad \frac{D_t}{I_t} = \frac{\bar{d}_t}{\bar{i}_t}, \tag{44}$$

where capital letters denote aggregate amounts net of tax.

The equilibrium aggregate investment in the economy is determined by

$$\frac{N_t}{I_t} = g(\bar{\kappa}_t^*), \tag{45}$$

where $g(\bar{\kappa}_t^*)$ is given by equation (41).

Using the relation (27), the equilibrium rate of return to bank capital is given by

$$1 + \bar{r}_t^{a*} = \frac{1 + \gamma \rho_t \frac{I_t}{A_t}}{(1 + r_t)^{-1} + \frac{\Delta p}{p_H}}. \tag{46}$$

Next, the laws of motion of the three types of capital are described by the following equations. In equilibrium, the capital stock in the economy evolves according to

$$K_{t+1} = (1 - \delta) K_t + p_H R I_t. \tag{47}$$

Entrepreneurial and bank net worth are defined to evolve according to

$$N_{t+1} = \lambda^e (1 + \bar{r}_t^e) \frac{r_{t+1}^K + (1 - \delta) q_{t+1}}{q_t} N_t \tag{48}$$

$$A_{t+1} = Z_t^b \lambda^b (1 + \bar{r}_t^a) \frac{r_{t+1}^K + (1 - \delta_t) q_{t+1}}{q_t} A_t, \tag{49}$$

where $r_{t+1}^K + (1 - \delta) q_{t+1}$ is the marginal value of a unit of capital in period $t + 1$, which is composed of two parts: the rental income at the beginning of the period r_{t+1}^K, and the value of undepreciated capital $(1 - \delta) q_{t+1}$ remaining at the end of the period.[5] λ^e and λ^b are the fractions of entrepreneurs and bankers, respectively, surviving from period t to $t+1$. The return to entrepreneurial capital is simply defined as $1+\bar{r}_t^e \equiv \frac{q_t p_H R_t^e I_t}{N_t}$, which is the ratio of expected profit to net worth.

To introduce a shock arising in the financial market into the model, I let the accumulation of bank capital be affected by an aggregate shock, Z_t^b. I assume Z_t^b is an AR(1) process with a normally distributed i.i.d. innovation term. A negative shock to Z_t^b corresponds to an exogenous and unanticipated decrease in the accumulation of bank capital, or in other words, a sudden erosion of bank net worth, common to the whole banking sector. The shock hinders the banks' ability to extend funding to entrepreneurs, and could lead to a credit crunch if severe enough.

Notice that here, I assume that the total bank net worth is not directly taxed. It is however affected through the indirect effect of the smaller return on bank capital, $\bar{r}_t^{a*}$. The assumption means that since only the total assets of the bank are taxed, the banker is in effect able to shift the tax burden on the depositor. A similar law of motion applies to after-tax entrepreneur net worth.

Finally, the aggregate consistency constraint of the economy is:

$$Y_t = C_t + I_t + G_t, \tag{50}$$

which states that all output must be either consumed or invested, taking into account the monitoring cost. C_t denotes aggregate private consumption, and G_t is aggregate government consumption (specified below).[6]

2.8 Government policies

To close the model, I specify two different policy rules in the baseline model. The monetary policy is set by the central bank. In the baseline model, it uses a Taylor-type rule to set the short-term interest rate r_t^d. The monetary

[5]Recall that the proceeds of the investment project, Ri_t, are paid in capital goods.

[6]I assume that the monitoring of investment projects does not consume real resources. If it did, the resource constraint would be $Y_t = C_t + (1+\kappa_t^*)I_t + G_t$. This assumption is not restrictive, as κ_t^* is very small in equilibrium, and it facilitates the computation of the steady state of the model.

policy targets inflation and the output gap.

In addition, the government sets the leverage tax to mitigate fluctuations in the financial market. The goal of this macroprudential policy is to facilitate credit intermediation in a downturn, and restrain excessive credit growth in an upturn. The policy targets the output-to-loans ratio, which measures indebtedness of the economy.

2.8.1 Monetary policy

First, the central bank sets the nominal short-term interest rate r_t using a Taylor rule:

$$1 + r_t = \frac{1}{\beta} \Pi_t^{\phi_\pi} X_t^{\phi_x}, \tag{51}$$

where Π_t is the period-to-period gross inflation rate and $X_t = \frac{Y_t}{Y_t^e}$ is the gap between the actual output Y_t and the efficient level of output, Y_t^e, that would prevail in a perfectly frictionless real economy[7]. $\frac{1}{\beta}$ is a normalisation that ensures that the gross nominal interest rate equals the inverse of the discount factor in the steady state equilibrium.

2.8.2 Macroprudential policy

I assume that the government follows a balanced budget policy, and that the leverage tax and subsidy system is financed by lump sum taxes and transfers on households. This implies that the households' optimal decisions are not affected. This fiscal device, while rather abstract, can under these conditions also be interpreted as a bank resolution fund. The effects of the tax on banking sector dynamics are similar to capital ratio regulation (as, for example, discussed in Christensen et al. (2011)) but the advantage of the fiscal approach is that unlike a restriction on the capital ratio of the bank, the leverage tax does not impose a constraint on the bank's choice of monitoring intensity, and the financing problem remains simple and tractable.

The financial regulator sets the level of the tax according to a Taylor-type policy rule. The policy target is the credit-to-output ratio $\Upsilon_t = \frac{I_t - N_t}{Y_t}$. When

[7] The efficient level of output is a benchmark computed as the output level achievable with the resources of the economy in the absence of monopolistic competition, the pricing friction, and the financial friction.

this ratio is above its steady state level $\Upsilon = \frac{I-N}{Y}$, i.e. the "credit gap" $\frac{\Upsilon_t}{\Upsilon}$ is above unity, the tax rate is positive. When the ratio is below its steady state level, the tax rate is negative, i.e. it is a subsidy to lending. The steady-state level of the tax is set to zero, so that the steady state of the economy is not affected by the distortionary tax/subsidy transfer.

This choice of target means that the macroprudential policy seeks to restrain the indebtedness of the economy; the credit-to-output ratio is a simple measure of it.

Specifically, the leverage tax is set according to the rule:

$$1 + \tau_t = \left(\frac{\Upsilon_t}{\Upsilon}\right)^{\phi_\Upsilon}, \tag{52}$$

where ϕ_Υ is the policy parameter defining the intensity of the policy.

The government budget constraint is:

$$\tau_t(A_t + D_t) = G_t, \tag{53}$$

where G_t are net lump sum taxes on or transfers to the household.

2.9 Equilibrium

The competitive equilibrium of the economy is a time path

$$\left\{C_t, K_t, L_t, I_t, A_t, N_t, D_t, q_t, r_t^K, r_t, \bar{r}_t^{a*}, \bar{r}_t^e, w_t, \psi_t, P_t, P_t^*, R_t^b, R_t^e, R_t^w, \bar{\kappa}_t^*, \tau_t\right\}_{t=0}^{\infty} \tag{54}$$

that satisfies the households' problem, the final and intermediate firms' problems, the optimal financing contract, and the aggregate consistency condition. The equilibrium dynamics as well as the deterministic steady state equilibrium of the model economy are summarised in Appendix A.

2.10 Timing of events

The timing of the events is as follows. Each time period is divided into two phases, described in Table 1.

The production phase
• Households rent capital K_t and supply labour L_t to intermediate firms. • The aggregate productivity shock Z_t is realised; intermediate and final production take place.
The consumption and investment phase
• Entrepreneurs acquire funding for new investment projects. The financing contract is agreed upon, given N_t and A_t. • Monitoring and realisation of the investment projects take place. • The outcome of the project is observed. Returns to investment are distributed according to the contract. • The aggregate financial shock Z_t^b is realised. Entrepreneurs and bankers accumulate net worth • N_{t+1} and A_{t+1}. Exiting bankers and entrepreneurs transfer their accumulated wealth to their household. • The demand shock Z_t^c is realised. Consumption and saving decisions take place.

Table 1: Timing of events

3 Implications of the financial friction

In addition to the nominal friction arising from staggered price setting, and the friction caused by monopolistic competition in intermediate good production, there is an additional real friction compared to the standard New Keynesian model: the friction arising from the agency costs in the financial sector.

If $b(\kappa_t) = 0$, i.e. there are no private benefits available for the entrepreneur, and consequently, no need for monitoring ($\kappa_t = 0$), the incentive constraints (20) and (21) always hold: there is no incentive problem.

Then, the entrepreneur and the banker are indifferent between undertaking the good project and not when $R_t^e = R_t^b = 0$. The depositor-worker receives the whole gross return, $R_t^w = R$. In this case, the financial intermediation becomes "invisible" in the sense that it is as if the worker himself would directly undertake the project, i.e. the household becomes a capital producer. This is in essence equal to the standard New Keynesian case, where there is no role for financial intermediation, and the household's savings are directly channelled into productive investment.

As a consequence, since there are no more retained earnings, the banker and the entrepreneur can no longer accumulate own wealth, and $n_t = a_t = 0$. The balance sheet constraint becomes

$$i_t = d_t, \tag{55}$$

that is, the deposits of the worker are invested in new capital, and there is no leverage.

Aggregation can be done as in the case with the friction, so that

$$I_t = D_t \tag{56}$$

determines the aggregate investment level directly. The choice of aggregate investment level reduces to the standard choice of next-period capital stock, K_{t+1}, given the household's budget constraint, and the optimality condition that determines I_t can be derived directly from the household problem. The standard New Keynesian model is thus nested within the model presented in this paper, and makes comparison with the dynamics of the standard model straightforward.

Frictions in the financial market cause aggregate investments to be at a sub-optimal level. When these frictions are present, aggregate investments I_t depend on the total amount of entrepreneurial and bank capital, N_t and A_t, and – through their effect on leverage – on the size of private benefits $b(\kappa_t)$ and the monitoring intensity κ_t. The more severe the incentive problems, the less funds can be channelled into the investment projects. The inefficiency of credit intermediation is exacerbated by the monitoring cost: because of it, less resources are available for productive investments. Both the entrepreneurs and the bankers are capital-constrained.

An efficient steady state allocation thus requires that investments be at the level determined by a perfectly competitive and frictionless economy. The government can replicate this allocation by introducing a constant investment subsidy that restores the efficient amount of investment. In the analysis presented in the following sections, it is assumed that such a subsidy is in place; see Appendix A.2 for details.

4 Calibration

The calibration of the model largely follows the calibration strategy discussed in Haavio et al. (2014). Assuming that a steady state investment subsidy is in place, so that steady state investments are at the efficient level, the steady state of the New Keynesian macro block is not affected by the parameters of the financial sector. Thus the macro and the financial block can be calibrated independently.

The macro block of the model is calibrated in a standard fashion in the New-Keynesian literature to match a quarterly frequency in data, in order for the model to be easily comparable to a benchmark New Keynesian model without financial frictions. The parameter values are summarised in the upper panel of Table 2.

The financial block is calibrated to match some steady state characteristics of the model. The entrepreneur and banker survival rates, λ^e and λ^b respectively, are calibrated to match a steady state excess return on entrepreneurial capital of 4.5 % and an excess return on (core) private bank capital of 20 % per annum, compared to the short-term market interest rate. These values are consistent with the the estimates in Albertazzi and Gambacorta (2009).

The calibration of the monitoring parameters γ and Γ pin down the monitoring cost in the steady state, and also steady state leverage, because the steady state entrepreneur leverage is fully determined by the monitoring intensity. On the other hand, also bank leverage depends on the monitoring intensity, as it determines its ability to attract deposits. Hence, these two parameters are the key parameters governing the financial sector dynamics.

The exact cost of monitoring activities in banks is hard to pin down empirically. Banks' overheard costs as a fraction of total assets in the U.S. are estimated to be around 3 % by the World Bank (2013). Overhead costs, however, include also costs not related to monitoring activities. Philippon (2014) estimates that the unit cost of financial intermediation has been stable at around 1.5% to 2% in the U.S. over the past decades. The calibration of γ and Γ matches a per annum monitoring cost of 1.2 % of total bank assets in steady state.

The leverage of non-financial U.S. firms is estimated to be around 2.3-2.5

Panel 1: New Keynesian block		
Discount factor	β	0.9951
Risk aversion	σ	2
Habit persistence	b	0
Capital depreciation rate	δ	0.025
Elasticity of substitution (mark-up: 10 %)	ϵ	11
Capital share	α	0.33
Frisch elasticity of labour supply	θ	0.5
Disutility of labour supply	ξ	2
Calvo parameter	ω	0.8
Persistence of productivity shock	ρ	0.95
Persistence of preference shock	ρ_c	0.7
Std. dev. of productivity shock	σ_ϵ	0.006
Std. dev. of preference shock	σ_c	0.005
Panel 2: Financial block		
Elasticity of monitoring	γ	0.2992
Monitoring intensity	Γ	0.0017
Survival rate of entrepreneurs	λ^e	0.9842
Survival rate of bankers	λ^b	0.9507
Success probability of good project	p_H	0.95
Gross return of investment project: $R = \frac{1}{p_H}$	R	1.0526
Probability differential	Δp	0.0454
Persistence of bank capital depreciation shock	ρ_b	0.5
Std. dev. of bank capital depreciation shock	σ_b	0.006
Panel 3: Policy parameters		
Taylor rule weight on inflation	ϕ^π	1.5
Taylor rule weight on output gap	ϕ_x	0.5
Leverage tax policy parameter	ϕ_Υ	1

Table 2: Benchmark calibration of the model

by Kalemli-Ozcan et al. (2011). They also find that leverage ratios of financial firms are very heterogenous in the U.S. and depend on the type of the bank. Large investment banks have leverage ratios in the order of 20, while commercial banks typically have leverage ratios ranging around 10-12. The elasticity of monitoring and monitoring intensity are calibrated in such a way as to produce a leverage ratio of around 1.5 for non-financial firms (entrepreneurs, in this model), and a leverage ratio of 16.5 for banks.

The success probability of the good project and the gross return from the project, p_H and R, are normalised such that $p_H R = 1$, which makes the evolution of the aggregate capital accumulation comparable to the standard New Keynesian case. I set $p_H = 0.95$, which implies a net return $R - 1$ on the investment project equal to approximately 5%.

The financial shock is calibrated to be rather transitory at $\phi_b = 0.5$. The standard deviance of the shock is calibrated to be the same than that of the productivity shock. The parameters of such a financial shock is hard to pin down empirically, but the calibration is intended to represent the financial shock as a strong but brief event on the financial markets.

Finally, Panel 3 summarises the baseline policy parameters. The benchmark Taylor rule parameters are set to the standard response values of 1.5 on inflation and 0.5 on output gap.

The macroprudential tax policy, when active, targets a steady state credit-to-output ratio. In the context of the present model, credit only includes loans to entrepreneurs who are the only borrowers in the model. A natural empirical counterpart is the ratio of commercial and industrial loans to GDP. The average of this ratio from 1990 to 2014 has been rather stable at roughly 8.8 % in the U.S.[8] The corresponding steady state ratio in the model is 8.7 %. The parameter governing the intensity of the policy, ϕ_Υ, is set to unity, so that the macroprudential policy is rather aggressive and responds one-to-one to deviations of the credit-to-output ratio from its steady state value.

[8] Author's own calculations.

5 Aggregate dynamics

This section presents the benchmark model dynamics under the rule-based policies presented in Section 2.8. For purposes of comparability with the optimal policy responses computed in Section 5.3, I approximate the full non-linear model by a second-order Taylor approximation in logs around the deterministic steady state of the model.[9]

This section discusses the responses of the approximated model to various shocks through impulse response analysis. All figures presented in the following sections show the resulting dynamics as percentage deviations from steady state values.

5.1 Comparison to the model without financial frictions

Consider first the model where the leverage tax is inactive, i.e. τ_t is set to zero in all periods, and only the Taylor rule for the nominal interest rate is active.

I first compare the responses of the macro block's variables in the financial frictions and the standard New-Keynesian model. Figure 1 shows the response of key variables to an adverse 1 % labour-augmenting productivity shock under the baseline Taylor rule ($\phi_\pi = 1.5, \phi_x = 0.5$). The financial friction creates an additional barrier to adjustment in the economy.

The financial frictions hinder the adjustment of the economy further and create additional stickiness compared to the standard New-Keynesian model. In particular, a much bigger and positive output gap opens in the economy with financial frictions than in the economy without them in response to the productivity shock. The presence of the financial friction prevents investments from adjusting enough compared to the efficient, frictionless benchmark economy. Consequently, output cannot adjust enough in response to the decreased productivity. Inflation is also more volatile than in the model without the financial friction.

Figure 2 shows the response of the economy to an adverse demand shock

[9] A second-order approximation is needed for the computation of Ramsey-optimal policy discussed in Section 5.3.

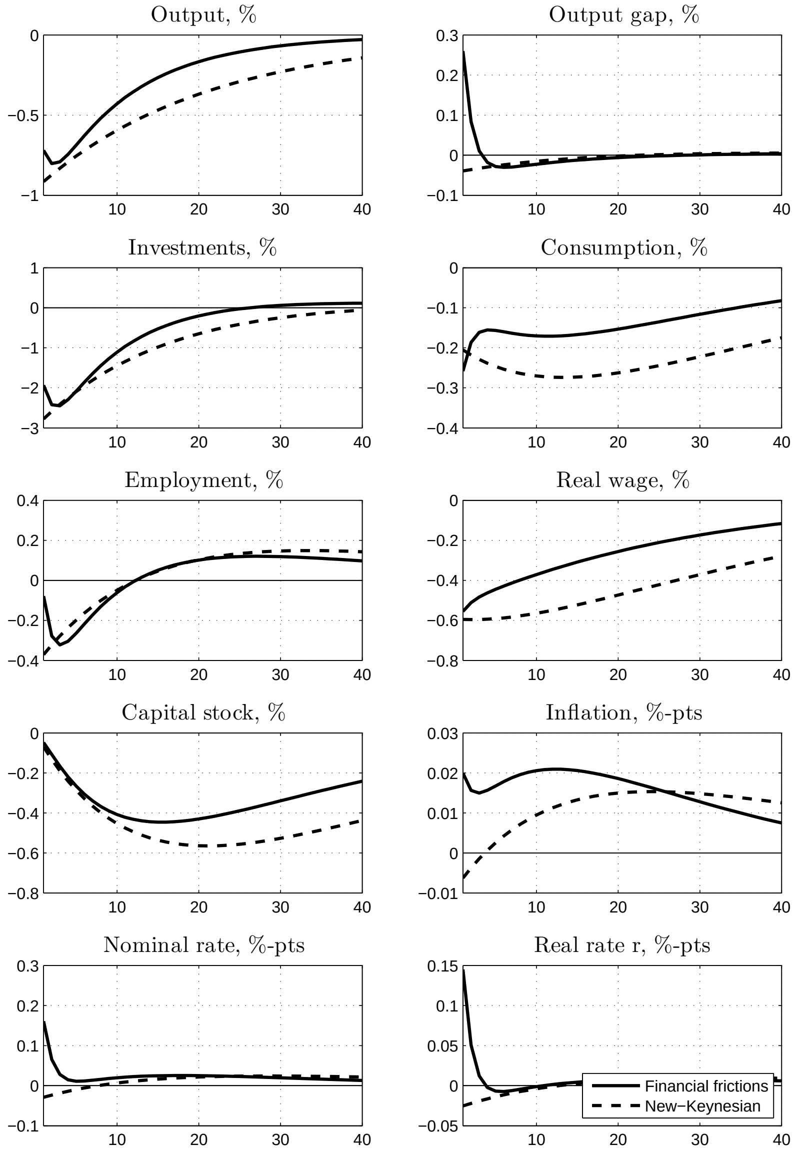

Figure 1: Effects of a 1 % negative total factor productivity shock under baseline Taylor rule. "Financial frictions": baseline model with financial frictions. "New-Keynesian": standard New-Keynesian model without financial frictions, nested within the "financial frictions" model.

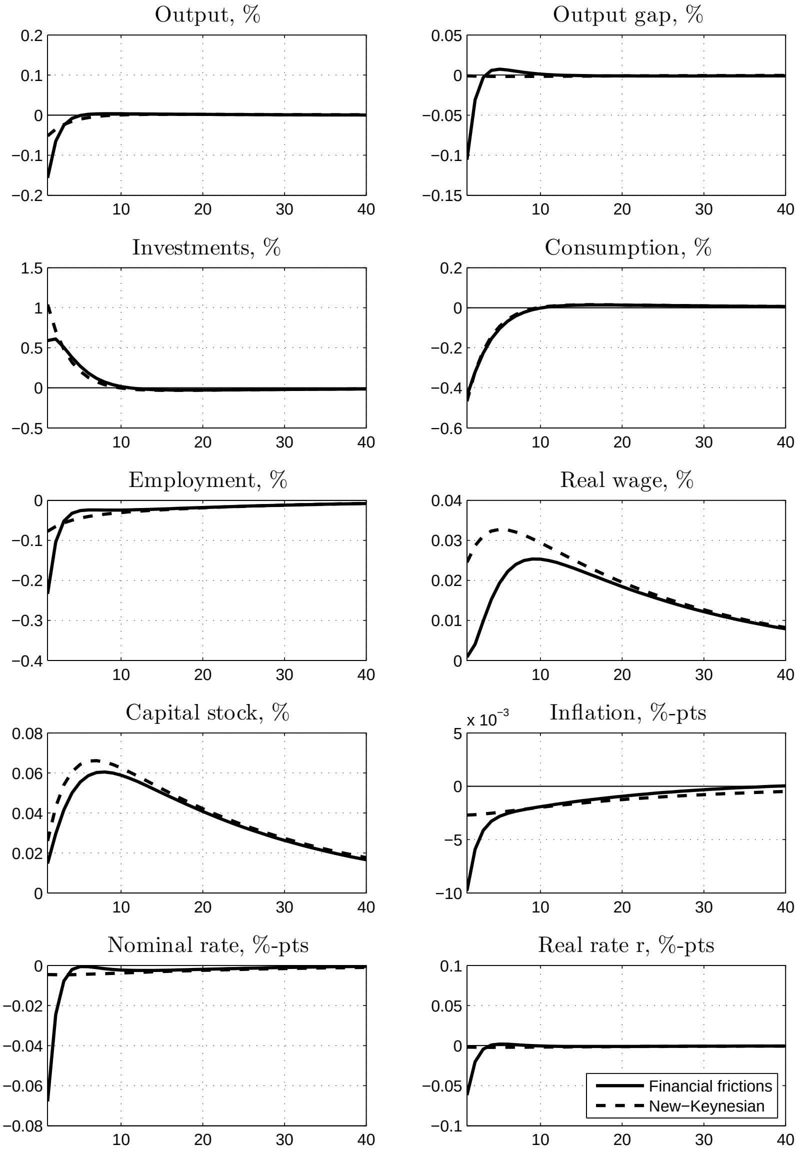

Figure 2: Effects of a 1 % negative demand (preference) shock under baseline Taylor rule. "Financial frictions": baseline model with financial frictions. "New-Keynesian": standard New-Keynesian model without financial frictions, nested within the "financial frictions" model.

(a negative 1 % preference shock), which decreases consumption and increases saving by the household. Again, the reaction of the economy where financial frictions are present is more dramatic than that of the standard New-Keynesian economy. The reason is again that investments are not able to adjust enough to attain the efficient level of investment because of the imperfect credit intermediation.

5.2 Dynamics under simple policy rules

Next, I look more closely at the dynamics of the financial sector under the two policy rules. Figure 3 shows the policy responses to a negative productivity shock in the economy with financial frictions. The shock is inflationary and produces a positive output gap, so that monetary policy responds by raising the nominal interest rate.

When the macroprudential policy tool is also active, it seeks to stabilise credit intermediation. The adverse shock triggers subsidies to lending as there is downward pressure, and as a consequence credit falls very little. This leads investments also fall initially less than without the tax. As a consequence, the impact on lending is almost perfectly neutralised, and investments and output fall less than when the leverage tax is inactive. This, however, is counterproductive when the economy is hit by a productivity shock, as proper economic adjustment – closing the output gap – would require reducing investments to adapt to the decreased productivity level. As a consequence, both inflation and output gap outcomes are worse than without the tax, and the monetary policy has to counteract the macroprudential policy by raising the nominal interest rate more.

Next, Figure 4 shows the policy response to an adverse demand shock. The reduced demand increases savings, which channel into increased investments. Aggregate output, however, falls. This shock is deflationary and produces a negative output gap. The increased savings induce an increase in deposits, which stimulates lending.

Now, if the macroprudential tool is active, it seeks to stabilise lending by taxing the banks, which dampens the increase in investment and further depresses output. Consequently, the outcome is again worse than if the tax were inactive, as savings are not fully intermediated into investment.

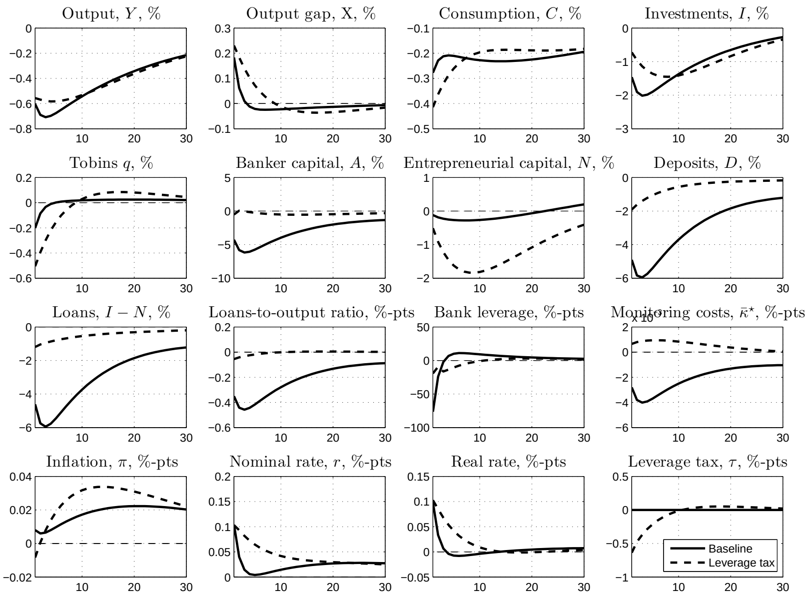

Figure 3: Policy response to a one-standard-deviation adverse productivity shock. “Baseline”: the financial frictions model with Taylor rule only; inactive leverage tax. ”Leverage tax”: the financial frictions model with both policy rules active.

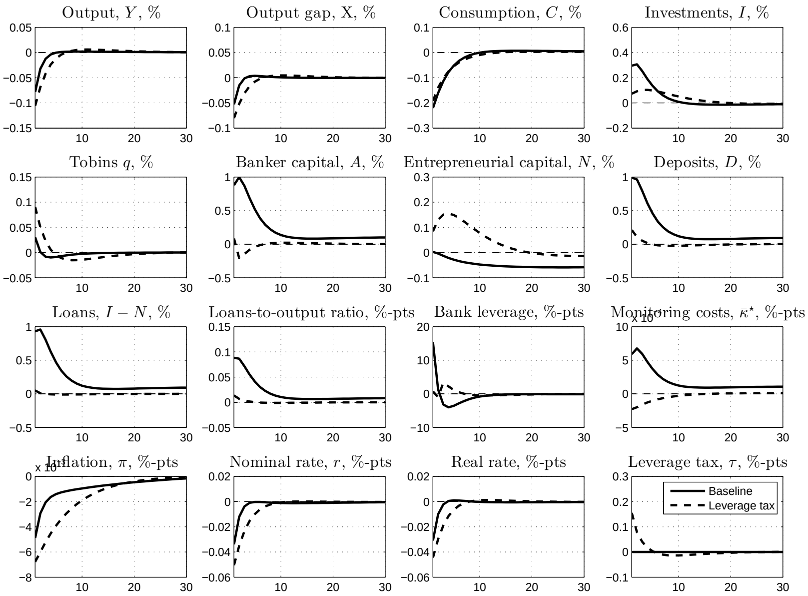

Figure 4: Policy response to a one-standard-deviation adverse demand (preference) shock. “Baseline”: the financial frictions model with Taylor rule only; inactive leverage tax. ”Leverage tax”: the financial frictions model with both policy rules active.

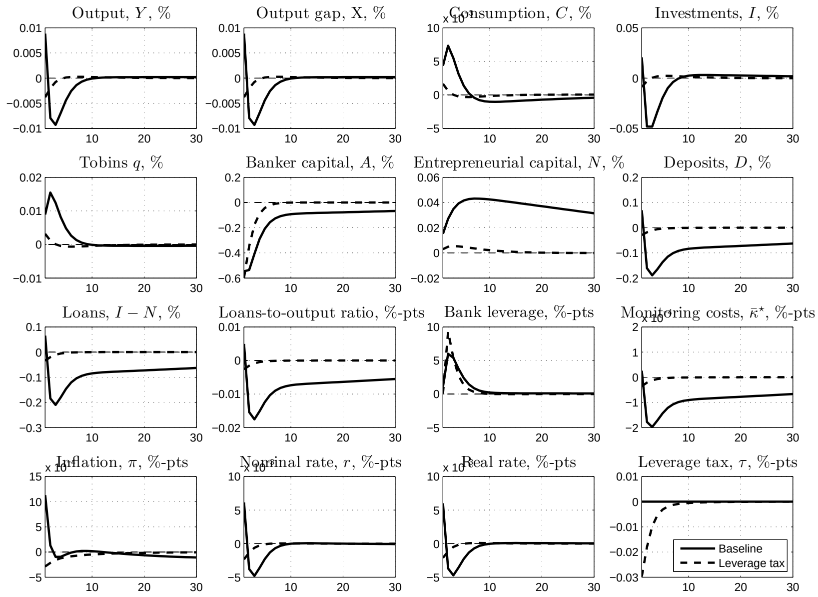

Figure 5: Policy response to a one-standard-deviation adverse bank capital shock. "Baseline": the financial frictions model with Taylor rule only; inactive leverage tax. "Leverage tax": the financial frictions model with both policy rules active.

Monetary policy has to react by further lowering the interest rate to stimulate investment.

These two scenarios illustrate how such a macroprudential policy tool, which aims at stabilising credit intermediation in face of disturbances in the economy, can be very counterproductive when real shocks arise either from the supply or the demand side of the economy. The reason is that such financial stabilisation artificially supports lending and investments, when they should rather be let to adjust to the business cycle. The monetary policy then seeks to undo the macroprudential policy by counteracting it with the nominal interest rate.

In contrast, when the shock arises in the financial sector, the macroprudential policy tool can be helpful. Figure 5 shows the policy responses to a negative shock to bank net worth. Such a shock results in a deterioration of bank capital, which hinders the banks' ability to monitor investment projects.

This in turn worsens the moral hazard problem, discourages depositors, and leads to higher requirements of entrepreneurial capital. The decrease in lending translates into decreased investments and output.

However, the shock is also inflationary, because the drop in investments implies an increase in the real price of capital, which in turn encourages households to subsitute savings for consumption. When only conventional monetary policy is active, this results in an initial increase of the inflation rate. A policy trade-off thus arises between stabilising inflation and output gap. The shock also leads to a persistently lower level of bank capital and lending, because it takes time for banks to re-accumulate net worth.

Now, if the leverage tax is active, the macroprudential policy can support the banks and stabilise credit intermediation, which dampens the effect of the financial shock to real economic activity considerably. In particular, the impact of the shock on inflation is negative, as the shock's effect on the real price of capital is dampened. As the inflationary pressure is removed, monetary policy, supported by macroprudential policy, can instead act on the negative output gap and decrease the interest rate. In addition, bank capital levels are restored much more quickly thanks to the subsidy. In a sense, the policymaker "bails out" banks by providing more capital. The availability of two separate policy tools removes the policy trade-off.

This shows that when there are shocks arising in the financial sector itself, there are benefits to a separate macroprudential tool. However, it can be counterproductive in stabilising fluctuations caused by shocks arising from outside, but affecting, the financial sector. This also highlights the importance of credit intermediation as a channel through which the economy adjusts to real shocks by adapting the level of investments.

These simple examples demonstrate that there is scope for a separate macroprudential tool in dealing with financial market disturbances, but also a need to identify the sources of business cycle fluctuations, as well as to properly coordinate the activation and use of these two policy tools.

In the next section, I look more carefully at the coordination of the two policies. I compute the optimal Ramsey policy with one instrument only – the nominal interest rate – and compare it to the optimal Ramsey policy with two instruments, which jointly optimises both policies.

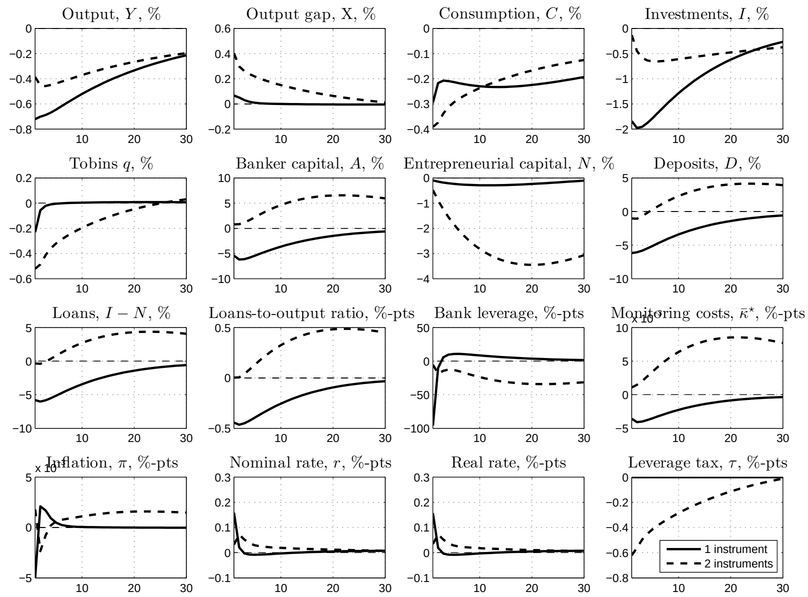

Figure 6: Effects of a one-standard-deviation negative total factor productivity shock, under Ramsey policy

5.3 Jointly optimal policy

This section presents the dynamics of the economy under jointly optimal monetary and macroprudential policies.

Solving the Ramsey-optimal policy consists of finding the path for the policy instruments that maximises the household's welfare, subject to the equilibrium conditions of the economy. In this case, the two policy instruments are the nominal interest rate and the leverage tax. Details of the Ramsey problem are given in Appendix B.

As a benchmark, I deactivate the leverage tax ($\tau_t = 0$ in all periods), and solve for the Ramsey-optimal monetary policy with the nominal interest r_t rate as the policy instrument. Then, I solve for the jointly optimal policy with both instruments in use. Note that the one-instrument Ramsey problem, where the tax rate is constrained to zero, is nested within the two-instrument one, so that by definition household must always be at least as well off under the two-instrument regime as under the one-instrument regime.

Figure 6 shows the response to a negative productivity shock. The shock causes output and investments to fall. It is also inflationary, as the marginal cost of the firm increases. The shock decreases the rental rate of capital, which in turn pushes down the real price of capital, q_t. Through this channel, the shock propagates to the financial sector: as q_t erodes, the net worth of both the bank and the entrepreneur decreases, which negatively affects lending.

Now, if the Ramsey planner only has one policy instrument, the optimal response is to raise the interest rate to push down both inflation and output to adjust to the decreased productivity. This is the standard policy response in New Keynesian literature.

In contrast, when the planner has two instruments, the optimal response consists of raising the interest rate and setting a negative leverage tax, or in other words subsidising lending as there is downward pressure in investments. As a result, both investments and output fall less, creating a more persistent positive output gap. As bank capital is subsidised, lending falls less and actually increases after the first few periods above its steady state level. This joint policy trades off some current consumption for more investments, but consumption recovers more quickly to its steady state levels than under the single instrument policy.

It is noteworthy to discuss the financial incentives under the joint monetary and macroprudential policy. Notice that monitoring cost, or equivalently monitoring intensity, increases under the two-instrument regime. It measures the extent of the moral hazard problem: when the tax is active, the cost is increased, which means banks use more resources in monitoring, and entrepreneurs' incentives for misbehaviour are reduced. This means that less entrepreneurial net worth is needed for investments, and more deposits can be attracted. The availability of both instruments allows to dampen the agency cost, which monetary policy alone cannot do.

Next, Figure 7 shows the Ramsey policy response to an adverse demand shock. The shock decreases demand for consumption, and households substitute consumption for leisure. As a result, savings (deposits) increase, which increases lending and investments. Again, when both policy instruments are in use, the leverage tax and the nominal interest rate move in

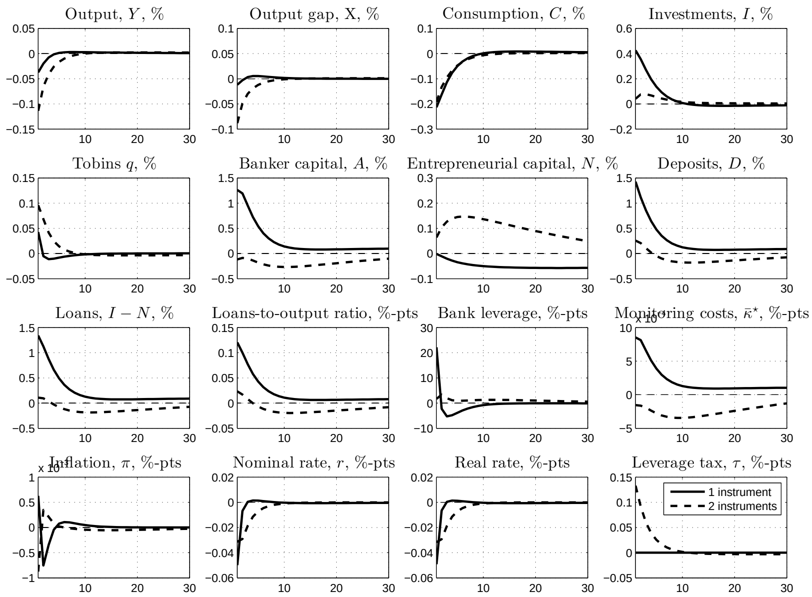

Figure 7: Effects of a one-standard-deviation negative preference shock, under Ramsey policy.

opposite directions. Now, the financial markets are stabilised by taxing the banks to discourage increasing lending. This encourages to consume more and compensates for the adverse demand shock, allowing consumption to recover slightly faster. But this makes output fall more, which forces the planner to decrease the interest rate more to compensate for the tax.

Finally, Figure 8 shows the response to a negative shock to bank capital. Now, it is clear that the two policies do not counteract each other. The jointly optimal policy response might seem somewhat counter-intuitive at first glance: it consists of first taxing the banks that have just suffered a negative shock (with $\tau_t > 0$ in the initial periods after the shock), and then switching to subsidising them.

The mechanism is the following. The bank capital shock decreases monitoring resources, which makes the household less willing to deposit savings in the bank. The decreased supply of funds increases the real price of capital, which makes consumption relatively cheaper for households. As a consequence, households prefer to consume more rather than save, and substitute

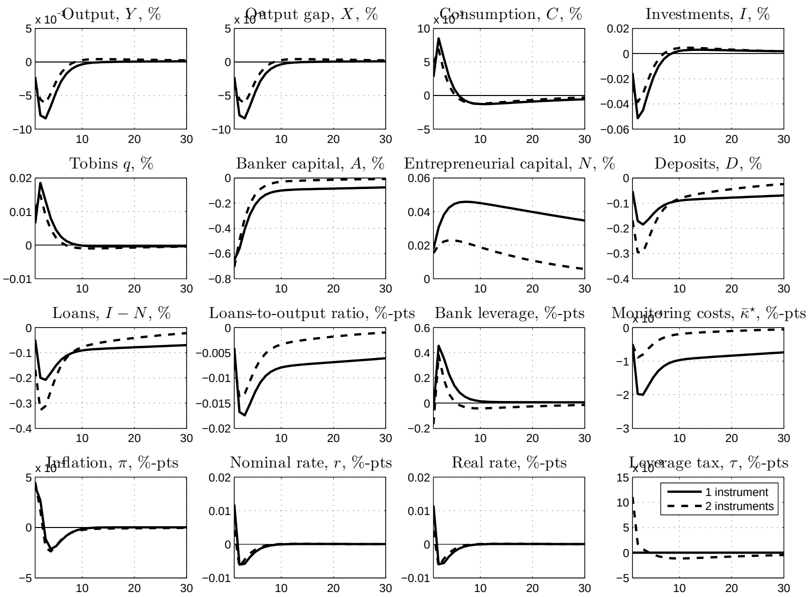

Figure 8: Effects of a one-standard-deviation negative bank capital shock, under Ramsey policy.

current consumption for future consumption. The tax, on the other hand, pushes down the price of capital. After the initial periods, where households prefer to consume, they have to start saving, at which point the macroprudential policy switches to subsidising the banks to support lending. Thus when the tax is active, there is less substitution of consumption for savings, investments fall less, and bank capital, lending, and output recover more quickly. As a result, the monetary policy does not have to react as strongly to stabilise the output gap.

The analysis in this section supports the discussion of the optimal policy responses in Section 5.2. Having a second instrument at hand is useful only when stabilising the economy after a financial shock. The bank capital shock erodes the bank's resources and worsens the agency problem, which leads to decreased lending. The monetary policy response to this would be to decrease the nominal interest rate to decrease the cost of funding of the bank and stimulate lending.

On the other hand, the bank capital shock is initially inflationary because

Model	Policy	Welfare cost (%)	σ_π	σ_x
NK	Ramsey	-	0.0000	0.0000
FF	Ramsey 2	0.31	0.0001	0.0089
”	Ramsey 1	0.37	0.0001	0.0010
”	Rules 1	0.38	0.0013	0.0022
”	Rules 2	0.40	0.0017	0.0039

Table 3: Consumption-equivalent welfare costs under different policies, relative to Ramsey policy regime in the New Keynesian benchmark model. NK refers to the standard New Keynesian model without financial frictions, and FF to the model with the financial friction. NK Ramsey: benchmark policy. Ramsey 2: two-instrument Ramsey policy. Ramsey 1: single-instrument Ramsey policy. Rules 2: policy rules for interest rate and leverage tax. Rules 1: policy rule for interest rate, leverage tax inactive. σ_π: standard deviation of inflation. σ_x: standard deviation of output gap.

of the increase in real capital price. The monetary policy should respond to the inflationary pressure by raising the interest rate. There exists thus a policy trade-off in the face of such a financial shock, and monetary policy alone cannot mitigate the agency problem in credit intermediation while at the same time fighting inflation. The macroprudential policy takes care of reducing the inflationary pressure by initially bringing down the price of capital, after which it can stimulate lending by subsidising the banks.

5.4 Welfare analysis

In this section, I evaluate the performance of the different policy regimes. I compute the welfare cost associated with each policy as consumption-equivalent amounts relative to a benchmark policy. The welfare evaluation follows the strategy described in Schmitt-Grohé and Uribe (2006). The details of the derivation of the welfare measure are outlined in Appendix C.

The consumption-equivalent welfare cost is defined as the fraction of consumption that the household must give up under the benchmark policy regime, in each period, to be indifferent between the benchmark policy and the policy it is being compared to. A positive cost indicates that the household is better off under the benchmark policy.

Table 3 reports the welfare costs of the different policy regimes. The benchmark policy to which the others are compared is the Ramsey-optimal policy in the standard New Keynesian economy, where the financial friction is absent. The welfare cost can thus be interpreted as the cost imposed by the additional friction in the financial sector, which even Ramsey-optimal policies cannot completely offset. In addition, the fourth and fifth columns of Table 3 display the standard deviations of inflation and output gap under the different policy regimes.

Notably, it is no longer optimal to completely stabilise inflation and output gap, as it is in the standard New Keynesian case. The standard deviations of inflation and output gap are close to, but not equal to zero in neither of the Ramsey policy regimes under financial frictions.

The two-instrument Ramsey-policy generates the highest welfare for the household. The single-instrument Ramsey problem, where the leverage tax is constrained to be zero in all periods, is nested within the two-instrument problem, and can by definition perform at most as well as the unconstrained two-instrument problem. Interestingly, when there are financial frictions in the economy, it is only optimal to stabilise inflation, but not the output gap, as shown in the second row of the table.

The rule-based policies do not fall far behind in welfare levels compared to the two Ramsey policies. The economy where both an interest rate rule and a rule-based leverage tax is in use fares the worst in terms of household welfare. As discussed in Section 5.2, the procyclical leverage tax is counterproductive except when stabilising financial shocks. This is confirmed by the fact that inflation is more volatile when the tax rule is active than when it is not. It is thus not surprising that when such a rule is always active, it is detrimental for household welfare.

6 Concluding remarks

This paper investigates the policy implications of jointly setting monetary and macroprudential policies when there are important financial frictions in the economy. The framework is otherwise a standard New Keynesian one, with an additional friction arising from agency costs in financial intermediation.

I study the effects of an active procyclical leverage tax tool that aims at stabilising the loans-to-output ratio in the economy, which is a measure of indebtedness. It is a simple proxy for the stability of the financial system. The leverage tax is a fiscal policy tool that, while stylised, mimics a bank resolution fund. In "good times", the banks pay a fraction of their total assets to restrict their leverage, and in downturns, the government subsidises credit intermediation in a way that lets bank leverage increase and stimulates lending. The dynamics created by the leverage tax are similar to a countercyclical capital ratio regulation on banks, as discussed for example in Christensen et al. (2011), but has the benefit of keeping the optimal financing problem of the firm unconstrained.

The first important finding is that optimal monetary policy alone can stabilise the economy in face of real demand or supply shocks. Using an optimal mix of interest rate and macroprudential policies trades off output gap stability for a similar level of inflation variance, compared to optimising monetary policy only. However, the single-instrument Ramsey policy cannot offset fluctuations in agency costs in the financial markets.

On the other hand, if there are important fluctuations arising from financial shocks, the availability of a separate macroprudential tool enhances the effectiveness of policy in stabilising the economy. The policy supporting credit intermediation can remove inflationary pressures and leave the monetary policy to deal with stabilising the output gap only. When the fluctuations are caused by demand or supply shocks to the real economy, the rule-based monetary policy and the macroprudential policy can counteract each other, as the leverage tax creates an additional friction on the proper adjustment of investments.

Finally, the analysis reveals that having a rule for macroprudential policy that is active at all times is likely to be counter-productive, suggesting that the macroprudential policy should rather be used as a discretionary tool to stabilise financial shocks only, and left inactive in the face of shocks arising from the real economy.

In summary, the sector of origin and the cause of cyclical fluctuations in the economy matter a great deal for the appropriate policy mix to be used. This implies that there are considerable gains from properly coordinating the use of macroprudential policy with conventional monetary policy, and suggests that it should be a discretionary policy to be activated when needed.

The limitations of the present framework relate to the fact that it is a representative agent model without default. Thus, the “stability” of the financial system has to be interpreted as the credit conditions implied by the agency problem. Questions related to systemic risk or financial contagion cannot be analysed here. A macroprudential policy should, in this context, be understood as one that seeks to minimise the agency costs in credit intermediation to guarantee that investments reach their efficient level.

A Summary of the model

A.1 The dynamic equilibrium conditions

This section summarises the dynamic model equations.

A.1.1 The macro block

The household's optimality conditions are:

$$w_t = \frac{\chi L_t^{\theta}}{U_C(C_t, L_t)} \qquad \text{(Labour supply)}$$

$$1 = \beta E_t \left[\frac{U_C(C_{t+1}, L_{t+1})}{U_C(C_t, L_t)} \frac{1 + r_t}{\pi_{t+1}} \right] \qquad \text{(Bond Euler eq.)}$$

$$q_t = \beta E_t \left[\frac{U_C(C_{t+1}, L_{t+1})}{U_C(C_t, L_t)} (r_{t+1}^K + (1 - \delta) q_{t+1}) \right] \qquad \text{(Capital Euler eq.)}$$

where $U_C(C_t, L_t) = Z_t^c \left[\frac{1}{1-b}(C_t - bC_{t-1}) \right]^{-\sigma}$ and $\log Z_t^c = \phi_c \log Z_{t-1}^c + \epsilon_t^c$, $\epsilon_t^c \sim N(0, \sigma_c^2)$, i.i.d.

The symmetric equilibrium conditions of the intermediate production sector are:

$$Y_t = K_t^{\alpha} (Z_t L_t)^{1-\alpha} \qquad \text{(Production technology)}$$

$$\frac{r_t^K}{w_t} = \frac{\alpha L_t}{(1 - \alpha) K_t} \qquad \text{(Relative factor price)}$$

$$\psi_t = \left(\frac{r_t^K}{\alpha} \right)^{\alpha} \left(\frac{w_t}{Z_t (1 - \alpha)} \right)^{(1-\alpha)} \qquad \text{(Real marginal cost)}$$

$$P_t^* = \frac{\varepsilon}{\varepsilon - 1} \frac{E_t \sum_{k=0}^{\infty} \omega^k Q_{t,t+k} \psi_{t+k|t} Y_{t+k|t} P_{t+k}^{\varepsilon+1}}{E_t \sum_{k=0}^{\infty} \omega^k Q_{t,t+k} Y_{t+k|t} P_{t+k}^{\varepsilon}}$$

(Optimal pricing decision)

where $Q_{t,t+k} \equiv \beta^k \frac{U_C(C_{t+1}, L_{t+1})}{U_C(C_t, L_t)} \frac{P_t}{P_{t+k}}$ and $\log Z_t = \phi \log Z_{t-1} + \epsilon_t$, $\epsilon_t \sim N(0, \sigma^2)$, i.i.d.

Furthermore, the optimal pricing decision can be reformulated as:

$$P_t^* = \frac{\varepsilon}{\varepsilon - 1} P_t \, \frac{E_t \sum_{k=0}^{\infty} \omega^k \, Q_{t,t+k} \, \psi_{t+k|t} \, Y_{t+k|t} \, \pi_{t+k}^{\varepsilon+1}}{E_t \sum_{k=0}^{\infty} \omega^k \, Q_{t,t+k} \, Y_{t+k|t} \, \pi_{t+k}^{\varepsilon}}.$$

The numerator of this expression can be expressed recursively as:

$$\text{Num}_t = \psi_t Y_t + \omega (1 + r_t)^{-1} E_t \, \pi_{t+1}^{\varepsilon+1} \, \text{Num}_{t+1},$$

and the denominator as:

$$\text{Denom}_t = Y_t + \omega (1 + r_t)^{-1} E_t \, \pi_{t+1}^{\varepsilon} \, \text{Denom}_{t+1},$$

which allows expressing the optimal price relative to the aggregate price level recursively (for computational convenience) as:

$$\frac{P_t^*}{P_t} = \frac{\varepsilon}{\varepsilon - 1} \frac{\text{Num}_t}{\text{Denom}_t}.$$

The aggregate dynamic equilibrium conditions are:

$$\begin{aligned}
Y_t &= (C_t + I_t + G_t) s_t && \text{(Aggregate consistency constraint)} \\
K_{t+1} &= I_t + (1 - \delta) K_t && \text{(Capital accumulation)} \\
P_t &= \left[\omega P_{t-1}^{1-\varepsilon} + (1 - \omega)(P_t^*)^{1-\varepsilon} \right]^{\frac{1}{1-\varepsilon}} && \text{(Aggregate price level)} \\
\pi_t &= \left[\omega + (1 - \omega) \left(\frac{P_t^*}{P_{t-1}} \right)^{1-\varepsilon} \right]^{\frac{1}{1-\varepsilon}} && \text{(Inflation dynamics)} \\
1 &= \omega \pi_t^{\varepsilon - 1} + (1 - \omega) \left(\frac{P_t^*}{P_t} \right)^{1-\varepsilon} && \text{(Price dispersion)}
\end{aligned}$$

where the correction for price dispersion is $s_t = (1 - \omega)(P_t^*)^{-\varepsilon} + \omega \pi_t^{\varepsilon} s_{t-1}$.

A.1.2 The financial block

The aggregate equilibrium in the financial sector is described by the following equations.

$$\kappa_t^* = \frac{\gamma \rho_t}{1 + (1-\tau_t)\frac{p_H}{\Delta p}\left(\frac{1}{1+r_t} - \frac{1}{1+r_t^a}\right)} \qquad \text{(Optimal monitoring)}$$

$$b(\kappa_t^*) = \Gamma(\kappa_t^*)^{-\frac{\gamma}{1-\gamma}} \qquad \text{(Private benefit)}$$

$$\rho_t = (1-\tau_t)\frac{q_t p_H R}{1+r_t} - 1 \qquad \text{(Net pledgeable income)}$$

$$g_t = (1-\tau_t)\frac{p_H}{\Delta p}\frac{b(\kappa_t^*)}{1+r_t} - (1-\gamma)\rho_t$$

(Entrepreneur's inverse leverage ratio)

$$R_t^e = \frac{b(\kappa_t^*)}{q_t \Delta p} \qquad \text{(Entrepreneur's return share)}$$

$$R_t^b = \frac{\kappa_t^*}{q_t \Delta p} \qquad \text{(Banker's return share)}$$

$$R_t^w = R - R_t^e - R_t^b \qquad \text{(Worker's return share)}$$

$$1 + r_t^a = \frac{p_H}{\Delta p}\kappa_t^* \frac{I_t}{A_t} \qquad \text{(Return on bank capital)}$$

$$1 + r_t^e = \frac{p_H}{\Delta p} b(\kappa_t^*) \frac{I_t}{N_t} \qquad \text{(Return on entrepreneurial capital)}$$

$$I_t = \frac{N_t}{g_t} \qquad \text{(Investment size)}$$

$$N_{t+1} = \lambda^e (1 + r_t^e) \frac{r_{t+1}^K + (1-\delta) q_{t+1}}{q_t} N_t$$

(Accumulation of entrepreneur's net worth)

$$A_{t+1} = Z_t^b \lambda^b (1 + r_t^a) \frac{r_{t+1}^K + (1-\delta_t) q_{t+1}}{q_t} A_t$$

(Accumulation of banker's net worth)

where $\log Z_t^b = \phi_b \log Z_{t-1}^b + \epsilon_t^b$, $\epsilon_t^b \sim N(0, \sigma_b^2)$, i.i.d.

A.1.3 Government policy

Finally, the model is closed by the Taylor rule for the nominal interest rate, and the rule for the macroprudential leverage tax.

$$1 + r_t = \frac{1}{\beta} \pi_t^{\phi_\pi} \tilde{x}^{\phi_x} \qquad \text{(Taylor rule)}$$

$$1 + \tau_t = \tilde{\Upsilon}_t^{\phi_\Upsilon} \qquad \text{(Leverage tax rule)}$$

$$G_t = \tau_t (A_t + D_t) \qquad \text{(Government budget constraint)}$$

Here, $\tilde{x}_t \equiv \frac{Y_t}{Y_t^e}$ is the output gap and $\tilde{\Upsilon}_t \equiv \frac{(I_t - N_t)/Y_t}{(I-N)/Y}$ is the deviation of the loans-to-output ratio from its steady state value, or the "credit gap".

A.2 Deterministic steady state

The deterministic steady state of the model is as follows. It is assumed that a steady state employment subsidy is in place such that $\mu = 1$, so that the steady state is not distorted by the monopolistic competition.

A.2.1 The macro block

The steady state of the macro block of the model is:

$$1 + r = \frac{1}{\beta}$$

$$P^* = P = 1$$

$$\pi = 1$$

$$s = 1$$

$$\psi = 1$$

$$q = \frac{1 + \rho}{\beta p_H R}$$

$$r^K = q(r + \delta)$$

$$w = (1 - \alpha) \left(\frac{r^K}{\alpha} \right)^{\frac{\alpha}{\alpha - 1}}$$

$$K = \left[\left(\frac{r^K}{\alpha} \right)^{\frac{\theta + \alpha}{\alpha - 1}} \frac{1 - \alpha}{\chi} \left(\frac{r^K}{\alpha} - \frac{\delta}{p_H R} \right)^{-\sigma} \right]^{\frac{1}{\theta + \sigma}}$$

$$L = K \left(\frac{r^K}{\alpha} \right)^{\frac{1}{1-\alpha}}$$
$$Y = \frac{r^K K}{\alpha}$$
$$I = \frac{\delta K}{p_H R}$$
$$C = Y - I - G$$
$$G = 0 \quad (\tau = 0)$$
$$Z = Z^c = Z^b = 1$$

The steady state is non-distorted and identical to the efficient steady state (where prices are assumed flexible and there is no financial friction in investment) when $q = 1$. The efficient steady state can thus be replicated by imposing a steady state investment subsidy on the gross return of the investment project, R. Denote this subsidy by $1 + \varsigma$. Then, the subsidy needed to replicate the efficient steady state is:

$$q = \frac{1+\rho}{\beta p_H R(1+\varsigma)} = 1 \quad \Leftrightarrow \quad \varsigma = \frac{1}{\beta} - 1 + \frac{\rho}{\beta} = r + \frac{\rho}{1+r}.$$

A.2.2 The financial block

The steady state of the financial block of the model is:

$$1 + r^a = \frac{\beta}{\lambda^b}$$
$$1 + r^e = \frac{\beta}{\lambda^e}$$
$$R^b = \frac{c^*}{q\Delta p}$$
$$R^e = \frac{b(c^*)}{q\Delta p}$$
$$R^w = R - R^e - R^b$$

$$
\begin{aligned}
c^* &= \left(\Gamma \frac{\gamma}{1-\gamma}\right)^{1-\gamma} \left(\frac{\beta - \frac{\lambda^e}{\beta}}{\beta - \frac{\lambda^b}{\beta} + \frac{\Delta p}{p_H}}\right)^{1-\gamma} \\
b(c^*) &= \Gamma (c^*)^{-\frac{\gamma}{1-\gamma}} \\
\rho &= \frac{c^*}{\gamma}\left[1 + \frac{p_H}{\Delta p}\left(\beta - \frac{\lambda^b}{\beta}\right)\right] \\
g &= \beta \frac{p_H}{\Delta p} b(c^*) - (1-\gamma)\rho \\
A &= \frac{\lambda^b}{\beta}\frac{p_H}{\Delta p} c^* I \\
N &= \frac{\lambda^e}{\beta}\frac{p_H}{\Delta p} b^* I
\end{aligned}
$$

B The Ramsey problem

The problem of the Ramsey planner can be formulated as follows. Let y_t be a vector containing the n endogenous variables of the economy, including the planner's policy instruments, and u_t the vector of exogenous variables. The agents in the economy optimise taking the planner's decision variables (the policy instruments) as given. The equilibrium of the private economy is described by the m first-order conditions and transition equations:

$$E_t[f(y_{t-1}, y_t, y_{t+1}, u_t)] = 0.$$

This leaves $n - m$ policy instruments for the planner.

The Ramsey planner chooses the values of the policy instruments in each period to maximise household welfare, subject to the economy's equilibrium conditions:

$$
\begin{aligned}
&\max_{\{y_\tau\}_{\tau=t}^{\infty}} E_\tau \sum_{\tau=t}^{\infty} \beta^{\tau-t} U(C_\tau, L_\tau) \\
&s.t. \quad E_\tau[f(y_{\tau-1}, y_\tau, y_{\tau+1}, u_\tau)] = 0 \quad \forall\, \tau \in \{\ldots, t-1, t, t+1, \ldots\}.
\end{aligned}
$$

In other words, the Ramsey planner chooses a competitive equilibrium that maximises household welfare.

C The welfare measure

The welfare cost of the different policy measures are computed as consumption equivalent costs relative to a benchmark policy as described in Schmitt-Grohé and Uribe (2006).

Define the welfare under the benchmark Ramsey-optimal policy, conditional on the state of the economy at time zero, as

$$V_0^R = E_0 \sum_{t=0}^{\infty} \beta^t U(C_t^R, L_t^R),$$

where C_t^R and L_t^r denote the plans for consumption and hours worked under the benchmark policy regime.

Similarly, define the conditional welfare under an alternative policy plans as

$$V_0^A = E_0 \sum_{t=0}^{\infty} \beta^t U(C_t^A, L_t^A).$$

Assume that at time zero, all variables are equal to their steady-state values. Since the steady state of the model is undistorted and unaffected by the different policy regimes, the initial state of the economy is the same for the benchmark and the alternative policies.

Next, denote by x the consumption-equivalent conditional welfare cost of the alternative policy regime, relative to the benchmark regime. Formally, the cost x is implicitly defined by:

$$V_0^A = E_0 \sum_{t=0}^{\infty} \beta^t U((1-x)C_t^R, L_t^R).$$

Using the CES functional form for periodic utility and solving for x yields:

$$\begin{aligned} V_0^A &= E_0 \sum_{t=0}^{\infty} \beta^t \left[Z_t^c \frac{((1-x)C_t^R)^{1-\sigma}}{1-\sigma} - \frac{\chi (L_t^R)^{1+\theta}}{1+\theta} \right] \\ &= E_0 \sum_{t=0}^{\infty} \beta^t \left[((1-x)^{1-\sigma} - 1) Z_t^c \frac{(C_t^R)^{1-\sigma}}{1-\sigma} \right] + V_0^R \\ \Leftrightarrow \quad x &= 1 - \left[1 + \frac{V_0^A - V_0^R}{E_0 \sum_{t=0}^{\infty} \beta^t Z_t^c \frac{(C_t^R)^{1-\sigma}}{1-\sigma}} \right]^{\frac{1}{1-\sigma}}. \end{aligned}$$

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