

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 there is a financial friction besides the standard nominal friction, the optimal policy can replicate the first-best if the social planner has two separate instruments, one for controlling inflation and one for the investment level. One instrument is not enough to replicate first-best: using monetary policy only is inefficient. When policy follows simple rules instead, 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)).

The main contribution of this research paper 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 find that the first-best optimal outcome can be replicated when a social planner can jointly use both a monetary and a macroprudential instrument. I also compare the performance of rule-based policies to the optimal policies.

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, among others, counter-cyclical 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).

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).

I model macroprudential policy first, in the Ramsey policy problem, as the optimal aggregate bank leverage. The planner sets bank leverage, which determines the aggregate level of investments, jointly optimally with the nominal interest rate. Both instruments aim at maximising the same objective, namely household welfare. By using these two instruments, the planner can replicate the first-best outcome, which is the flexible price real business cycle (RBC) equilibrium.

Then, I compare the constrained optimum to a set of simple rule-based policies, which are more realistically implementable. I first look at an augmented Taylor rule, where the monetary authority also reacts to real asset prices. Then, I analyse conventional Taylor rule policies together with a separate macroprudential tool. One such tool is a cyclical leverage tax on banks that aims at smoothing out credit cycles; another is a cyclical investment tax-and-subsidy scheme on investment project returns, which stimulates financial investment in recessions.

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, a separate macroprudential policy regulating the banking sector can be counterproductive as it tends to hinder proper economic adjustment by creating an additional friction on the adjustment of investments. A unified mandate for the monetary authority, where besides price developments the central bank also pays attention to financial

developments, can however be beneficial.

Most theoretical macroeconomic models that deal with policy issues 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. The Ramsey-optimal policy analysis in this paper supports this view.

The literature on jointly optimising monetary and macroprudential policies is not large. Most authors only look at rule-based policies. 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 mostly 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.

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 presents the calibration and discusses the empirical fit of the model. The main contribution of this paper is presented in Section 4, which discusses the implications of the frictions in the financial sector to the aggregate economy and the Ramsey-optimal policy plans that can

offset the effects of this friction to restore the first-best. Section 5 analyses the aggregate dynamics of the model economy under various disturbances, and Section 6 discusses the welfare implications of different policy regimes. Finally, Section 7 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-consumer¹. 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.

¹The 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.

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.

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:

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

subject to a budget constraint:

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

where C_t is real consumption, B_t are nominal bonds issued by the govern-

ment, 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 substitution, 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:

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

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

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

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

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

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 :

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

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

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

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

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 :

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

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

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:

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

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:

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

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

$$P_t = [\omega P_{t-1}^{1-\varepsilon} + (1-\omega)(P_t^*)^{1-\varepsilon}]^{\frac{1}{1-\varepsilon}}, \quad (14)$$

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

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

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 bank²; 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.

²To 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.

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

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”.

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:

$$i_t - n_t \leq a_t + d_t - \kappa_t i_t \quad (16)$$

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):

$$R \geq R_t^w + R_t^b + R_t^e. \quad (17)$$

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 $\lim_{\kappa \rightarrow \infty} b'(\kappa) = 0$. 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:

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

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

$$q_t p_H R_t^b i_t - \kappa_t i_t \geq q_t p_L R_t^b i_t \quad (20)$$

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

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

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

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

$$R_t^b = \frac{\kappa_t}{q_t \Delta p} \quad (22)$$

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

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

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

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:

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

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

Combining (22) with (26) yields:

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

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

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

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 :

$$i_t = \frac{n_t}{g_t}, \quad (29)$$

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

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

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 ex-

pected 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):

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

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

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

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

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

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 (32):

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

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

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

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 entrepreneur, 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 Aggregation

I focus on the symmetric equilibrium where all projects are monitored at the same intensity κ_t^* given by (34), and the capital structure, given by the ratios of own and external funds to total investment ($\frac{n_t}{i_t}$, $\frac{a_t}{i_t}$ and $\frac{d_t}{i_t}$), is equal across entrepreneurs, bankers and depositors, respectively. Notice the size of the project i_t may vary.

Then, the corresponding aggregate ratios are simply given by

$$\frac{N_t}{I_t} = \frac{n_t}{i_t}, \quad \frac{A_t}{I_t} = \frac{a_t}{i_t}, \quad \frac{D_t}{I_t} = \frac{d_t}{i_t}, \quad (36)$$

where capital letters denote aggregate amounts.

The equilibrium aggregate investment in the economy is determined by

$$\frac{N_t}{I_t} = g(\kappa_t^*), \quad (37)$$

where $g(\kappa_t^*)$ is given by equation (35).

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

$$1 + r_t^{a*} = \frac{1 + \gamma \rho_t \frac{I_t}{A_t}}{(1 + r_t)^{-1} + \frac{\Delta p}{p_H}}. \quad (38)$$

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

$$K_{t+1} = (1 - \delta)K_t + p_H R I_t. \quad (39)$$

Entrepreneurial and bank net worth are defined to evolve according to

$$N_{t+1} = \lambda^e (1 + r_t^e) \frac{r_{t+1}^K + (1 - \delta)q_{t+1}}{q_t} N_t \quad (40)$$

$$A_{t+1} = Z_t^b \lambda^b (1 + r_t^a) \frac{r_{t+1}^K + (1 - \delta)q_{t+1}}{q_t} A_t, \quad (41)$$

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 $1 + r_t^e \equiv \frac{q_t p_H R_t^e I_t}{N_t}$, 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.

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

Finally, the aggregate consistency constraint of the economy is:

$$Y_t = C_t + I_t, \quad (42)$$

where C_t denotes aggregate private consumption and I_t aggregate investment.⁶

To close the model, a monetary policy for setting the nominal interest rate r_t needs to be specified. A macroprudential policy for dealing with the agency cost in financial intermediation is not needed to close the model, but it is required to approximate an efficient equilibrium of the model.

I start by analysing the constrained optimal policies under a social planner's solution in Section 4.3. Then, I look at simple policy rules that can be used to approximate the constrained optimum, detailed in Section 5.3. The policy rules consist of a Taylor-type rule for monetary policy, and a similar rule for macroprudential policy that aims at mitigating the moral hazard problem in the financial sector.

In essence, the policies – whether optimal or not – consists of dealing with the two frictions in the model, the nominal rigidity and the rigidity in investments created by the agency problem in financial intermediation.

2.7 Equilibrium

The competitive equilibrium of the economy is a time path

$$\left\{ C_t, K_t, L_t, I_t, A_t, N_t, D_t, q_t, r_t^K, r_t, \bar{r}_t^{a*}, \bar{r}_t^e, w_t, \psi_t, P_t, P_t^*, R_t^b, R_t^e, R_t^w, \bar{\kappa}_t^*, \tau_t \right\}_{t=0}^{\infty} \quad (43)$$

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.

⁶I assume that the monitoring of investment projects does not consume real resources. If it did, the resource constraint would be $Y_t = C_t + (1 + \kappa_t^*)I_t$. 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.

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

2.8 Timing of events

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

3 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.

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

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 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' overhead 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 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%.

Finally, 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.

4 The constrained optimum

This section discusses the implications of the agency problem in financial intermediation, and analyses the constrained optimal solution under both flexible and sticky prices, when the moral hazard problem is nonetheless present. Optimal policy responses of the Ramsey planner are presented through impulse response analysis, and the efficiency of the optimum is discussed. The efficient first-best optimum, to which the constrained optimal solutions are compared, is the equilibrium of the standard flexible price real business cycle (RBC) model without any friction in financial intermediation. It turns out that if the model economy suffers from both a nominal and a financial friction, the Ramsey planner needs *two* separate instruments to reach an efficient optimum. After the optimal policy analysis, I will compare the results to dynamics under non-optimised simple policy rules in the next section.

4.1 Implications of the financial friction

In addition to the nominal friction arising from staggered price setting, and the inefficiency 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.

Let us focus on the flexible price model. 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 $R_t^c = R_t^b = 0$. 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 flexible price RBC model, where the household’s savings are directly channelled into productive investment. As a consequence, aggregate investment equals household savings in equilibrium: $I_t = D_t$. The RBC 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.

4.2 Constrained optimum in a flexible price economy

This section and the following sections present the model dynamics under Ramsey-optimal policy plans. I approximate the full non-linear model by a first-order Taylor approximation in logs around the deterministic steady state of the model. The Ramsey policy problem then consists of maximising the household’s lifetime welfare (1), conditional on the linearised equilibrium conditions of the model economy.

I discuss 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.

An efficient allocation requires that investments be at the level determined by a perfectly competitive and frictionless economy. Let us for a moment drop the assumption of monopolistic competition and sticky prices, and concentrate on the model where prices are fully flexible and intermediate good production is perfectly competitive, but the moral hazard problem in finan-

cial intermediation is present. The government can replicate the efficient *steady-state* 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.

In order to analyse the constrained optimal dynamic equilibrium, I look at a social planner's problem. The Ramsey policy problem of a social planner is described in technical detail in Appendix B. Assume that the planner cannot remove the moral hazard problem (i.e cannot force $b(\kappa_t) = 0 \forall \kappa_t$), but can set aggregate bank leverage, or equivalently, the level of aggregate investments, to the value that maximises household welfare. This Ramsey policy problem leads to the constrained optimal equilibrium.

The constrained optimum is defined as being efficient when it replicates the flexible price perfect competition outcome, which is the first-best outcome. In the flexible price economy where the financial friction is present, the fluctuation of the real price of capital (q_t) away from unity creates a wedge between the first best and the actual outcome. The value of Tobin's q fixed at unity is a key feature of the flexible price RBC model, which follows from the frictionless adjustment of capital. In order to replicate the first-best, the Ramsey planner thus needs to offset this wedge.

Figure 1 shows the response of the economy to a one-standard-deviation negative productivity shock. The figure illustrates that the constrained optimal solution of the social planner is efficient: the allocation replicates the first-best (unconstrained) optimum, which in this case is the flexible price frictionless outcome, denoted by the solid line in the figure.

The output gap X_t is defined as the gap between actual output in a given model and the output in the flexible price RBC model: $X_t = \frac{Y_t}{Y_t^e}$, where Y_t is the actual output and Y_t^e is the efficient level of output⁷.

In particular, the social planner re-allocates resources between the three parties of the financial contract in such a way as to keep the real price of capital, q_t , fixed at unity. The stabilisation of Tobin's q allows the replicate

⁷The 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.

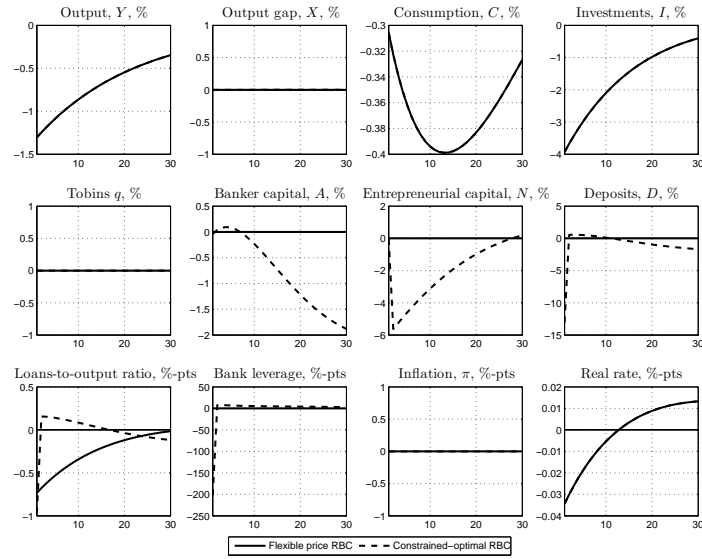


Figure 1: Effects of a one percent negative total factor productivity shock in the RBC model. “Flexible price RBC”: model with fully flexible prices and no financial friction. “Constrained-optimal RBC”: model with fully flexible prices, but with the financial friction.

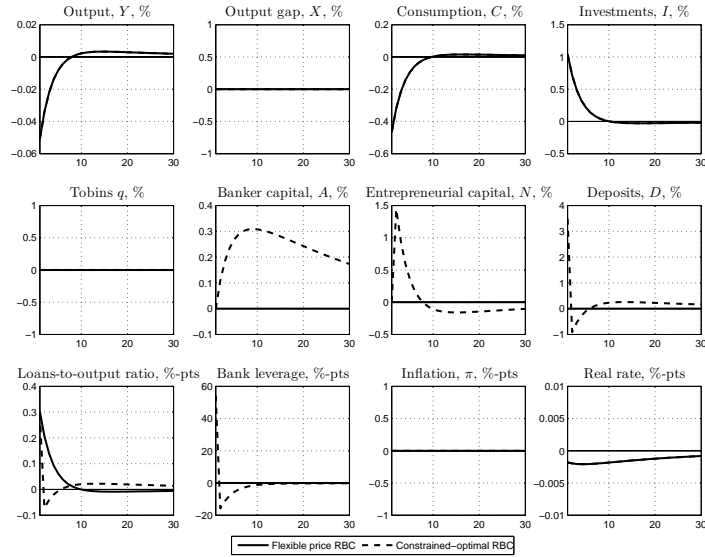


Figure 2: Effects of a one percent negative preference (demand) shock in the RBC model. “Flexible price RBC”: model with fully flexible prices and no financial friction. “Constrained-optimal RBC”: model with fully flexible prices, but with the financial friction.

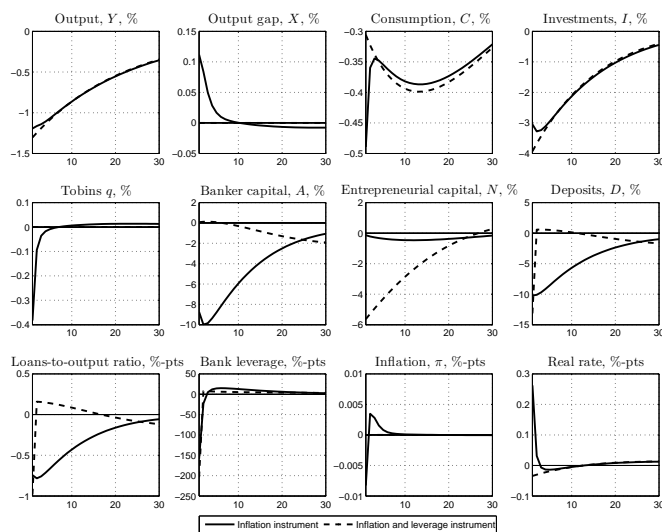


Figure 3: Effects of a one percent negative total factor productivity shock in the New Keynesian model. “Inflation instrument”: model with sticky prices and the financial friction; social planner sets inflation rate. “Inflation and leverage instrument”: model with sticky prices and the financial friction; social planner sets inflation rate and aggregate bank leverage.

the first-best outcome for the aggregate macro variables. An exactly similar logic applies to stabilising the economy after a negative preference shock, shown in Figure 2, and the first-best outcome can again be replicated.

4.3 Constrained optimum in a sticky price economy

Next, let us re-introduce the nominal rigidity into the model. Now, besides the financial friction, there is a second friction – price stickiness – affecting the economy. As was seen in the previous section, the social planner’s solution is efficient when prices are fully flexible, but the financial friction is present, when the planner can optimally set the level of investments.

With both frictions at work, the planner has to offset fluctuations caused not only by the agency problem, but also those caused by price stickiness to achieve efficiency of the constrained optimum. I first look at the case where the planner only has one instrument at use. Namely, the planner controls monetary policy and sets the rate of inflation (or equivalently, the nominal

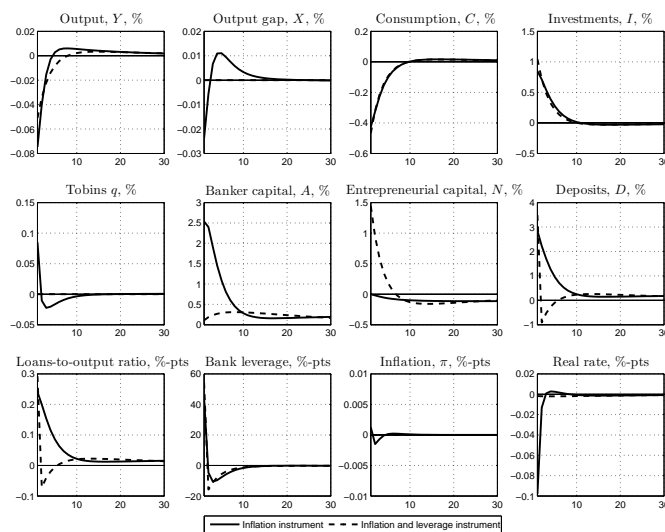


Figure 4: Effects of a one percent negative preference shock in the New Keynesian model. “Inflation instrument”: model with sticky prices and the financial friction; social planner sets inflation rate. “Inflation and leverage instrument”: model with sticky prices and the financial friction; social planner sets inflation rate and aggregate bank leverage.

interest rate) to maximise household welfare.

The solid lines in Figure 3 show the response of the economy to a negative productivity shock, when the social planner optimally sets the inflation rate. With only one instrument, the planner cannot fully offset the shock. The planner sets the inflation rate to zero. However, a positive output gap opens up, while at the same time Tobin’s q drops. The planner is not able to stabilise both with one instrument, as the two move in opposite directions. The presence of two distinct inefficiencies – sticky prices and the financial friction – create a policy trade-off. The constrained optimum when the planner has only one instrument is not efficient, as it does not fully replicate the first best outcome (the flexible price RBC equilibrium).

In contrast, the dashed lines in Figures 3 show the constrained optimal response when the planner has two instruments at hand: inflation rate and the aggregate bank leverage. Now the first best outcome can be replicated, and the constrained optimum is efficient. When the planner has two instruments, one can be used to offset the distortion caused by price stickiness by stabilis-

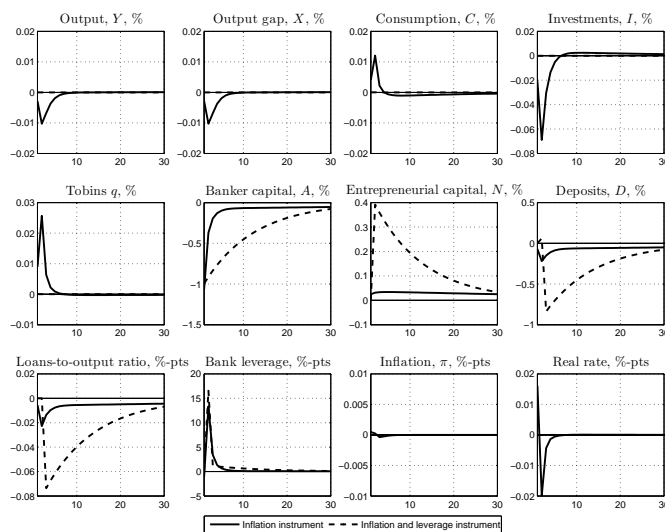


Figure 5: Effects of a one percent negative bank capital shock in the New Keynesian model. “Inflation instrument”: model with sticky prices and the financial friction; social planner sets inflation rate. “Inflation and leverage instrument”: model with sticky prices and the financial friction; social planner sets inflation rate and aggregate bank leverage.

ing inflation, and the other to offset the distortion in financial intermediation by stabilising Tobin’s q , so that the policy trade-off is resolved.

The same applies when the economy is hit by a demand shock or a bank capital shock, as depicted in Figures 4 and 5, respectively. With only one instrument, the planner cannot fully offset the shocks. In both cases, Tobin’s q and the output gap move in opposite directions, causing a policy trade-off. This trade-off can only be resolved by adding a second instrument that can deal with the wedge in real capital price.

In particular, after a bank capital shock, when the planner only controls the inflation rate, the deterioration of bank capital causes a drop in investments and leads to a negative output gap. At the same time, the decrease of capital stock leads to an increase in the real price of capital and causes households to substitute savings for current consumption, which reinforces the drop in investments. In contrast, when the investment instrument is also available, the planner can reallocate resources from the depositors and the banks to the entrepreneurs and stabilise Tobin’s q , as the ability of banks to finance

investments is reduced.

5 Simple policy rules

The Ramsey policy plans described above represent a constrained optimal solution to setting the monetary and macroprudential policies. The Ramsey policy is, however, a rather abstract policy plan that serves as a benchmark for simpler policy plans and as a tool to help understand how the frictions in the model economy should be dealt with.

From the optimal policy analysis, it becomes clear that the policymaker needs (at least) two separate policy instruments in order to stabilise the economy: one to deal with inflation, and one to deal with the financial frictions. A need for separate macroprudential regulation then naturally arises in this context.

In the next sections, I analyse the dynamics of the model economy under various simple policy rules. First, as a benchmark, I look at how the economy performs under a conventional Taylor rule type policy, where the monetary authority reacts to inflation and output gap. This means that there is no macroprudential policy, and the monetary authority is not directly concerned with any financial developments. Then, I consider an augmented Taylor rule, where in addition to inflation and output gap, the central bank also reacts to the real capital price, which in this model is the key channel through which the real economy and the financial markets are linked. Finally, I analyse the dynamics of the model economy where conventional monetary policy is supplemented by an independent macroprudential policy: there is a rule-based policy that deals with financial imbalances, and the central bank only targets inflation and output gap using a standard Taylor rule.

5.1 Policy mandates

As was seen in the previous section, the stabilisation of the economy requires in general two distinct policy tools to deal with the two separate frictions. The key to stabilising the economy, i.e. to close the output gap in order to replicate the first-best flexible price allocation, is to stabilise inflation on

	Policies	Instruments
<i>(i)</i>	MP	Taylor rule
<i>(ii)</i>	MP + MR	Augmented Taylor rule
<i>(iii)</i>	MP + MR	Taylor rule + leverage tax
<i>(iv)</i>	MP + MR	Taylor rule + investment subsidy

Table 3: Policy regimes under simple rules. MP: monetary policy; MR: macroprudential policy. Instruments: policy instruments at use.

the one hand, and Tobin’s q on the other hand. A potential trade-off arises, because Tobin’s q moves in the opposite direction from the output gap.

The Ramsey policies assume that the policymakers act under commitment, observe all variables in the economy, and can set the instrument values to maximise the household’s lifetime welfare. In a more realistic model, the policymakers use simple policy rules, which react to a few key variables. Several possible combinations of policy rules are considered here. I investigate how closely the optimal policy plans can be approximated with these policy rules.

Based on the Ramsey policy analysis, the question arises: what is the most suitable policy mandate – one where the monetary authority jointly deals with both price and financial stability, or one where distinct authorities deal with each friction? The Ramsey planner, by jointly setting two instruments, can replicate the first best. The responses to both inflation and financial imbalances are perfectly coordinated in the sense that they are jointly optimal, and set to maximise the same objective, the household welfare. However, in the absence of such a Ramsey planner, it is not immediately clear what the policy targets should be and how the policy mandates should be divided.

The simple policy rule set-ups simulate four distinct policy regimes: *(i)* a regime where only conventional monetary policy that aims at price stability is conducted; *(ii)* a regime where the monetary authority deals with both price stability and financial stability; and two different regimes where there are two independent policymakers, one for the monetary policy and one for the macroprudential policy, each with their own policy targets, *(iii)* and *(iv)*.

The next question is what the specific macroprudential policy should be, if monetary policy is not concerned with financial stability directly as in cases *(iii)* and *(iv)* described above. There could be many ways to stabilise

Tobin's q . Two specific tools for financial stability are considered: a leverage tax/subsidy on banks, and a tax/subsidy scheme on investment returns. The former restricts bank lending in an expansion and supports it in a recession by controlling their leverage, and thus aims at stabilising credit intermediation. The latter subsidises the returns of the investment projects when they are too low, i.e. when Tobin's q is below unity and thus stimulates investments, and taxes them when investment demand is too high and Tobin's q is above unity. These policies are detailed in Section 5.2.

The policy regimes are summarised in Table 3. The first column specifies which policies are at use: monetary policy, or both monetary and macroprudential policies. The second column specifies the policy instruments.

Each of these regimes is then compared against the first-best allocation, i.e. the perfect competition flexible price RBC model. In Section 6, I compute welfare measures that further quantify the performance of the different regimes.

The first regime (on the first row of Table 3) consists of a conventional monetary policy rule, which reacts to inflation and output gap. The parameters are chosen to correspond to conventional values in the literature: a weight of 1.5 is given on inflation, and a weight of 0.5 on the output gap. This policy regime consists of one where there is no separate macroprudential policy at all, and conventional monetary policy is assumed to be enough to stabilise the economy.

Next, on the second row of Table 3, the second regime consists of an augmented monetary policy rule. In addition to inflation and output gap with the same weight as above, the monetary authority reacts to the real price of capital, or Tobin's q , with a weight of unity, so that fluctuations in q are offset one-to-one, other things equal. The price of capital was found to be the key variable to stabilise in order to offset the financial friction and replicate the first-best. This policy regime corresponds to one where the central bank tries to explicitly deal with financial imbalances as well as price stability, but only has one instrument at use. It is a dual mandate, and could be thought of as an approximate counterpart to the one-instrument Ramsey policy.

Finally, the third and fourth regime are ones where the tasks of price and financial stability are divided to two different authorities with different pol-

Regime	Taylor rule			Leverage tax	Investment subsidy
	$[\phi_\Pi$	ϕ_x	$\phi_q]$	ϕ_τ	$1 + s_t$
(i)	[1.5	0.5	0]	0	no
(ii)	[1.5	0.5	1]	0	no
(iii)	[1.5	0.5	0]	1	no
(iv)	[1.5	0.5	0]	0	yes

Table 4: Calibration of policy parameters. Regimes: (i) standard Taylor rule; (ii) augmented Taylor rule; (iii) standard Taylor rule and leverage tax; (iv) standard Taylor rule and investment subsidy;

icy targets. These are described in the third and fourth rows of Table 3. Monetary policy follows a standard Taylor rule, with the same conventional weights as in the first regime described above. In addition, there is a macroprudential policy that aims at financial stability. I look at two different macroprudential policies. The first is a cyclical leverage tax on banks, which targets the loans-to-output ratio of the economy. When this ratio is above its steady-state level, the tax is positive, so that the banks' aggregate leverage is reduced and lending and thus investment is restricted. When this ratio is below its steady-state level, in a downturn, bank lending is subsidised to stimulate lending.

The second macroprudential policy is a subsidy on investment returns. If Tobin's q is above one, i.e. there is too much investment relative to the first-best, it is a transfer from banks and entrepreneurs to depositors that makes investments less profitable and drives down Tobin's q . Conversely, when Tobin's q is below unity and investment is low relative to first-best, it is a subsidy on investments that make them more profitable. This policy aims at stabilising the value of q to unity.

5.2 Monetary and macroprudential policy rules

5.2.1 Monetary policy

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

$$1 + r_t = \frac{1}{\beta} \Pi_t^{\phi_\pi} X_t^{\phi_x} q_t^{\phi_q}, \quad (44)$$

where Π_t is the period-to-period gross inflation rate, $X_t = \frac{Y_t}{Y_t^e}$ is the output gap, and q_t is the real price of capital. The calibration of the policy parameters is given in Table 4.

5.2.2 Macprudential policy

I assume that the government follows a balanced budget policy, and that both the leverage tax/subsidy scheme and the investment tax/subsidy scheme is financed by lump sum taxes and transfers on households. This implies that the households' optimal decisions are not affected.

The bank leverage tax

First, the leverage tax on banks, 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.

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:

$$\mathcal{B} = \frac{a_t + d_t}{a_t}. \quad (45)$$

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:

$$\bar{\mathcal{B}}_t = (1 - \tau_t)\mathcal{B}_t = (1 - \tau_t)\frac{a_t + d_t}{a_t}. \quad (46)$$

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:

$$i_t - n_t + \kappa_t i_t \leq (1 - \tau_t)(a_t + d_t). \quad (47)$$

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, as well as the aggregate variables, can then be derived exactly as presented in Section 2.

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 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, of which the credit-to-output ratio is a simple measure.

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

$$1 + \tau_t = \left(\frac{\Upsilon_t}{\Upsilon} \right)^{\phi_\Upsilon}, \quad (48)$$

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

The investment subsidy

Next, the financial sector can be controlled through a tax and subsidy scheme on the returns of the investment projects. The goal is to stabilise Tobin’s q at unity to remove the effects of the agency costs on the level of investments.

On the demand side of loanable funds, the real price of capital is related to the pledgeable income of the investment project through the definition of

the pledgeable income:

$$\begin{aligned} \rho_t &= \frac{q_t p_H R}{1 + r_t} - 1 \\ \Leftrightarrow q_t &= \frac{(1 + \rho_t)(1 + r_t)}{p_H R} \end{aligned} \quad (49)$$

Now define $R(1 + \varsigma_t)$ as the subsidised return on the project when $\varsigma_t > 0$, and taxed return when $\varsigma_t < 0$. Then, the policy objective is to set ς_t such that the subsidised price of capital q_t^* is:

$$q_t^* = \frac{(1 + \rho_t)(1 + r_t)}{p_H R(1 + \varsigma_t)} = 1. \quad (50)$$

By rearranging and substituting (34) for ρ_t , the subsidy that fulfils this condition is:

$$1 + \varsigma_t = \left[1 + r_t + \gamma^{-1} \kappa_t^* \left(1 + r_t + \frac{p_H}{\Delta p} \left(1 - \frac{1 + r_t}{1 + r_t^a} \right) \right) \right] (p_H R)^{-1}. \quad (51)$$

5.3 Dynamics under simple policy rules

Figure 6 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.

The adverse shock also affects financial intermediation. There is downward pressure in investments, which decreases lending. The weakened demand for investments pushes down the real price of capital, or Tobin's q . When a macroprudential policy is active – in all cases except under the first regime where only a conventional Taylor rule is at use, shown by the solid black lines – it attempts to directly address this issue.

The augmented Taylor rule, shown in solid grey lines, attempts to offset the fall in real capital price q , but in doing so it allows for a greater output gap, as the two move in opposite directions. The fall in real capital price, however, decreases inflationary pressure.

The investment subsidy also reacts directly to the downward pressure in q .

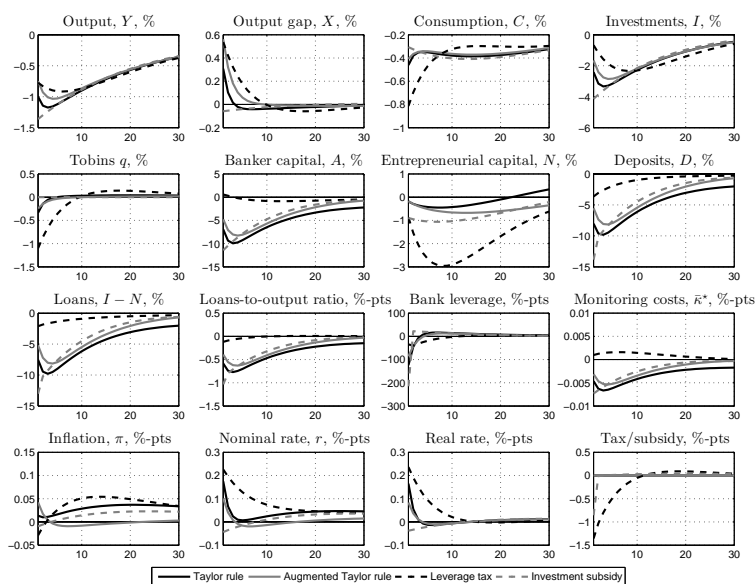


Figure 6: Policy response to a one percent adverse productivity shock. “Taylor rule”: the financial frictions model with standard Taylor rule that reacts to inflation and output gap; “Augmented Taylor rule”: the financial frictions model with an augmented Taylor rule that reacts to inflation, output gap and real capital price; “Leverage tax”: the financial frictions model with standard Taylor rule and leverage tax; “Investment subsidy”: the financial frictions model with standard Taylor rule and investment subsidy.

The policy reactions under this regime are shown in dashed grey lines. By imposing a negative subsidy (in effect, a tax) on investment returns, the policy encourages more consumption and less saving by the households, which leads to less supply of funds for investment. This removes the downward pressure from the capital price, and the policy stabilises q at the desired value of unity. At the same time, the monetary policy is left to take care of the inflation, but the stabilisation of q removes some of the inflationary pressure, so that monetary policy does not need to react as aggressively as under the other policy regimes.

Finally, the policy regime with a leverage tax, which aims at smoothing out credit cycles by stabilising the loans-to-output ratio, imposes a negative tax (a subsidy) on banks' total assets. This policy mix does stabilise financial intermediation, and it is the only policy that leads to improved monitoring resources (and a mitigation of the moral hazard problem). At the same time, however, it prevents investments from adjusting enough to the new productivity levels. 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 than it otherwise would have to.

Next, Figure 7 shows the policy response to an adverse demand shock. The reduced demand for consumption increases savings, which channel into increased investments. Aggregate output however falls. This shock is deflationary and produces a negative output gap. At the same time the shock induces an increase in the stochastic discount factor, which increases q . The increased savings induce an increase in deposits, which stimulates lending.

Now, if macroprudential policy is active, it again seeks to stabilise financial imbalances either by stabilising Tobin's q , or by stabilising credit intermediation. As before, it seems that the augmented Taylor rule and the investment subsidy policies are the most successful in stabilising the effects of the shock. The leverage tax policy seeks to stabilise lending by taxing the banks, which dampens the increase in investment and further depresses output. 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 leverage tax

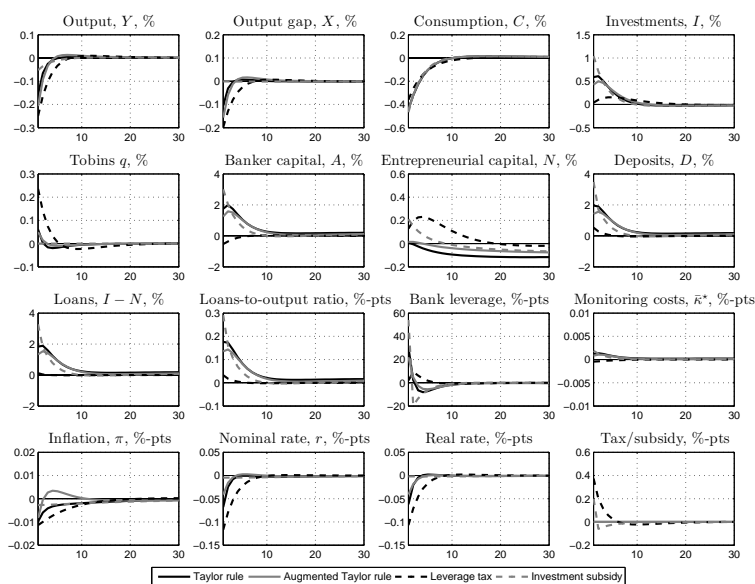


Figure 7: Policy response to a one percent adverse demand (preference) shock. “Taylor rule”: the financial frictions model with standard Taylor rule that reacts to inflation and output gap; “Augmented Taylor rule”: the financial frictions model with an augmented Taylor rule that reacts to inflation, otuput gap and real capital price; ”Leverage tax”: the financial frictions model with standard Taylor rule and leverage tax; “Investment subsidy”: the financial frictions model with standard Taylor rule and investment subsidy.

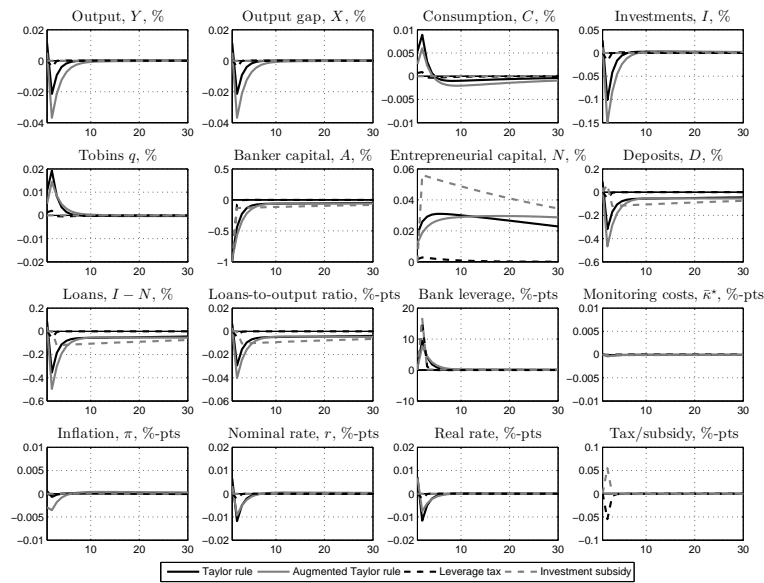


Figure 8: Policy response to a one percent adverse bank capital shock. “Taylor rule”: the financial frictions model with standard Taylor rule that reacts to inflation and output gap; “Augmented Taylor rule”: the financial frictions model with an augmented Taylor rule that reacts to inflation, output gap and real capital price; “Leverage tax”: the financial frictions model with standard Taylor rule and leverage tax; “Investment subsidy”: the financial frictions model with standard Taylor rule and investment subsidy.

can be helpful. Figure 8 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 substitute savings for consumption. 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. The investment subsidy has a similar effect: it increases the profits of the bankers and entrepreneurs from the investment projects, which also stimulates investments and helps banks rebuild their balance sheets.

In turn, the augmented Taylor rule does not perform very well, as it cannot stop the shock from propagating from the financial sector to the real economy as well as a separate macroprudential policy can.

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.

In turn, when shocks arise from outside of the financial sector but affect fi-

financial intermediation, it seems that a unified, dual mandate of the monetary authority is more beneficial. A coordinated response from one policymaker – here in the form of an augmented Taylor rule, which reacts explicitly both to inflation and real asset prices – seems to yield good results.

These simple examples demonstrate that there is scope for a separate macroprudential tool in dealing with disturbances that arise from the financial sector itself, but also a need to identify the sources of business cycle fluctuations, as well as to properly coordinate the use of monetary and macroprudential policies.

In the next section, I quantify the welfare effects of the different policy regimes. While the quantitative differences in welfare under the different policy regimes are small, the exercise can provide us with an ordering of the regimes in terms of household welfare, compared to the first-best outcome.

6 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 fixed 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. The benchmark model to which the others are compared here is the flexible price RBC model, which yields the first-best allocation. In the RBC model, both the financial friction and the nominal friction are absent. The details of the computation of the consumption-equivalent welfare measure is given in Appendix C.

The third column of Table 5 reports the welfare costs of the different policy regimes. In addition, the fourth and fifth columns of Table 5 display the standard deviations of inflation and output gap in percentages, respectively, under the different policy regimes.

Model	Policy	Welfare cost (%)	$100 \times \sigma_\pi$	$100 \times \sigma_x$
RBC		-	0.000	0.000
FF	Ramsey 2 instr.	0.000	0.000	0.000
"	Ramsey 1 instr.	0.001	0.006	0.093
"	Aug. Taylor rule	0.004	0.036	0.413
"	Investment subsidy	0.009	0.072	0.080
"	Taylor rule	0.020	0.111	0.214
"	Leverage tax	0.037	0.141	0.512

Table 5: Consumption-equivalent welfare costs under different policies, relative to the flexible price RBC model. A positive figure indicates a welfare loss relative to the first-best. “RBC” refers to the perfect competition, flexible price RBC model, and “FF” to the model with both the financial friction and the nominal rigidity. “Ramsey 2 instr.”: Ramsey policy with inflation and leverage instrument. “Ramsey 1 instr.”: Ramsey policy with inflation instrument only. “Augmented Taylor rule”: Taylor rule that reacts to inflation, output gap and real capital price. “Investment subsidy”: Standard Taylor rule and investment subsidy. “Taylor rule”: Standard Taylor rule that reacts to inflation and output gap. “Leverage tax”: Standard Taylor rule and leverage tax. σ_π : standard deviation of inflation. σ_x : standard deviation of output gap.

First, the welfare costs compared to the first-best allocation are small in absolute terms under any policy regime. For example, the worst-performing policy (entitled “Leverage tax” in the table) results in a welfare cost of 0.04 % of consumption in each period compared to the first-best. This result is in line with many earlier studies comparing welfare effects of different monetary policy regimes. The welfare analysis allows, however, to order the different policies by welfare losses and thus compare their desirability in qualitative terms.

Notably, as was demonstrated in Section 4.3, a Ramsey planner with two policy instruments, that can optimally set both the inflation and the bank leverage, can replicate the first-best allocation: the welfare cost to the household under this policy regime is zero, and both inflation and output gap are fully stabilised. The availability of two distinct instruments is required to offset both frictions in the economy.

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 optimal to focus on stabilising inflation, but not the output gap, as shown in the third row of the table: the standard deviation of inflation is very close to zero, while the standard deviation of output gap is clearly positive. Thus some deviation from the first-best output is traded off for price stability.

The rule-based policies do not fall far behind in welfare levels compared to the two Ramsey policies. The best regime is the augmented Taylor rule, shown on the fourth row of the table, and second comes the policy mix that which combines a standard Taylor rule for monetary policy with an investment subsidy, shown on the fifth row. These two policies come very close to the Ramsey-optimal policy plans in terms of welfare losses. The augmented Taylor rule achieves a very low inflation volatility, but a relatively high output gap volatility.

The welfare evaluation seems to somewhat contradict earlier results in monetary policy literature. In this model, where fluctuation in Tobin's q are a key source of wedges compared to the first-best outcome, it is beneficial for the monetary authority to react to real asset prices. This is likely a result of the specific financial friction modeled here, as the general view in the literature is that the central bank need not concern itself with asset price fluctuations, except insofar as they reflect changes expected inflation.⁸ In this model, even when prices are fully flexible, the fluctuations of real asset prices reflect the sub-optimal levels of investment caused by the agency cost, and are not directly linked to inflation expectations.

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 5.3, the cyclical leverage tax is counter-productive 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.

⁸See for example Carlstrom and Fuerst (2007) and the references therein.

7 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.

First, the main finding is that with both a nominal and a financial frictions, a social planner needs two separate policy instruments to replicate the first-best outcome. With two instruments – a monetary and a financial one – the constrained optimum is efficient. One instrument is not enough to replicate the efficient outcome.

This result suggests that there could be a need for two distinct policies even when the Ramsey policy solution is not available. The optimum under such simple policy rules does not perfectly replicate the first-best outcome, but approximate it. Different policy regimes with simple rules are analysed: one with no macroprudential policy; one with a single monetary instrument which also reacts to financial developments; and two regimes with separate monetary and macroprudential instruments.

The second important finding is that a policy regime where the monetary authority adjusts the nominal interest rate also in reaction to real asset prices, besides inflation and output gap, performs well in this model economy. This suggests that a unified mandate, whereby monetary policy pays attention to financial developments, could be useful. Especially when shocks other than financial ones – such as technology or demand shocks – are the main drivers of business cycles, it seems that conventional interest-rate-based monetary policy is enough to deal with cyclical fluctuations.

However, 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 inflation.

Finally, the analysis reveals that 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.

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:

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

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

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

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:

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

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

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

$$P_t^* = \frac{\varepsilon}{\varepsilon - 1} \frac{E_t \sum_{k=0}^{\infty} \omega^k Q_{t,t+k} \psi_{t+k|t} Y_{t+k|t} P_{t+k}^{\varepsilon+1}}{E_t \sum_{k=0}^{\infty} \omega^k Q_{t,t+k} Y_{t+k|t} P_{t+k}^\varepsilon} \quad (\text{Optimal pricing decision})$$

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:

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

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.

$$\begin{aligned}
\kappa_t^* &= \frac{\gamma \rho_t}{1 + (1 - \tau_t) \frac{p_H}{\Delta p} \left(\frac{1}{1+r_t} - \frac{1}{1+r_t^a} \right)} && \text{(Optimal monitoring)} \\
b(\kappa_t^*) &= \Gamma(\kappa_t^*)^{-\frac{\gamma}{1-\gamma}} && \text{(Private benefit)} \\
\rho_t &= (1 - \tau_t) \frac{q_t p_H R (1 + \varsigma_t)}{1 + r_t} - 1 && \text{(Net pledgeable income)} \\
g_t &= (1 - \tau_t) \frac{p_H}{\Delta p} \frac{b(\kappa_t^*)}{1 + r_t} - (1 - \gamma) \rho_t && \text{(Entrepreneur's inverse leverage ratio)} \\
R_t^e &= \frac{b(\kappa_t^*)}{q_t \Delta p} && \text{(Entrepreneur's return share)} \\
R_t^b &= \frac{\kappa_t^*}{q_t \Delta p} && \text{(Banker's return share)} \\
R_t^w &= R - R_t^e - R_t^b && \text{(Worker's return share)} \\
1 + r_t^a &= \frac{p_H}{\Delta p} \kappa_t^* \frac{I_t}{A_t} && \text{(Return on bank capital)} \\
1 + r_t^e &= \frac{p_H}{\Delta p} b(\kappa_t^*) \frac{I_t}{N_t} && \text{(Return on entrepreneurial capital)} \\
I_t &= \frac{N_t}{g_t} && \text{(Investment size)} \\
N_{t+1} &= \lambda^e (1 + r_t^e) \frac{r_{t+1}^K + (1 - \delta) q_{t+1}}{q_t} N_t && \text{(Accumulation of entrepreneur's net worth)} \\
A_{t+1} &= Z_t^b \lambda^b (1 + r_t^a) \frac{r_{t+1}^K + (1 - \delta) q_{t+1}}{q_t} A_t && \text{(Accumulation of banker's net worth)}
\end{aligned}$$

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.

$$\begin{aligned}
1 + r_t &= \frac{1}{\beta} \pi_t^{\phi_\pi} \tilde{x}^{\phi_x} && \text{(Taylor rule)} \\
1 + \tau_t &= \tilde{\Upsilon}_t^{\phi_\Upsilon} && \text{(Leverage tax rule)} \\
1 + \varsigma_t &= \left[1 + r_t + \gamma^{-1} \kappa_t^* \left(1 + r_t + \frac{p_H}{\Delta p} \left(1 - \frac{1 + r_t}{1 + r_t^a} \right) \right) \right] (p_H R)^{-1} && \text{(Investment subsidy)}
\end{aligned}$$

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:

$$\begin{aligned}
1 + r &= \frac{1}{\beta} \\
P^* &= P = 1 \\
\pi &= 1 \\
s &= 1 \\
\psi &= 1 \\
q &= \frac{1 + \rho}{\beta p_H R} \\
r^K &= q(r + \delta) \\
w &= (1 - \alpha) \left(\frac{r^K}{\alpha} \right)^{\frac{\alpha}{\alpha-1}} \\
K &= \left[\left(\frac{r^K}{\alpha} \right)^{\frac{\theta+\alpha}{\alpha-1}} \frac{1 - \alpha}{\chi} \left(\frac{r^K}{\alpha} - \frac{\delta}{p_H R} \right)^{-\sigma} \right]^{\frac{1}{\theta+\sigma}}
\end{aligned}$$

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

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:

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

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

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:

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

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 of the household under the benchmark allocation (denoted by R), 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 plan (denoted by A) 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:

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

Note that when $V_0^A = V_0^R$, the measure equals zero.

Simulating the models for a long enough time horizon T and repeating the simulation N times, for N large enough, yields an estimate of the conditional expectations V_0^R and V_0^A , which allows to estimate the cost x .

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