Booms, Banking Crises, and Monetary Policy

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Abstract

This paper develops a New Keynesian model that features endogenous build-ups of financial imbalances, where financial crises typically follow credit booms and are characterized by sharp output drops. A quantitative analysis of the model shows that if the macroprudential authority does not implement the optimal policy, a central bank that is leaning against the wind, i.e. sets higher interest rates in response to build-ups of imbalances, reduces the frequency of financial crises and improves welfare at the cost of more volatile inflation. The result stems from a failure of the 'divine coincidence' due to financial frictions in the banking sector.

Keywords: Financial Crisis, Leaning Against the Wind, Welfare, New Keynesian, Non-linear Dynamics.
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1 Introduction

The financial crisis of 2007-2009 has prompted a rethinking of macroeconomic policy frameworks (Smets, 2014). This has not only led to an accelerated introduction of macroprudential policy tools but has also ignited a debate on whether monetary policy frameworks should be expanded to include financial stability considerations (see e.g. Smets, 2014; Svensson, 2017; Gourio et al., 2018). While some researchers have argued that monetary policy should only be concerned with its traditional mandate (e.g. price stability) and financial stability should be addressed using macroprudential policy, others have argued that macroprudential policy might be insufficient to address financial stability issues since these tools are limited and inflexible (Caballero and Simsek, 2019).

In this paper, I reconcile some of the disparate views on whether monetary policy should be concerned with financial stability. Within a New Keynesian framework featuring endogenous build-ups of financial imbalances, I show that as long as the macroprudential authority implements the optimal policy, there is no tradeoff between price stability and financial stability for the central bank. In this case, monetary policy should aim at stabilizing inflation at the target to maximize welfare. However, should the macroprudential authority be unable to implement the optimal policy,[1] a tradeoff between price and financial stability arises for the central bank. In such a situation, leaning against the wind (LAW), i.e. setting higher interest rates in response to a build-up of financial imbalances, is not only able to attenuate the build-up but is also welfare improving. Furthermore, leaning against the wind reduces the frequency of financial crises and volatility of macroeconomic aggregates such as output and consumption substantially, while increasing the volatility of inflation. The result arises due to a failure of the divine coincidence[2] which introduces a tradeoff between financial stability and price stability for the central bank.

The model developed in this paper captures important features of financial crises that have been highlighted in the literature. Financial crises are rare events (Boissay et al., 2016) that typically follow credit booms (Schularick and Taylor, 2012). They are characterized by sharp drops in output (Paul, 2020) and, usually, last longer than the average recession (Boissay et al., 2016). Furthermore, as shown by Gorton and Ordoñez (2014) in the case of the 2007-2009 financial crisis, there does not need to be a large shock to, ultimately, trigger a financial crisis. While financial frictions have increasingly been incorporated into macroeconomic models, these models typically rely on large exogenous shocks to generate

[1] Considering the difficulties of coordinating and implementing macroprudential policy as highlighted by Dudley (2015) in the context of the U.S. regulatory structure, it does not seem far fetched that the optimal policy cannot be implemented perfectly in practice. Furthermore, as noted by Stein (2013), "the scope of the regulatory authority does not extend equally to all parts of the financial system", which is another reason that might prevent the optimal macroprudential policy from being implemented.

[2] The divine coincidence is a term coined by Blanchard and Galí (2007) and refers to the fact that in New Keynesian models without non-trivial real frictions, it is optimal for a central bank to purely focus on inflation stabilization. Such a policy also closes the welfare-relevant output gap and there are no further welfare gains to be made by trying to target other variables than inflation.

a financial crisis (Galí, 2018). As a result, they cannot capture the endogenous dynamics leading to a credit boom with a subsequent crash that is caused by an only moderately adverse shock.

To capture endogenous build-ups of financial imbalances and other salient features of financial crises, I extend an otherwise standard New Keynesian model with heterogeneous banks and solve it using global solution methods due to the strong non-linearities inherent to the model.[3] The setup of the banking sector closely follows Boissay et al. (2016), which features banks that differ in their profitability (i.e. some banks can generate a higher return on loans made to firms). This gives rise to an interbank market which is characterized by asymmetric information (efficiency of banks is private information) and moral hazard (possibility to divert funds without repercussions). These financial frictions can lead to endogenous dynamics that may or may not result in a banking crises. A typical run of events leading to such a crisis in the model starts with a sequence of small positive, transitory productivity shocks. The associated higher interest rates induce the household to increase savings to smooth out consumption. This leads to an expansion in credit and a booming economy. After some time, the productivity shocks start to phase out, which leads to a decline in the demand for corporate loans, while the household holds onto a large amount of savings at banks. As a result, a savings glut develops and interest rates fall. The decline in interbank loan rates implies that less efficient banks are more likely to borrow and, at the same time, these banks become more likely to divert the funds. Thus, counterparty fears in the interbank market increase. This leads to a decline in loans and, ultimately, even a small negative productivity shock can push the economy beyond a threshold where counterparty fears in the interbank market become too large and a financial crisis with an associated freeze in the interbank market and a credit crunch ensues. The central bank in the model follows a Taylor-type rule reacting to deviations of inflation from target and a measure of bank asset growth, which is equivalent to credit growth in the model during normal times. While the behavior of the central bank is not crucial for the fundamental dynamics leading to the build-up of financial imbalances, it, nevertheless, can play an important role in, both, dampening or exacerbating the build-up. As mentioned above, by leaning against the wind the central bank can dampen the credit boom and reduce the probability of it leading to a financial crisis.

This paper is related to a growing literature studying the interactions of monetary policy and financial stability. Smets (2014) provides a survey of this literature and concludes that macroprudential policy should be the main tool to address financial stability, but that monetary policy should keep an eye on financial stability issues and lean against the wind if necessary. More recently, Svensson (2017) developed a simple, reduced form framework for evaluating leaning against the wind type of policies and concludes that the

[3]As a matter of fact, the resulting model features discontinuous policy functions as in Boissay et al. (2016). A linearization of the model around a particular point (e.g. the steady state as it is usually done) would not be able to capture this discontinuity.

costs of LAW outweigh its benefits. Most closely related to the model presented in this paper is Boissay et al. (2022), who in independent, contemporaneous work developed a New Keynesian model with microfounded, endogenous crisis dynamics by also building on Boissay et al. (2016). They reach similar conclusions regarding the desirability of a systematic (i.e. Taylor-type rule based) leaning against the wind policy and, in addition, study discretionary monetary policy interventions. However, they do not study the interaction of monetary and macroprudential policy, which is at the core of my paper. Several other papers extended New Keynesian models with reduced form regime switching crisis (e.g. Woodford, 2012; Gourio et al., 2018; Kockerols et al., 2021). In contrast to these papers, the model developed in this paper does not rely on reduced form relationships to vary the probability of crisis based on financial variables in the model, but provides a microfounded mechanism for dynamics that can lead to a crisis.

More generally, this paper is related to the literature that adds financial frictions to macroeconomic models such as Bernanke et al. (1999) and Gertler and Karadi (2011). Brunnermeier et al. (2012) provide a survey of this strand of the literature. A crucial difference compared to most of this literature, however, is that the model of Boissay et al. (2016) and my New Keynesian extension do not rely on large exogenous shocks to generate crises but have endogenous boom-bust cycles. In this regard it is related to Martinez-Miera and Repullo (2017) who present a model that also features endogenous boom-bust cycles. They focus on banks monitoring decisions in response to low interest rates and abstract from an interbank market, while in the model of this paper, the frictions in the interbank play a crucial role. In an extension to Martinez-Miera and Repullo (2017), Martinez-Miera and Repullo (2019) also study the role of macroprudential and monetary policy in addressing financial stability risks. However, they focus on a two-period model, while I develop a dynamic stochastic general equilibrium (DSGE) model which allows one to study the full dynamics resulting of the build-up of financial imbalances. Another closely related paper is Paul (2020) in which financial fragility builds up during good times because of increasingly leveraged intermediaries and crises typically follow credit booms. However, Paul (2020) abstracts from monetary and macroprudential policy, which are the key objects of study in this paper. To capture the nonlinearities inherent in the model, I solved the model using nonlinear solution techniques. This is similar to, for example, Brunnermeier and Sannikov (2014), Martinez-Miera and Repullo (2017), Paul (2020) or Boissay et al. (2022), who also solve for full equilibrium dynamics while the related literature traditionally tends to analyze the behavior of log-linearized solutions around a steady state. The importance of analyzing nonlinear dynamics has also been highlighted by Dou et al. (2017) in a survey regarding macroeconomic models used for monetary policy analysis.

Finally, this paper is related to the literature on pecuniary externalities that can generate excessive financial fragility. For example, Bianchi (2011) analyzes how optimal decisions at an individual level can lead to overborrowing at a social level within a DSGE model. Similarly, in the model presented in this paper, the representative household does not internalize the effect of its savings decision on the stability of the economy and the demand for credit.

This paper is structured as follows: In Section 2, I describe the setup of the model. In Section 3, I show that the tradeoff between financial and price stability for the central bank arises only when the macroprudential policy does not follow the optimal policy. In section 4, I analyze the quantitative properties of the model and discuss the role of monetary policy in the build-up of financial imbalances. Section 5 concludes.

2 The Model

In order to be able to analyze the effects of monetary policy on price stability and financial stability in the presence of endogenous build-ups of financial imbalances, I extend an otherwise standard New Keynesian model with a banking sector as in Boissay et al. (2016). Financial crises in the resulting model typically follow credit booms, are characterized by sharp drops in output, and can be triggered by relatively small negative shocks.

2.1 Representative Household

The representative household chooses consumption c_t, labor n_t, assets a_t, and bond holdings b_t to maximize expected discounted lifetime utility subject to a budget constraint

$$\max_{\{c_t,n_t,a_t,b_t\}_{t=0}^{\infty}} \mathrm{E}_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{c_t^{1-\sigma}}{1-\sigma} - \chi \frac{n_t^{1+\nu}}{1+\nu} \right) ,$$

where $\beta \in (0,1)$ is the discount factor, $\sigma > 0$ is the coefficient of relative risk aversion and inverse of the intertemporal elasticity of substitution, $\nu > 0$ is the inverse of the Frisch labor supply elasticity and χ determines the preference for labor.

The household earns real wage w_t from supplying labor n_t, receives gross nominal interest rate R_{t-1} from bonds bought at $t-1$ and gross real return on assets r_t^a saved at the bank at the end of the previous period. As in Boissay et al. (2016), the composition of a_t is indeterminate and can be either thought of bank deposits or equity. I will refer to a_t as assets or deposits interchangeably. Furthermore, the household receives lump-sum transfers for profits made by firms Π_t, transfers from the government or macroprudential authority $\mathcal{T}_t$, price-adjustment costs incurred by intermediate good producers Θ_t, intermediation costs incurred by banks Ξ_t. In the case of the latter two, the lump sum transfers avoid real resource cost of inflation and intermediation, respectively. This results in the following budget constraint

$$c_t + a_t + b_t = w_t n_t + r_t^a a_{t-1} + \frac{R_{t-1}}{\pi_t} b_{t-1} + \Pi_t + \Theta_t + \Xi_t + \mathcal{T}_t ,$$

where $\pi_t = \frac{p_t}{p_{t-1}}$ is the gross inflation rate in period t.

2.2 Firms

2.2.1 Final Good Producer

The final good is produced by a representative final good producer in a perfectly competitive final good market. The continuum of intermediate goods, which are indexed by i, are combined to a final good $\hat{y}_t$ according to a CES production function

$$\hat{y}_t = \left(\int_0^1 \hat{y}_{it}^{\frac{\varepsilon-1}{\varepsilon}} di \right)^{\frac{\varepsilon}{\varepsilon-1}} ,$$

where ε is the elasticity of substitution between the goods.

From the profit maximization problem of the final good producer (see Appendix A.1), it follows that demand for intermediate good i is given by

$$\hat{y}_{it} = \left(\frac{p_{it}}{p_t} \right)^{-\varepsilon} \hat{y}_t \, .$$

Substituting this into the production function, one can derive an expression for the price level in the economy in terms of intermediate good prices

$$p_t = \left(\int_0^1 p_{it}^{1-\varepsilon} di \right)^{\frac{1}{1-\varepsilon}} .$$

2.2.2 Intermediate Good Producers

Intermediate good i is produced using labor n_{it} and capital k_{it} according to

$$\hat{y}_{it} = z_t k_{it}^{\alpha} n_{it}^{1-\alpha} ,$$

where total factor productivity z_t follows

$$\log z_t = \rho_z \log z_{t-1} + e_t ,$$

where $\rho_z \in (0, 1)$ and e_t is normally distributed with mean 0 and variance ω_z.

Each intermediate good producer has to pay $r_t^k + \delta - 1$ for renting one unit of capital from the banking sector, where r_t^k is the real gross corporate loan rate for capital and δ is the real depreciation rate. From a cost minimization problem of the intermediate good producers (see Appendix A.2), one can derive that marginal cost is

$$m_t = \frac{1-\bar{v}}{z_t}\left(\frac{r_t^k+\delta-1}{\alpha}\right)^{\alpha}\left(\frac{w_t}{1-\alpha}\right)^{1-\alpha},$$

where $\bar{v}$ is a government subsidy to firms that removes the inefficiency due to monopolistic competition if $\bar{v} = 1 - \frac{\varepsilon-1}{\varepsilon}$. Note that the marginal cost of production are the same for all intermediate good producers.

Since intermediate good producers act in a monopolistic competition framework, they can change prices to affect how much demand they face. There are price adjustment cost as in Rotemberg (1982), which will introduce price stickiness into the model.[4] The adjustment cost are quadratic in the price change relative to steady state inflation $\tilde{\pi}$ and expressed as a fraction of aggregate output $\hat{y}_t$ (produced by firms in the model) (as in Richter et al., 2014)

$$\Theta_t\left(\frac{p_{it}}{p_{it-1}}\right) = \frac{\theta}{2}\left(\frac{p_{it}}{p_{it-1}\tilde{\pi}}-1\right)^2 \hat{y}_t,$$

where $\theta > 0$ is the degree of price stickiness.

Finally, the problem of intermediate good producers is to choose a sequence of prices $\{p_{it}\}_{t\geq 0}$ to maximize

$$\mathrm{E}_t \sum_{k=t}^{\infty} q_{t,k}\left[\tilde{\Pi}_k(p_{ik}) - \Theta_t\left(\frac{p_{ik}}{p_{ik-1}}\right)\right],$$

where

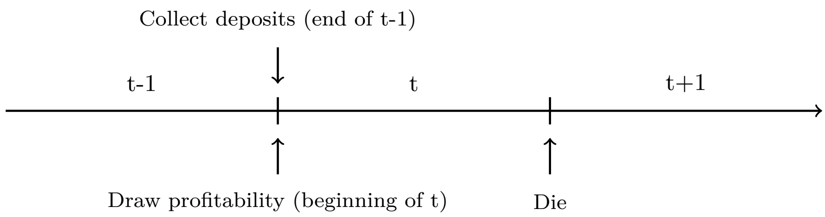
$$\tilde{\Pi}_k(p_{ik}) = \left(\frac{p_{ik}}{p_k} - m_t\right)\left(\frac{p_{ik}}{p_k}\right)^{-\varepsilon} \hat{y}_k,$$

are profits net of adjustment cost, $q_{t,t+1} = \beta\left(\frac{c_{t+1}}{c_t}\right)^{-\sigma}$, $q_{t,t} = 1$ and $q_{t,k} = \prod_{j=t+1}^{k} q_{j-1,j}$ is the stochastic discount factor. In a symmetric equilibrium, we have that $\tilde{\Pi}_t = (1-m_t)$ and $\Pi_t = \tilde{\Pi}_t - \Theta_t$. Also, note that adjustment cost will be rebated back to the household as a lump sum transfer $\Theta_t = \frac{\theta}{2}\frac{\pi_t}{\tilde{\pi}}\hat{y}_t$ to eliminate real resource cost of inflation, where $\pi_t = \frac{p_t}{p_{t-1}}$. Solving the problem of intermediate good producers yields the standard non-linear New Keynesian Phillips curve (see Appendix A.4 for derivation)

$$\left(\frac{\pi_t}{\tilde{\pi}}-1\right)\frac{\pi_t}{\tilde{\pi}} = \mathrm{E}_t\left[q_{t,t+1}\left(\frac{\pi_{t+1}}{\tilde{\pi}}-1\right)\frac{\pi_{t+1}}{\tilde{\pi}}\frac{\hat{y}_{t+1}}{\hat{y}_t}\right] + \frac{\varepsilon}{\theta}\left(m_t - \frac{\varepsilon-1}{\varepsilon}\right). \tag{1}$$

[4] There are different ways to introduce sticky prices into the model. Commonly used in the New Keynesian literature are adjustment cost à la Rotemberg (1982) or Calvo (1983). Both of the approaches are equivalent up to a first order approximation.

Figure 1: Basic Lifecycle of a Bank



2.3 Banking Sector

Capital is intermediated between households and firms through a banking sector as in Boissay et al. (2016), which receives capital in the form of deposits or equity from households and rents it out to intermediate good producers to be used in production. Within the banking sector, the interactions between banks determine the spread between deposit rate r_t^a and the corporate loan rate r_t^k. Banks are heterogeneous in their profitability of their lending opportunities, meaning that some banks can make loans to the corporate sector that yield a higher return. Key for the mechanism that leads to financial crises is going to be that there is asymmetric information and moral hazard in the interbank market. Note that there are no nominal rigidities in the banking sector itself, meaning that the setup of Boissay et al. (2016) can be transferred almost one to one to this model.

2.3.1 Basic Setup

The banking sector consists of a continuum of risk-neutral, competitive banks that live only for one period.[5] They are ex-ante identical and, thus, raise the same amount of deposits. At the beginning of period t, they draw a bank specific profitability of lending opportunities $p \in [0, 1]$, making them heterogeneous. The profitability p is distributed according to cumulative distribution $\mu(p)$, which satisfies $\mu(0) = 0$, $\mu(1) = 1$ and $\mu'(p) > 0$.

Banks participate in, both, retail and wholesale activities. In other words, they can use the deposits that they raise to make corporate loans (i.e. rent capital to firms) or they can lend or borrow in the interbank market at gross rate ρ_t. The return on corporate loans is dependent on the profitability p. A bank with intermediation skill p receives a gross return pr_t^k per unit of corporate loan, implying that banks with higher p have to pay less intermediation costs. Banks also have the ability to invest in an outside project yielding a constant return γ.[6] Note that it will be worth more to invest into the outside project than to just let the good depreciate, i.e. $\gamma \geq 1 - \delta$. This project is only used during crisis by

[5] As in Boissay et al. (2016), the banks are heterogeneous and their type is private information. The assumption that they only live for one period is made to preserve the asymmetric information over time and to rule out reputation effects.

[6] As shown by Boissay et al. (2016), the fact that the return γ is constant does not play a major role for the build-up.

some banks and as a "threat" during normal times. Furthermore, note that in equilibrium we need that $r_t^k > \rho_t > \gamma$, otherwise no bank would lend to other banks.

In normal times, the real gross return on deposits $\kappa_t(p)$ at bank with profitability p is

$$\kappa_t(p) = \begin{cases} p r_t^k (1+\eta_t) - \rho_t \eta_t & \text{if bank is a borrower in the interbank market}\,, \\ \rho_t & \text{otherwise}\,, \end{cases}$$

where $\eta_t \geq 0$ is publicly observable amount borrowed, which can be interpreted as the ratio of market funding to traditional funding. For this reason, I will refer to η_t as the market funding ratio. A bank with profitability p becomes a borrower in the interbank market if

$$p r_t^k (1+\eta_t) - \rho_t \eta_t \geq \rho_t \quad \Leftrightarrow \quad p \geq \bar{p}_t = \frac{\rho_t}{r_t^k}\,.$$

2.3.2 Frictions in the Interbank Market

In the first best, all inefficient banks ($p < 1$) should lend to the most efficient one (with $p = 1$) since this would avoid intermediation costs completely. However, two frictions prevent that all funds are lent to the most efficient bank: Moral hazard and asymmetric information.

As in Boissay et al. (2016), the return from the outside project is not traceable and cannot be seized by creditors. Thus, the bank can walk away with (i.e. divert) borrowed funds η_t and invest in the outside project which yields $\gamma(1+\vartheta\eta_t)$ (cost of walking away $\vartheta \in [0,1]$). As noted by Boissay et al. (2016), this is a standard moral hazard problem since the gains from diversion are increasing in η_t and the opportunity cost of diversion are increasing in the banks profitability p and in the spread between the gross corporate loan rate r_t^k and the the gross return on storage technology γ. It implies that efficient banks have less incentives to walk away than inefficient banks if they are are highly leveraged.

The profitability is private information and cannot be verified by lenders ex-ante or ex-post. Thus, banks do not know with whom they are trading with in the interbank market and contracts in the interbank market are the same for all banks. To deter borrowers from diverting, we need that the return from becoming a borrower and diverting the borrowed funds is not larger than the return from being a lender in the interbank market, i.e.

$$\gamma(1+\vartheta\eta_t) \leq \rho_t\,. \tag{2}$$

In equilibrium, equation (2) is binding (see Proposition 1 in Boissay et al., 2016): $\eta_t = \frac{\rho_t - \gamma}{\gamma\vartheta}$. Therefore, the market funding ratio, η_t, is increasing in ρ_t. This is because as ρ_t increases only banks with a high p still demand a loan and it becomes more profitable for low profitability banks to lend. Because high skill banks have less incentives to divert the funds, counterparty risks decrease and lenders are willing to lend more to each bank. Thus, the market funding ratio, η_t, goes up. Analogously, a fall in the interbank market rate, ρ_t, increases counterparty risks, and leads to a fall in the market funding ratio. In the limit we have that $\rho_t = \gamma$, which implies no trade in the interbank market or $\eta_t = 0$.

2.3.3 Interbank Market Equilibrium

The corporate loan rate r_t^k will be such that the corporate loan market clears and, given this, ρ_t will be such that the interbank market clears

$$\underbrace{a_{t-1}\mu\left(\frac{\rho_t}{r_t^k}\right)}_{Supply} = \underbrace{a_{t-1}\left[1-\mu\left(\frac{\rho_t}{r_t^k}\right)\right]\overbrace{\frac{\rho_t-\gamma}{\gamma\vartheta}}^{=\eta_t}}_{Demand} . \tag{3}$$

Alternatively, this can be written as

$$r_t^k = \Psi(\rho_t) = \frac{\rho_t}{\mu^{-1}\left(\frac{\rho_t-\gamma}{\rho_t-\gamma(1-\theta)}\right)} .$$

One can show that $\Psi(\rho_t)$ is a convex function in ρ_t and that it has a minimum at $\bar{\rho} \geq \gamma$.[7] This implies that there exists a corporate loan rate threshold $\bar{r}^k$ below which there cannot be an equilibrium with trade in the interbank market, i.e. below this threshold there is no ρ_t that satisfies equation (3). If there is no trade in the interbank market, less productive banks will prefer to use the outside project over making corporate loans which means that not all deposits will be channelled to the firms, i.e. there is a credit crunch. In particular, we have that

$$k_t = \begin{cases} a_{t-1} & \text{if an equilibrium with trade exists}\,, \\ \left[1-\mu\left(\frac{\gamma}{r_t^k}\right)\right]a_{t-1} & \text{otherwise}\,, \end{cases} \tag{4}$$

where k_t is the amount of capital that can be used for production. Since k_t is also the amount of corporate loans made by the banking sector, I will use the terms credit and capital interchangeably.

The banking sectors return on deposits also depends on the interbank market[8]

[7] For details see Boissay et al. (2016).

[8] Note that banks with $p \geq \bar{p}_t$ borrow η_t from other banks, which they use together with their own funds to lend to firms. We need that

$$\int_{\bar{p}_t}^{1}(1+\eta_t)d\mu(p) = 1 .$$

$$
\begin{aligned}
\hat{r}_t^a &= \int_0^1 \kappa_t(p)d\mu(p) \\
&= \begin{cases} r_t^k \int_{\bar{p}_t}^1 p \frac{d\mu(p)}{1-\mu(\bar{p}_t)} & \text{if an equilibrium with trade exists}\,, \\ r_t^k \left[q_t \mu\left(q_t\right) + \int_{q_t}^1 p d\mu(p) \right] & \text{otherwise}\,, \end{cases}
\end{aligned} \tag{5}
$$

where $q_t = \frac{\gamma}{r_t^k}$. Note that the effective return paid out to households is $r_t^a = \tau_{t-1}\hat{r}_t^a$ where τ_{t-1} is a macroprudential tax/subsidy on deposits a_{t-1} raised by banks.[9] For more details on the macroprudential tax/subsidy see Section 2.5.

Intermediation costs $(1-p)r_t^k$ are rebated back to the household through Ξ_t, so that there is no deadweight loss. As shown in Appendix A.5, we have that

$$
\Xi_t = \left(r_t^k - \hat{r}_t^a\right) a_{t-1} - \left(r_t^k - \gamma\right)\left(a_{t-1} - k_t\right) .
$$

The return from the outside project contributes to total output

$$
y_t = z_t k_t^{\alpha} n_t^{1-\alpha} + (\gamma + \delta - 1)(a_{t-1} - k_t) .
$$

Note that if there is an equilibrium with trade in the interbank market, we have that $k_t = a_{t-1}$ and, thus, in that case only firms add to total output in the economy.

2.4 Monetary Policy

The central bank sets the nominal interest rates according to a Taylor-type rule

$$
R_t = \tilde{R}\left(\frac{\pi_t}{\tilde{\pi}}\right)^{\phi_\pi}\left(\frac{a_t}{a_{t-1}}\right)^{\phi_a} , \tag{6}
$$

where $\phi_\pi > 1$ determines how strongly the central bank reacts to inflation π_t, ϕ_a determines how strongly the central bank reacts to asset growth, $\tilde{R}$ is the steady-state nominal interest rate and $\tilde{\pi}$ is the inflation target.

Note that if $\phi_a = 0$ the central bank is only concerned with price stability. In that case, higher ϕ_π imply that inflation is more strongly stabilized at the target $\tilde{\pi}$. As the limit where the central bank fully stabilizes inflation at the target ($\pi_t = \tilde{\pi}$ for all t), I consider a special rule where the central bank tracks the natural rate of interest arising from the same model without nominal frictions. I will refer to that case as Strict Inflation Targeting (SIT). If $\phi_a > 0$ the central bank also takes the build-up of financial imbalances into account. In particular, it reacts to growth in assets a_t, which is equivalent to reacting

Rearranging yields $1 + \eta_t = \frac{1}{1-\mu(\bar{p}_t)}$.

[9] τ_{t-1} is a gross rate meaning that $\tau_{t-1} \in [0, 1)$ represents a tax, while $\tau_{t-1} > 1$ represents a subsidy.

to credit growth during normal times (since then $k_t = a_{t-1}$). This is what I will be referring to as "leaning against the wind". The specification is akin to speed limit policies introduced by Walsh (2003) into the literature. However, in this case the "speed limit" is on asset growth instead of output growth.[10]

The central bank conducts open market operations such that the nominal interest rate follows equation (7) and the bond market clears. As usual, bonds b_t are in zero net supply, meaning that in equilibrium $b_t = 0$ for all t.

2.5 Macroprudential Policy

The macroprudential authority imposes a tax (or subsidy) on deposits raised by banks τ_t. This tax is dynamically set over the credit cycle. As we will see later on, the tax can be chosen by the macroprudential authority to implement the constrained efficient allocation in a model without nominal frictions. Alternatively, the macroprudential authority reacts to the credit-to-output gap,[11] which is defined here as the deviation of the current credit-to-output ratio from the credit-to-output ratio in the steady state. Let ψ_t denote the credit-to-output ratio

$$\psi_t = \frac{k_t}{y_t}\,.$$

The rule of the macroprudential authority is then defined as follows

$$\tau_t = \tilde{\tau} \left(\frac{\psi_t}{\tilde{\psi}} \right)^{\phi_c} , \tag{8}$$

where $\tilde{\psi}$ is the credit-to-output ratio in the steady state, ϕ_c determines how strongly the macroprudential authority reacts to the credit-to-output gap $\frac{\psi_t}{\tilde{\psi}}$.

The tax on deposits affects the profitability of the banking sector and, thus, affects the return on deposits r_t^a paid to households. This implies that the macroprudential authority is able to influence the household savings decision in a more direct way than the central bank which is able to affect this decision through adjusting R_t.

[10] Alternative specifications of the Taylor rule can deliver results similar to those presented in this paper. For example, since output also captures the build-up of financial imbalances in this setup, one could also use deviations of output from steady state instead of asset growth. The resulting policy rule

$$R_t = \tilde{R} \left(\frac{\pi_t}{\tilde{\pi}} \right)^{\phi_\pi} \left(\frac{y_t}{\tilde{y}} \right)^{\phi_a} , \tag{7}$$

would be closer to the original rule proposed by Taylor (1993). An earlier version of this paper and Boissay et al. (2022) are using such a Taylor rule specification. However, the policy rule adopted in this paper more clearly highlights that the central bank takes financial stability concerns into account.

[11] This is inspired by how the countercyclical capital buffer (CCyB) is determined in Germany (see Natalia Tente et al., 2015).

Note that while the tax rate is set at $t-1$, the tax is collected at the beginning of time t and rebated to households as a lump-sum transfer. Together with the factor subsidy that is made to firms to elminate the distortion from monopolistic competition, government transfers are

$$\mathcal{T}_t = (1-\tau_{t-1})\,\hat{r}_t^a a_{t-1} - \bar{v}\left[(r_t^k + \delta - 1)k_t + w_t n_t\right] .$$

2.6 Discussion

With the model setup in mind, a discussion of some of the theoretical model properties is in order. The following section defines the competitive equilibrium, explains how the equilibrium in the interbank market depends on the corporate loan rate, a key interest rate determining the fragility of the model economy, and how monetary policy can affect financial stability in the model.

2.6.1 Decentralized Equilibrium

A competitive equilibrium is defined as follows in this economy.

Definition 2.1 (Competitive Equilibrium)**.** A Competitive Equilibrium is defined by a sequence of prices $\mathcal{P}_t \equiv \{p_t, \{p_{it}\}_{i\in[0,1]}, \pi_t, R_t, r_t^a, r_t^k, \rho_t, w_t, \tau_t\}_{t=0}^{\infty}$, and a sequence of quantities $\mathcal{Q}_t \equiv \{c_t, n_t, a_t, k_t, b_t, x_t\}_{t=0}^{\infty}$ such that

1. Given prices, $\mathcal{P}_t$, $\mathcal{Q}_t$ solves the optimization problem of the representative household
2. Given prices, $\mathcal{P}_t$, $\mathcal{Q}_t$ solves the optimization problem of intermediate good producers
3. Markets clear

$$y_t = c_t + x_t \qquad \text{(Goods market)}$$

$$b_t = 0 \qquad \text{(Bond market)}$$

$$n_t = \int_0^1 n_{it} di \qquad \text{(Labor market)}$$

$$k_t = \int_0^1 k_{it} di = \begin{cases} a_{t-1} & \text{if eq. with trade exists} \\ \left[1-\mu\left(\frac{\gamma}{r_t^k}\right)\right] a_{t-1} & \text{otherwise} \end{cases} \qquad \text{(Corporate loan market)}$$

$$\mu\left(\frac{\rho_t}{r_t^k}\right) = \left[1-\mu\left(\frac{\rho_t}{r_t^k}\right)\right]\frac{\rho_t-\gamma}{\gamma\vartheta} \qquad \text{(Interbank market)}$$

where $x_t = a_t - (1-\delta)a_{t-1}$ are gross additions to the potential capital stock.[12] Depending

[12] Capital which can be used for production is underlying the deposits that are made at banks. These capital goods are depreciating when used in the corporate sector or in the outside project, which leads to

on whether there is an equilibrium with trade in the interbank market, we have $k_t = a_{t-1}$ or $k_t < a_{t-1}$.

2.6.2 Determination of Trade in Interbank Market

To check if an equilibrium with trade in the interbank market exists, I proceed in a sequential way as Boissay et al. (2016): I assume that an equilibrium with trade in the interbank market exists, and compute the implied corporate loan rate that clears the corporate loan market. Then, I check if this rate is below or above the corporate loan threshold $\bar{r}^k$ which is given by

$$\bar{r}^k = \min_{\bar{\rho}} \Psi(\bar{\rho}) = \min_{\bar{\rho}} \frac{\bar{\rho}}{\mu^{-1}\left(\frac{\bar{\rho}-\gamma}{\bar{\rho}-\gamma(1-\theta)}\right)}$$

If $\bar{r}^k$ is above the threshold, there is trade in the interbank market and the rest of the allocation can be computed. If the corporate loan rate is below the threshold, it must be the case there is no trade in the interbank market. Thus, the allocations have to be recomputed for that case. Note that the corporate loan rate that is computed under the assumption that the interbank market is not working may very well be above the threshold $\bar{r}^k$. What matters, however, is whether the corporate loan rate under the assumption that the interbank market is working is above the threshold.

It is instructive to think of corporate loan threshold from another perspective. The model features features two state variables: assets a_{t-1} and total factor productivity z_t. The corporate loan rate under the assumption of trade in the interbank market, $r_t^{k,trade}$, is a function of these two state variables. We need that

$$r_t^{k,trade}(a_{t-1}, z_t) \geq \bar{r}^k$$

in order to have an equilibrium with trade in the interbank market. In principle, solving this equation for a_{t-1} yields $\bar{a}_t$, which Boissay et al. (2016) called the absorption capacity of the economy

$$a_{t-1} \leq \bar{a}_t(\bar{r}^k, z_t)\,.$$

This absorption capacity $\bar{a}_t$ is the maximum amount of deposits that the banking sector can allocate efficiently, i.e. without any of the banks investing into the outside project. If

this equation that seems to imply that deposits are depreciating. However, if we consider that firms are paying the depreciation rate δ to banks (in addition to the corporate loan rate), the stock of physical assets in the banking sector does not change after production. Thus, from the perspective of the household, it does not pay for depreciation of the goods underlying the deposits explicitly. The payment is only implicit in lower profits from firms.

a_{t-1} exceeds this threshold, counterparty risk in the interbank market is too high and an equilibrium with trade is not possible.

Note that in the model of Boissay et al. (2016), there exists a closed form solution for the absorption capacity. In this model it is not possible to solve for $\bar{a}_t$ explicitly. However, using the baseline parametrization presented in Section 4, one can check for each node in the state space if it implies an equilibrium with trade or not. Figure 4 shows the absorption capacity as a dashed line. Note that the absorption capacity is increasing in productivity (TFP), meaning that as long as productivity is high enough a large amount of savings does not lead to a financial crisis within the model.

2.6.3 Monetary Policy and Financial Stability

As explained in the previous section, the level of corporate loan rate r_t^k determines whether the economy is in a financial crisis (with a dysfunctional interbank market) or whether it is in normal times. From the first-order conditions of the cost minimization problem of intermediate good producers (see Appendix A.2) one can show that the corporate loan rate r_t^k can be written as

$$r_t^k = \frac{\alpha}{1-\bar{v}} z_t m_t \left(\frac{k_t}{n_t}\right)^{\alpha-1} - \delta + 1\,,$$

or using the output produced by the corporate sector[13] $\hat{y}_t = z_t k_t^{\alpha} n_t^{1-\alpha}$

$$r_t^k = \frac{\alpha}{1-\bar{v}} m_t \frac{\hat{y}_t}{k_t} - \delta + 1\,. \tag{9}$$

These expressions show how monetary policy can affect financial stability in the model. First, in the short run, monetary policy does affect financial stability by affecting marginal costs m_t (or markups which are defined as the inverse of m_t) and output $\hat{y}_t$. Second, in the medium-run monetary policy does affect financial stability through the savings decision of households a_t and, therefore, the amount of capital k_t available to firms. Boissay et al. (2022) called these the YMK-channels, where Y refers to output, M to markups and K to capital accumulation.

3 Constrained Efficiency and Optimal Policy

In this section, I argue that as long as the macroprudential authority implements the optimal policy, there is no tradeoff between price stability and financial stability for the central bank. The argument rest on the fact that the macroprudential authority can

[13] During normal times, output produced by the corporate sector is equal to total output $\hat{y}_t = y_t$. Only during crisis times, when some banks invest in the outside project, we have that $\hat{y}_t \neq y_t$.

ensure that the natural allocation, i.e. the equilibrium allocation in the absence of nominal rigidities (Galí, 2015), is constrained efficient.

I proceed in three steps. First, I define the constrained efficient solution of the model without nominal rigidities, which results from the problem of a social planner. Then, I show that the constrained efficient allocation can be decentralized by an appropriately defined macroprudential tax/subsidy τ_t. Finally, I argue that conditional on this macroprudential tax, the optimal monetary policy ensures price stability[14] by tracking the natural rate of interest with the nominal rate R_t as in the textbook New Keynesian model.

3.1 Constrained Efficiency in the Model Without Nominal Rigidities

Consider a version of the model described in Section 2 without nominal rigidities and without monopolistic competition between intermediate good producers. This boils down to setting the price adjustment cost parameter to zero ($\theta = 0$) and setting the production subsidy for firms to $\bar{v} = 1 - \frac{\varepsilon - 1}{\varepsilon}$. Note that the resulting setup corresponds to a version of Boissay et al. (2016) with additively separable preferences.

The presence of financial frictions implies that the decentralized competitive equilibrium is not constrained efficient. This is due to the fact that the model features two externalities (see exposition in Section 4.3 and Boissay et al., 2016, for details). First, agents do not internalize how their savings decision affects the probability of crisis (savings glut externality), which implies that they tend to overaccumulate savings when financial crisis are imminent. Second, agents do not internalize that intermediation costs Ξ_t are rebated back to them, which implies that they tend to underaccumulate savings when the economy is far from the crisis.

We are interested in the constrained efficient allocation where the a social planner is subject to the same financial frictions as the household but takes into account that intermediation costs Ξ_t are rebated back to agents and how their savings decision affects the corporate loan rate r_t^k (and in turn the probability of crisis). As in the baseline model, there will be a threshold value $\bar{r}^k$ (determined by parameters) below which no equilibrium with trade in the interbank market exists. As in Boissay et al. (2016), the social planner is subject to the same allocations as in the decentralized equilibrium but not subject to the externalities. The problem of the constrained social planner is defined as follows (for details on the derivation see Appendix A.7).

Definition 3.1 (Recursive constrained efficient allocation)**.** A recursive constrained efficient allocation is defined by a set of decision rules $\{c(z_t, a_{t-1}),\ n(z_t, a_{t-1}),\ k(z_t, a_{t-1}),\ a'(z_t, a_{t-1}),\ r_t^k(z_t, a_{t-1})\}$ with the value function

[14] More precisely, the optimal monetary policy ensures full stabilization of inflation at the target $\tilde{\pi}$. This is due to the fact that the Rotemberg adjustment costs are indexed to the inflation target $\tilde{\pi}$.

$V^{CE}(z_t, a_{t-1})$ that solve the recursive optimization problem

$$
\begin{aligned}
V^{CE}(z_t, a_{t-1}) &= \max_{\{c_t, a_t, n_t, k_t, r_t^k\}} \frac{c_t^{1-\sigma}}{1-\sigma} - \chi \frac{n_t^{1+\nu}}{1+\nu} + \beta \mathrm{E}\left[V^{CE}(z_{t+1}, a_t) | z_t\right] , \\
\text{s.t.} \quad c_t + a_t &= z_t k_t^{\alpha} n_t^{1-\alpha} + (1-\delta) k_t + \gamma (a_{t-1} - k_t) \\
k_t &= \begin{cases} a_{t-1} & \text{if eq. with trade exists} , \\ \left[1 - \mu\left(\frac{\gamma}{r_t^k}\right)\right] a_{t-1} & \text{otherwise} , \end{cases} \\
r_t^k &= \alpha z_t \left(\frac{k_t}{n_t}\right)^{\alpha-1} - \delta + 1 , \\
n_t &= \left[\frac{1-\alpha}{\chi} z_t\right]^{\frac{1}{\nu+\alpha}} c_t^{-\frac{\sigma}{\nu+\alpha}} k_t^{\frac{\alpha}{\nu+\alpha}} .
\end{aligned}
$$

Note that whether there is an equilibrium with trade in the interbank market is determined in the same way as in the baseline model (see Section 2.6.2). Whether there is an equilibrium with trade for given states (z_t, a_{t-1}) also depends on the labor choice of the household. This is an important difference with the setup of Boissay et al. (2016) who used Greenwood–Hercowitz–Huffman (GHH) preferences.

3.2 Decentralizing the Constrained Efficient Allocation

The constrained efficient allocation can be decentralized using a macroprudential tax/subsidy τ_t on the deposits raised by banks. This is due to the fact that the social planner chooses an allocation that maximizes welfare of the household from the same set of allocations that are supported by a decentralized competitive equilibrium, while taking into account the savings glut and rebate externality. Since the allocation of the constrained social planner satisfies the first order condition for labor of the household from the decentralized competitive equilibrium by construction, the only additional equilibrium condition in the decentralized equilibrium is the Euler equation. Therefore, the constrained efficient macroprudential tax τ_t can be derived from the Euler equation

$$
\tau_t^{CE} = \left(\mathrm{E}_t \left[\beta \left(\frac{c_{t+1}^{CE}}{c_t^{CE}} \right)^{-\sigma} \hat{r}_{t+1}^{a,CE} \right] \right)^{-1}
$$

where $\hat{r}_{t+1}^{a,CE}$ is the return on assets net of the macroprudential tax such that $r_{t+1}^{a,CE} = \tau_t^{CE} \hat{r}_{t+1}^{a,CE}$.

Hence, in a model without nominal frictions and without inefficiencies due to monopolistic competition, a macroprudential tax/subsidy can implement the constrained efficient allocation. This is similar to, for example, Bianchi (2011), who showed that the constrained efficient allocation can be decentralized using a macroprudential tax in a DSGE model as well.

3.3 Conditionally Optimal Monetary Policy

The previous sections have shown that the macroprudential authority can make the natural allocation constrained efficient by choosing τ_t appropriately when there is also a production subsidy $\bar{v} = 1 - \frac{\varepsilon-1}{\varepsilon}$. Consider now the full model with nominal rigidities ($\theta > 0$) but maintain the assumption of a production subsidy to eliminate the distortions due to monopolistic competition and suppose that the macroprudential authority follows the constrained efficient macroprudential tax, i.e. $\tau_t = \tau_t^{CE}$. What would the optimal monetary policy look like in this case?

Under these assumptions, the constrained efficient allocation can be attained by stabilizing marginal cost m_t such that firms achieve their desired markups, i.e. $m_t = \frac{\varepsilon-1}{\varepsilon}$ for all t.[15] From the New Keynesian Phillips curve in equation (1), we know that if inflation is fully stabilized at the target, marginal costs are stabilized at their steady state value $\frac{\varepsilon-1}{\varepsilon}$. In that case, the allocation is equal to the natural allocation and the model behaves in the same way as the model without nominal rigidities.

Therefore, conditional on the optimal policy of the macroprudential policy, the central banks optimal policy entails fully stabilizing inflation at the target. By doing so the central bank closes the welfare relevant output gap, maximizes welfare and implements the constrained efficient allocation.

3.4 Failure of the Divine Coincidence

Consider the same setting as in the previous subsection but now the macroprudential authority does not implement the optimal policy, i.e. $\tau_t \neq \tau_t^{CE}$. While it is still true that stabilizing inflation at the target implements the natural allocation, said natural allocation is not constrained efficient anymore. As a result, deviating from strict inflation targeting is potentially welfare improving.

The result that inflation stabilization is not optimal anymore is due to a failure of the divine coincidence, which refers to the fact that in basic New Keynesian models without real frictions, fully stabilizing inflation at the target also closes the welfare relevant output gap (Blanchard and Galí, 2007). While strict inflation targeting still closes the output gap with respect to the model without nominal rigidities, this is not the welfare relevant output gap. In other words, if the macroprudential authority fails to ensure that the natural allocation is constrained efficient, inflation stabilization by the central bank does not close the welfare relevant output gap anymore.

Note that monetary policy alone is not able to achieve the constrained efficient real allocations. Only in conjunction with the macroprudential authority is it possible to achieve

[15] This is analogous to the optimal policy in the case of an efficient natural allocation in the textbook New Keynesian model in Galí (2015)

Table 1: Baseline Parametrization of the Model

Parameter		Value	Target/Source
Preferences			
β	Discount factor	0.995	2% real rate in steady state ($1/1.02^{0.25}$)
σ	Risk aversion	1	Common in NK literature
δ	Depreciation rate	0.025	As in Boissay et al. (2016)
$1/\nu$	Frisch elasticity of labor supply	1	Common in NK literature
χ	Disutility of labor	0.884	Labor Supply equal 1 in steady state
Production			
ε	Demand elasticity	7.67	15% price markup (in line with estimates in Loecker and Warzynski, 2012)
α	Capital share	0.3	Standard
θ	Price adjustment cost	78.87	Equivalent to 0.75 Calvo parameter
$\bar{z}$	Steady state TFP	1	Normalization
ρ_z	AR coefficient of process for TFP	0.95	Similar to Smets and Wouters (2007); Paul (2020)
ω_z	Standard deviation of TFP Shock	0.006	Similar to Smets and Wouters (2007); Paul (2020)
Monetary and Macroprudential Policy			
$\tilde{\pi}$	Steady state inflation	1.005	2% annual inflation target ($1.02^{0.25}$)
ϕ_π	Taylor rule coeff. on inflation	1.5	Common in NK literature
ϕ_a	Taylor rule coeff. on deposit growth from steady state output	0	Not considered in baseline parametrization
ϕ_c	Macropru coeff. on credit-to-output ratio	0	Not considered in baseline parametrization
$\tilde{\tau}$	Macropru intercept	1	Not considered in baseline parametrization
Banking Sector			
ϑ	Diversion cost	0.04	4% frequency of crises and 4.4% annualized corporate loan rate
γ	Gross return of storage technology	0.982	4% frequency of crises and 4.4% annualized corporate loan rate
λ	Bank distribution: $\mu(p) = p^\lambda$	90	4% frequency of crises and 4.4% annualized corporate loan rate

constrained efficiency. It is straightforward to see this from the New Keynesian Phillips curve in equation (1). Any deviation from strict inflation targeting will imply that markups deviate from the desired markups of firms. Nevertheless, as we will see in Section 4.5, it will be welfare improving to not follow strict inflation targeting and lean against the wind, when the macroprudential authority does not follow the optimal policy.

4 The Case for Leaning Against the Wind

In the following, I analyze the quantitative model properties and show how monetary policy can affect the build-ups of financial imbalances. The model is solved nonlinearly using a policy function iteration approach as in Richter et al. (2014) (for details see Appendix C). The nonlinear solution technique is critical for the analysis of the model. A log-linearized solution would not be able to capture the nonlinearities inherent in the banking sector. The optimality conditions are described in Appendix A.6.

4.1 Baseline Parametrization

Table 1 shows the chosen parameters. The model is calibrated to a quarterly frequency and parameters have been chosen in accordance to what is commonly used in the literature.

The discount factor is set such that the household discounts the future by 2% per annum. The risk aversion parameter is set to $\sigma = 1$ which is commonly chosen in the New Keynesian literature. This parameter is going to be critical for how strong the build-up in the model is going to be. Higher risk aversion by the household implies that it would want to smooth consumption more strongly and would accumulate more savings in response to a sequence of positive productivity shocks. The depreciation rate δ is set to 0.025, meaning that capital depreciates 10% per annum as in Boissay et al. (2016). The Frisch labor supply elasticity is set to $1/\nu = 1$, which is commonly chosen in the NK literature. The disutility for labor χ is set such that labor supply in the steady state is equal to 1.

The demand elasticity is set to $\varepsilon = 7.67$, which implies a markup in the steady state of 15% ($\frac{\varepsilon}{\varepsilon-1} = 1.15$). This is, both, commonly found in the NK literature and in line with estimates for price markups as found by, for example, Loecker and Warzynski (2012). The choice for the capital share $\alpha = 0.3$ is standard in both RBC and NK literature. Price adjustment cost $\theta = 78.87$ are set such that in a log-linearized version of the model prices change on average every 4 quarters, i.e. 75% of firms adjust prices every period.[16] The long-run total factor productivity (TFP) $\bar{z}$ is normalized to 1, while the AR(1) coefficient of the process $\rho_z = 0.95$, and the standard deviation of the TFP shock $\omega_z = 0.006$ are chosen in a similar range as commonly found in the literature (see e.g. Smets and Wouters, 2007; Paul, 2020).

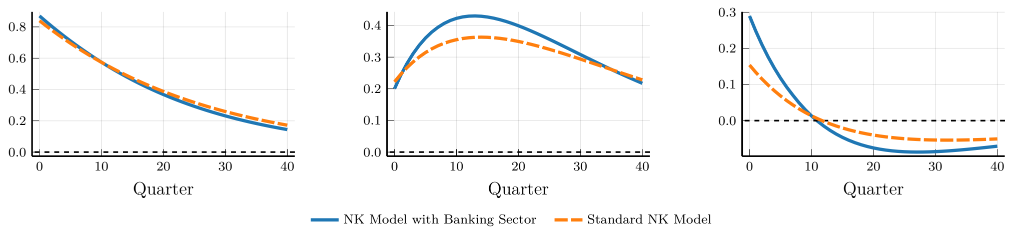
As for monetary policy, I set steady state inflation, $\tilde{\pi}$, equal to 2% per annum, which is a common inflation target chosen by central banks all over the world.[17] The Taylor rule coefficients are set to $\phi_\pi = 1.5$ and $\phi_a = 0$, meaning that in the baseline parametrization monetary policy does not react to asset growth. I will relax this assumption in the following sections and will also compare different choices for ϕ_π to analyze how the the build-up depends on the coefficients in the Taylor rule. In the baseline parametrization, macroprudential policy is not considered $\phi_c = 0$ and $\tilde{\tau} = 1.0$. However, as in the case of monetary policy, I will vary these coefficients in the following sections.

The banking sector specific parameters are calibrated jointly to match a 4% frequency of financial crisis and 4.4% annualized corporate loan rate. The frequency of financial crises was determined in Paul (2020) using macrohistory data by Jordà et al. (2017) for advanced economies from 1870 to 2013. The target for the corporate loan rate is the same as used in Boissay et al. (2016). The resulting parameter values are $\vartheta = 0.04$, $\lambda = 90$ and $\gamma = 0.98169$.

[16]This interpretation is based on the fact that Calvo type of price adjustment and Rotemberg type of price adjustment are the same up to a first order Taylor approximation (see, for example, Keen and Wang, 2007).

[17]Note that since Rotemberg adjustment costs are indexed to the inflation target $\tilde{\pi}$ of the central bank, the steady state is not distorted even if the target is different from zero. This means that the optimal inflation rate is not zero but 2% with this parametrization.

Figure 2: Impulse Response Functions: Productivity (TFP) Shock



Notes: IRFs are in response to a one standard deviation productivity (TFP) shock. See Appendix B for details on the model setup of the standard New Keynesian model. See Figure 9 in Appendix D for additional IRF comparisons.

4.2 Impulse Response Functions

Figure 2 shows the impulse response functions to a one standard deviation productivity shock, for the model developed in this paper and a standard New Keynesian model without a banking sector (see Appendix B). The model without a banking sector is equivalent to a parametrization where all the savings are channelled to the most efficient bank.

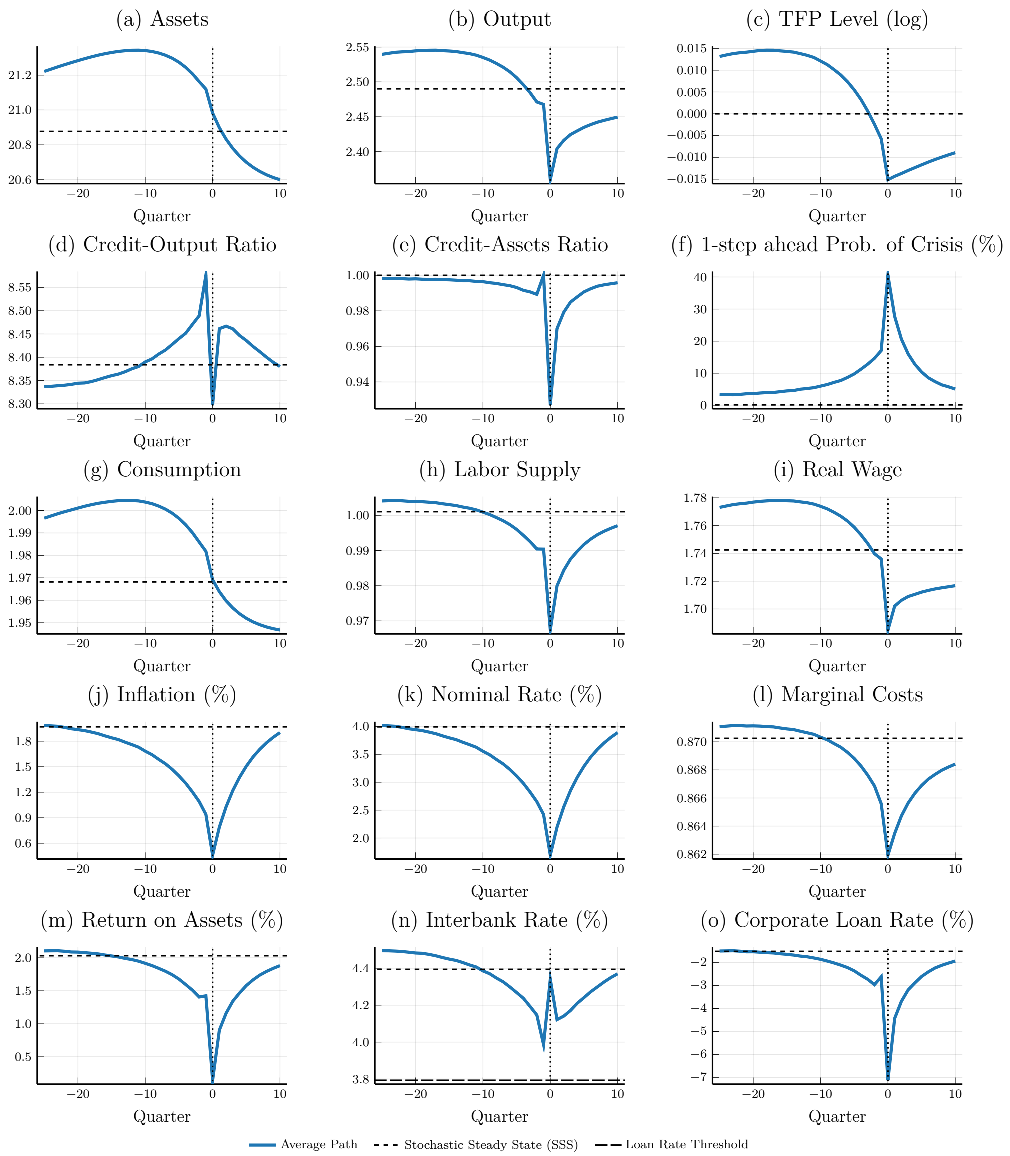
For the computation of the impulse responses, the economy starts from its stochastic steady state and in the case of a one standard deviation shock the economy does not experience a financial crisis, even though the corporate loan rate falls below its steady state value at a certain point (see Figure 9 in Appendix D). The key is that these shocks are not large enough to push the corporate loan rate below the threshold $\bar{r}^k$. Put in a different way, in the stochastic steady state, the economy is still far enough from its absorption capacity such that the banking sector is able to handle shocks of one standard deviation. Thus, the responses in both models are quite similar as long as the economy stays close to the stochastic steady state. Nevertheless, there seems to be a small financial accelerator effect present in the model, as also documented by Boissay et al. (2016) for the model without nominal frictions. More important differences will emerge once the economy is pushed beyond its absorption capacity as we will see in the next section.

4.3 Typical Paths to Financial Crises

To determine how the model behaves away from the stochastic steady state, I simulate the model for 500,000 periods and compute average paths leading to financial crises in the model. In particular, I identify the beginnings of a financial crisis as the period where the equilibrium in the interbank market changes from trade to no trade and collect the 25 periods before and 10 periods after beginning of each of the identified crisis. Figure 3 shows the average paths for some of the key variables.

The main mechanism leading to a build-up, as it existed in the RBC model of Boissay et al.

Figure 3: Typical Path to Financial Crises



Notes: Based on simulation of the model for 500,000 periods. Financial crises are identified as the period where the equilibrium in the interbank market changes from trade to no trade. In the figure a financial crisis starts at $t = 0$.

(2016), survives in this New Keynesian model. The average path is characterized by a long sequence of small positive productivity shocks, which drives total factor productivity (TFP) above its long run mean (see panel (c) of Figure 3). The increased productivity makes firms demand more capital for production and, thus, increases demand for corporate loans. This, in turn, increases the return on corporate loans and the return on assets, and encourages the household to increase its savings, in order to smooth out consumption. Thus, assets in panel (a) of Figure 3 follow a similar path as TFP at the beginning. There is an expansion in credit and the economy is booming. This period is also characterized by a very low probability of a crisis happening as can be seen from the panel (f) in Figure 3. The counterparty risk in the interbank market is low during this period, since the high corporate loan rate increases the opportunity cost of diversion of highly profitable banks and the comparatively high interbank loan rate ensures that only banks with higher profitability demand loans from the interbank market.

After some time the productivity shocks start to phase out and TFP begins to return to its long run mean. This results in a decline in the demand for corporate loans and the corporate loan rate. However, at the same time the household is still holding onto a large amount savings that it built up during the good times that came before. Key here is that the household does not internalize the effects of its savings on the corporate loan rate, r_t^k, which Boissay et al. (2016) referred to as a savings glut externality. It implies that as TFP decreases, asset holdings remain relatively high such that the economy is moving closer to its absorption capacity. We have an excess amount of savings that coupled with the declining demand for corporate loans, leads to a fall in the corporate loan rate and interbank rate as can be seen in panels (n) and (o) in Figure 3. The fall in the interbank market loan rate makes it more profitable for less efficient banks to become a borrower in the interbank market. Furthermore, the lower corporate loan rate decreases the opportunity cost of diversion in the interbank market and makes it more likely that the low profitability banks divert the funds that they borrow. As a consequence, counterparty risk in the interbank market and the probability of crisis increase as can be seen from panel (f) of Figure 3. Furthermore, during this reversion of TFP to its long run level, the credit-to-output ratio (or capital-to-output ratio) increases strongly (see panel (d) in Figure 3) since the household reduces assets more slowly than output decreases.

To some extent monetary policy exacerbates the build-up dynamics. The positive productivity shocks reduce inflation and marginal costs (i.e. increase markups) in the run up to the crisis, since the central bank does not fully offset the inflationary and deflationary pressures when following a Taylor-type rule as in the baseline calibration (see panels (j) and (l) in Figure 3). From the expression for the corporate loan rate in equation (9), we can see that this contributes to pushing down the corporate loan rate and, therefore, increases financial fragility. As we will see in the following sections, strict inflation targeting (i.e. fully stabilizing inflation at the target) would eliminate this channel and enhance financial stability.

Once the economy has reached the point where it is close to its absorption capacity (i.e. the corporate loan rate is close to its threshold value), even a moderately sized negative TFP shock can lead to a financial crisis.[18] In the simulation the average productivity shock has a size of $1.61 \times \omega_z$ which is remarkably similar to the median shock of $1.45 \times \omega_z$ required for a financial crisis in Boissay et al. (2016). It is important to realize that a shock of this size is not very unlikely to happen (there is around 5.4% probability to experience an even larger shock). This fact also shows up in the 1-step ahead probability of crisis in Figure 3. The average probability of crisis is 17.0% one period before the crisis actually breaks out, which is more than around 5 times as high as 20 periods before the crisis, when the probability of crisis was only 3.4%.

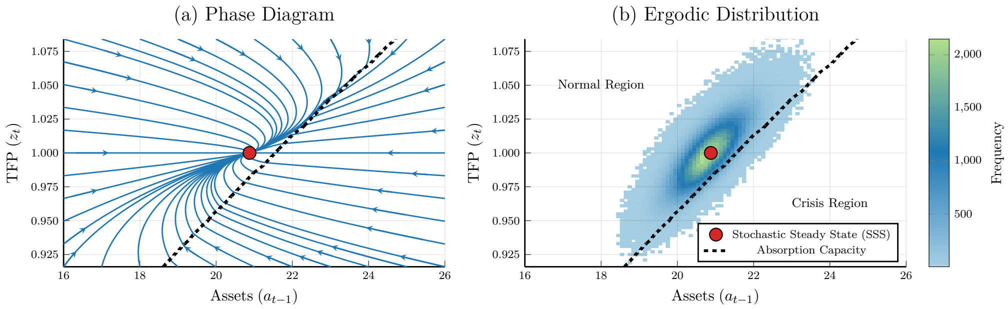
The crisis itself is then characterized by a contraction in output, consumption and the real wage as can be seen in Figure 3. The drop in output from $t = -1$ to $t = 0$ is around -4.37%, which is in line with the empirical estimates in Paul (2020). Furthermore, it is accompanied by a credit crunch since not all savings are channelled to firms as capital (see panel (e) in Figure 3). Note that a financial crisis in the model lasts about 1.8 quarters on average, meaning that during this time the interbank market does not function properly. However, more than 2 years (10 quarters) after the outbreak of the crisis the average path of output is still below its steady state, meaning that the impact of the crisis can be felt for much longer.

In the explanations above I focused on the average path as the typical path to a financial crisis. However, the economy does not have to exactly follow this path to end up in a crisis. As a matter of fact, since this is a pointwise average, there is not going to be any actual path that exactly corresponds to the average path. What all the paths have in common is that there is a sequence of events that brings the economy close or beyond its absorption capacity. For example, there are cases in Figure 3 where TFP does not fall below its long run trend but a crisis is still happening. This means that in these cases, there must be an even higher amount of assets such that the corporate loan rate would still fall below the threshold and an equilibrium with trade in the interbank market could not be sustained. In some cases in the sample (0.01% of the crisis in the simulation), a negative productivity shock was not even necessary for a crisis to break out. It is important to note that normal recessions, defined as at least two consecutive quarters with negative output growth and without a financial crisis, follow very different paths from the ones shown in this section (see Figure 11 in the Appendix). They do not feature a credit boom, output falls by much less from peak to trough and output returns much more quickly to a value close to its steady state.

Figure 4 provides a different perspective on the dynamics to crisis in the model. Boissay

[18] Note that in my simulations the average shock leading to crisis is preceded by several negative productivity shocks which are very close to zero. The basic story of the build-up to crisis remains the same. The key point is that the economy moves towards its absorption capacity and becomes more fragile because of that.

Figure 4: Phase Diagram and Ergodic Distribution



Notes: Ergodic distribution based on simulation of the model for 500,000 periods. The phase diagram traces out the model dynamics starting from different combinations of the state variables (a_{t-1}, z_t) while no additional shocks hit the economy.

et al. (2016) have shown that there are two crucial features of the households behavior leading to the results discussed and explain why crisis follow credit booms. First, the consumption smoothing behavior affects financial stability. During times when TFP is relatively low the household dissaves, meaning that financial crisis become less likely since we move away from the absorption capacity of the economy (movement to the left in panel (a) of Figure 4). If TFP is relatively high, on the other hand, the household accumulates savings meaning that the economy moves towards its absorption capacity (movement to the right in panel (a) of Figure 4). In other words, the households behavior during bad times stabilizes the banking sector, while it makes it more fragile during good times. Second, as already mentioned above, the household does not internalize the effects its saving have on the stability of the economy. If the household would internalize this savings glut externality, it would not accumulate as much assets, which would decrease the likelihood of crisis. Since the New Keynesian model works in the same way in these regards, the aforementioned features of the household behavior are also critical in this model.

To summarize, the typical path to financial crises is characterized by a long sequence of positive productivity shocks, which brings the economy closer to its absorption capacity, i.e. closer to the amount of assets that can be handled efficiently by the banking sector. The associated increase in demand for corporate loans, induces an increase in savings by the household. As productivity shocks phase out and demand for corporate loans declines, interest rates fall. This increases counterparty risks in the interbank market and makes the economy more vulnerable to small shocks that decrease the corporate loan rate even further and push it below a certain threshold. The crisis breaks out when the corporate loan rate falls below said threshold, leading to a freeze in the interbank market and a contraction in output and consumption. The households behavior plays a crucial role in generating a credit boom and increasing the vulnerability to small shocks as the economy moves closer to its absorption capacity. Monetary policy exacerbates the build-up dynamics to some extent in the baseline calibration but as we will see next it can play a crucial role in preventing crises.

4.4 Tradeoffs of Financial and Price Stability

As shown in the previous section, the model features a mechanism to generate credit booms that, ultimately, might lead to financial crises. We have seen that monetary policy can exacerbate the build-up dynamics through its effect on markups and the corporate loan rate if inflation is not fully stabilized at the target. In that case, promoting price stability also promotes financial stability. However, by affecting the savings decisions of the household through its interest rate policy the central bank can further improve financial stability in the medium run, while being less stringent on its price stability objective.[19]

I simulate the model under different specifications for the central banks policy while keeping the rest of the parameters the same. I am going to consider only three different cases to simplify the exposition. First, the baseline case ($\phi_\pi = 1.5$, $\phi_a = 0.0$), which has also been used to generate the results in the previous section. This corresponds to a Taylor rule as it is commonly found in the literature, where the central bank only reacts to inflation and satisfies the Taylor principle. Second, a case where the central bank strongly commits to stabilizing inflation at the inflation target which I call the Strict Inflation Targeting (SIT) specififcation. In this case, the central bank sets the nominal rate equal to the natural rate of interest and reacts very strongly to deviations of inflation from the target. As discussed in Section 3 this is the optimal monetary policy conditional on optimal macro prudential policy. And finally, I consider a case where the central bank also takes the credit boom directly into account by reacting to deposit growth in the economy, which I denote Leaning Against the Wind (LAW). For simplicity, in all three cases macroprudential policy is "turned off". This implies that the divine coincidence does not hold as discussed in Section 3 and that there are potential gains from taking financial stability into account when setting the central bank policy rate.

Table 2 shows the summary statistics of a simulation of the model under the three specifications described above. The standard deviations are expressed relative to the baseline specification and show that a central bank more concerned with inflation stabilization is successful in not only reducing the volatility of inflation but also reducing the volatility of consumption, output, labor supply and assets to a small degree. In comparison, a central bank that does not only focus on inflation stabilization but leans against the wind (i.e. responds to an ensuing credit boom) is able to achieve much higher reductions in consumption, output, labor supply and assets volatility at the cost of higher volatility in inflation and nominal rates. Overall, the means of all simulated variables are quite similar with marginally higher average inflation in the LAW case. However, the frequency of crisis falls to 0.89% in the SIT case in comparison the baseline and the frequency of crisis drops to 0.0% in the case of a central bank that leans against the wind.

[19] In the following, I will focus on the analysis of the systematic component of monetary policy. However, monetary policy shocks (i.e. a shock entering the Taylor rule of the central bank) could in principle also push the economy into crisis if it is already close to its absorption capacity.

Table 2: Simulation Statistics

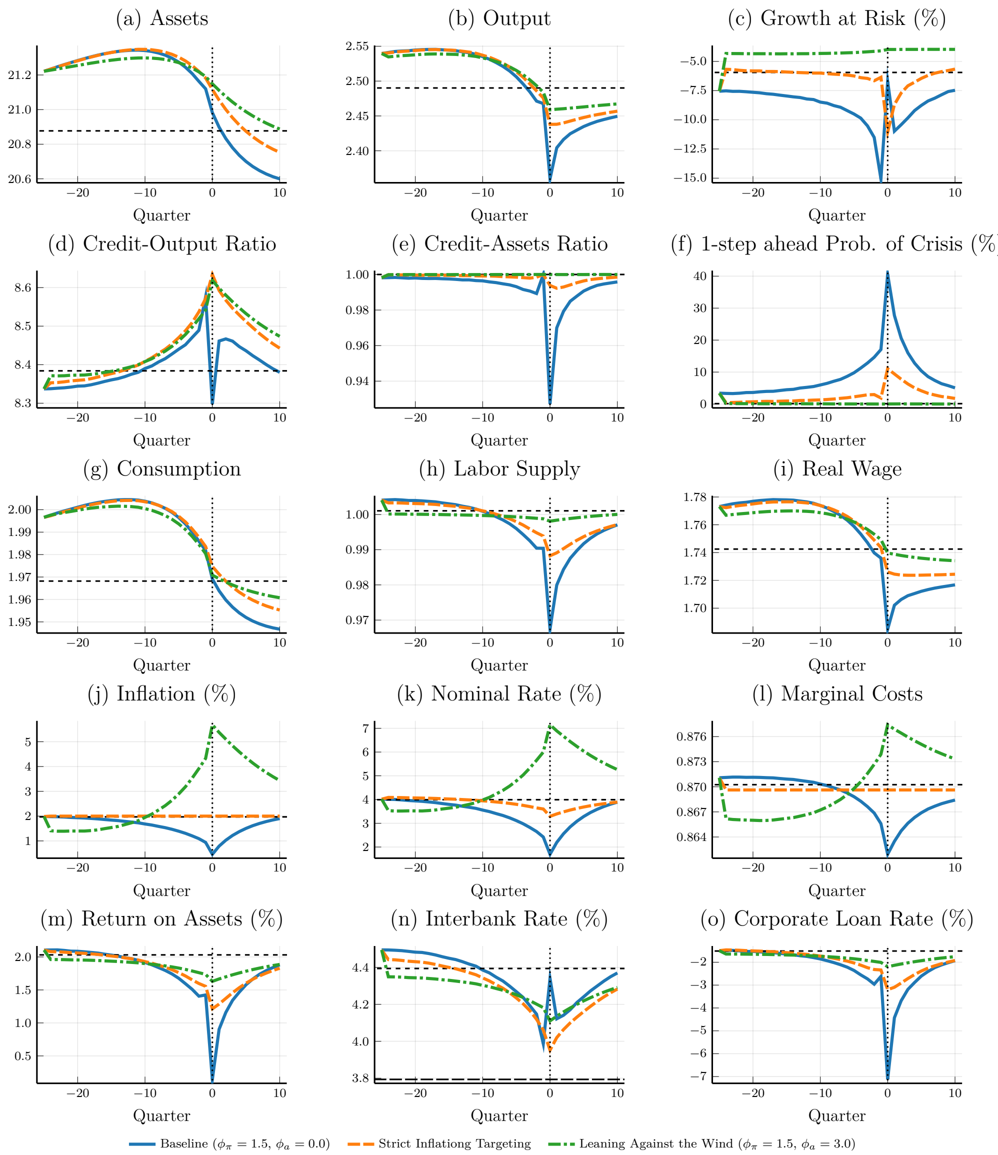
	Means			Std. Dev.	
	Baseline	SIT	LAW	SIT	LAW
Nominal Rate (%)	4.02	4.04	4.06	0.32	1.62
Inflation (%)	1.99	2.00	2.02	0.00	2.91
Corporate Loan Rate (%)	4.44	4.39	4.37	0.89	0.52
Consumption	1.97	1.97	1.97	0.94	0.82
Output	2.49	2.49	2.49	0.91	0.75
Labor Supply	1.00	1.00	1.00	0.64	0.15
Assets	20.83	20.87	20.90	0.93	0.76
Crisis Frequency (%)	4.15	0.89	0.00	-	-
Crisis Duration (Quarters)	1.80	1.57	1.27	-	-

Notes: The statistics are computed based on the simulation of 500,000 periods for three different specifications: Baseline ($\phi_\pi = 1.5$, $\phi_a = 0.0$), Strict Inflation Targeting (SIT), and Leaning Against the Wind (LAW; $\phi_\pi = 1.5$, $\phi_a = 3.0$). The standard deviations have been scaled by the standard deviation of the baseline specification to simplify comparison.

Price stability implies financial stability to some extent as can be seen in the reduction of the frequency of financial crises in the case of SIT. However, by leaning against the wind, monetary policy can dampen the build-up in financial imbalances in the medium run and further reduce the frequency of crises. Such a policy then also reduces the volatility of macroeconomic aggregates since financial crisis are characterized by sharp drops in consumption and output. However, leaning against the wind comes at the cost of higher volatility in inflation and marginally higher mean inflation rate, implying a tradeoff between price stability and financial stability.

Figure 5 shows counterfactual paths to a financial crisis. Financial crises have been identified in the baseline parametrization as the period where the equilibrium in the interbank market changes from trade to no trade. For each identified crisis, the state variables together with the shocks that lead up to the crisis are fed into the three specifications discussed above. This exercise confirms the evidence regarding volatility of macroeconomic aggregates and the tradeoffs associated with price and financial stability. A central bank that leans against the wind slows down the accumulation of savings by the households (see panel (a)). This reduces the fragility of the banking sector in the model and prevents most financial crises from materializing. As a result of the dampened build-up there is no sharp drop in output (panel (b)) and consumption (panel (g)) resulting in lower volatility of macroeconomic aggregates. However, inflation and nominal rates sharply rise shortly before the financial crisis would have happened in the baseline parametrization (see panels (j) and (k)). A central bank that follows a strict inflation targeting regime is able to keep

Figure 5: Counterfactual Paths to Financial Crises



Notes: Based on simulation of the model for 500,000 periods. Financial crises are identified as the period where the equilibrium in the interbank market changes from trade to no trade in the baseline calibration. The identified states at $t = -25$ and the path of shocks are then fed into the model under alternative parameterizations. All paths are medians over all identified crises paths.

inflation at the target even in the face of the credit boom. While it fails to dampen the build-up relative to the baseline parametrization, it nevertheless prevents financial crises due to the fact that marginal costs (markups) are fully stabilized and as a result the corporate loan rate does not fall as much in the run up to the crises. This also shows up in the 1-step ahead probability of crisis which is substantially lower than in the baseline parametrization, but not as low as in the case of a central bank that is leaning against the wind (see panel (f)). In general, the downside risks to growth as measured by growth at risk, i.e. the 5th percentile of 1-step ahead output growth rates, are much lower under LAW than under the other policies (see panel (c)).

Figure 10 in Appendix D compares the IRFs under the alternative monetary policy specifications. It shows how the response of assets to TFP shocks is more dampened when the central bank leans against the wind. Note, however, that these IRFs start at the stochastic steady state. Since the model is solved non-linearly the IRFs will also be dependent on where the economy is in the state space when the shocks hit.

To summarize, in the short run price stability promotes financial stability. However, in the medium run the central bank can improve financial stability even further by leaning against the wind. This reduces the frequency of financial crisis and the volatility of macroeconomic aggregates beyond what strict inflation targeting can achieve.

4.5 Welfare Implications

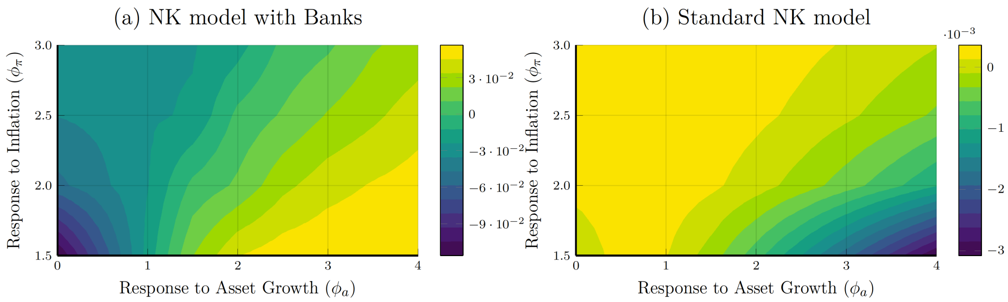
While Section 4.4 has shown the central bank can have important effects on financial stability in the model and it is beneficial to lean against the wind from the perspective of reducing macroeconomic volatility and the frequency of financial crises, this does not mean that it is actually beneficial from a welfare perspective. For example, output and consumption during the boom phases are dampened under the leaning against the wind policy in comparison to the baseline or strict inflation targeting cases, meaning there could be potentially welfare losses associated with leaning against the wind.

Figure 6 shows the consumption equivalent welfare relative to the strict inflation targeting case for different combinations of the Taylor rule parameters ϕ_π and ϕ_a. Additionally, Table 3 shows the welfare results for some parameter combinations in tabular form. While the welfare gains are relatively modest, they show an interesting pattern. Given a level of the Taylor rule coefficient on inflation ϕ_π, a stronger response of the central bank to deposit growth (higher ϕ_a) improves welfare.[20] Thus, a leaning-against-the-wind type of policy is welfare improving in this framework.

As discussed before, these welfare gains are due to the fact that a higher ϕ_a reduces the

[20]This relationship does not need to be monotone, i.e. does not imply that the central bank should try to slow down deposit growth at all cost. At some point costs of higher inflation and the implicit losses in output due to lower accumulation of assets will reduce welfare again. For the range of values shown in Figure 6, this does not seem to be the case yet.

Figure 6: Consumption Equivalent Welfare



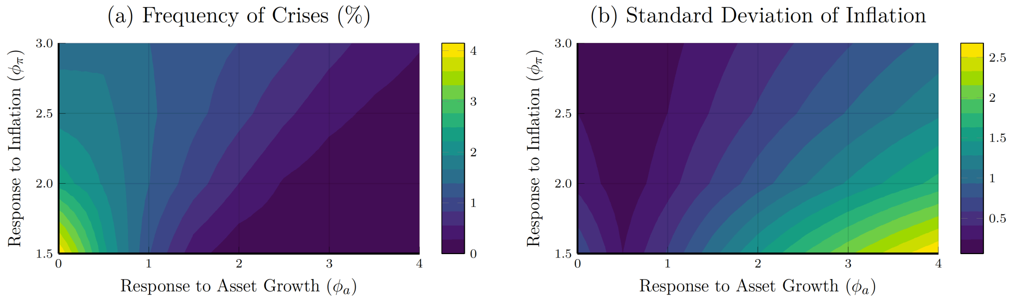
Notes: Consumption equivalent welfare is computed relative to the strict inflation targeting case. For example, suppose that $\phi_\pi = 1.5$ and $\phi_a = 3.0$ yields a value of 0.06%. This means that a household would be indifferent between living in the strict inflation targeting economy and an economy where $\phi_\pi = 1.5$ and $\phi_a = 3.0$, if it receives 0.06% additional consumption each period in the strict inflation targeting economy. In other words, the economy with $\phi_\pi = 1.5$ and $\phi_a = 3.0$ yields a higher welfare.

Table 3: Welfare Statistics

	Consumption Equivalent Welfare (%)	
Reference Model	Strict Inflation Targeting	Constrained Efficient
$\phi_\pi = 1.5,\ \phi_a = 0.0$	−0.12	−0.60
$\phi_\pi = 1.5,\ \phi_a = 2.0$	0.04	−0.44
$\phi_\pi = 1.5,\ \phi_a = 3.0$	0.06	−0.43
$\phi_\pi = 1.5,\ \phi_a = 4.0$	0.06	−0.43
$\phi_\pi = 2.0,\ \phi_a = 0.0$	−0.05	−0.53
$\phi_\pi = 2.5,\ \phi_a = 0.0$	−0.04	−0.52
$\phi_\pi = 3.0,\ \phi_a = 0.0$	−0.03	−0.51

Notes: Consumption equivalent welfare is computed relative to the strict inflation targeting (without macroprudential policy) or the constrained efficient case where in addition to strict inflation targeting the macroprudential authority follows an optimal policy. A positive value means that welfare is higher under the specification denoted on the left than in the specification of a particular column.

Figure 7: Frequency of Financial Crises and Inflation Volatility



Notes: Based on simulations of the specifications for 500,000 periods.

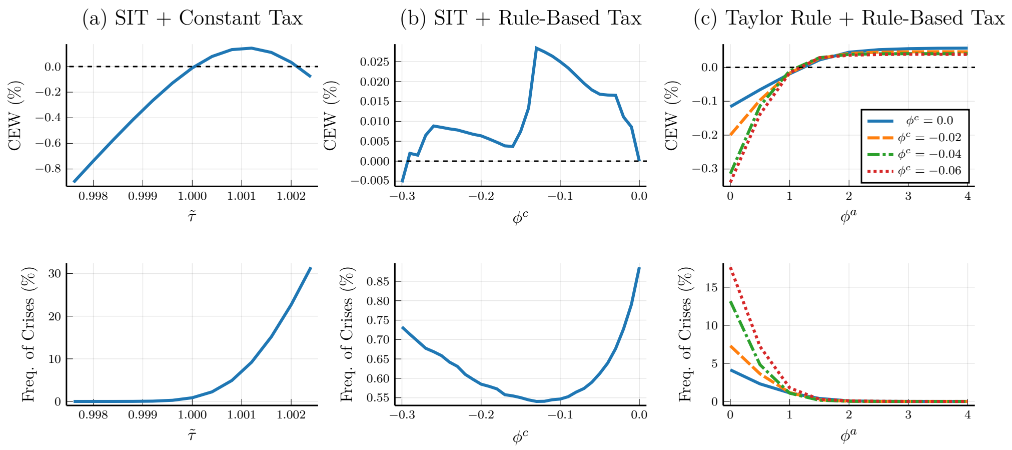
frequency of financial crises in the model as shown in the first panel of Figure 7, which results in less volatile consumption stream for households and a response to shocks closer to the constrained efficient response, which, ultimately, leads to higher welfare. Leaning against the wind helps agents partially internalize the savings glut externality in the absence of optimal macroprudential policy.

The results for the New Keynesian model developed in this paper stand in strong contrast with the results in the standard New Keynesian model. As Figure 6 shows, reacting to asset growth[21] is always welfare decreasing in the standard model. As discussed in Section 3.4, this is related to the fact that the divine coincidence holds in the standard New Keynesian model with capital. The divine coincidence does not hold in the model presented in this paper if the macroprudential authority does not implement the optimal policy. This is due to the fact that the constrained efficient allocation does not coincide with the natural allocation in such a case (see Section 3 for details).

This failure of the the divine coincidence introduces a tradeoff between financial stability and price stability. Alternatively, one can think of it as an inflation-output-gap stabilization tradeoff for the central bank, since strict inflation targeting does not close the welfare-relevant output gap anymore. A Taylor rule reacting to asset growth does take advantage of this and is a simple way to make agents (at least partially) internalize that they save too much if the economy is close to the absorption capacity. However, following such a Taylor rule, asset growth is slowed down in the whole state space, meaning that economic growth might be unnecessarily slowed down if the economy is still far away from the absorption capacity. Better results could be achieved in theory by implementing the optimal monetary policy in the presence of imperfect macroprudential policy, which this paper has not attempted to derive. However, the Taylor rule proposed in this paper provides a simple way that could also be followed in practice to reap some of the welfare gains of leaning against the wind.

[21] Since the banking sector is efficient in the standard New Keynesian model, we have that $k_t = a_{t-1}$ for all t and, thus, asset growth is equal to growth of the capital stock.

Figure 8: Macroprudential Rule Comparison



Notes: Consumption equivalent welfare is computed relative to SIT without macroprudential tax/subsidy except in column (c) where it is relative to SIT with the same coefficient for the macroprudential rule. A positive value means that welfare is higher under a given specification specification than the reference SIT specification. Frequency of crises is computed based on simulations of the specifications for 500,000 periods. The Taylor rule in column (c) uses $\phi_\pi = 1.5$.

4.6 Macroprudential Policy and Leaning Against the Wind

Leaning against the wind remains beneficial from a welfare perspective, even if the macroprudential authority follows a simple rule and reacts, for example, to the credit-to-output gap. This is not surprising, given that the argument for the non-optimality of strict inflation targeting under non-optimal macroprudential policy in Section 3 did not rely on any particular form for the suboptimal rule of the macroprudential authority.

Figure 8 compares different parametrization of the macroprudential rule and also shows how it interacts with monetary policy. Column (a) shows the results for strict inflation targeting (SIT) where the macroprudential authority chooses a constant tax/subsidy τ_t. As expected, a sufficiently large tax ($\tau_t = \tilde{\tau} < 1$) can reduce the frequency of financial crisis down to zero. By discouraging savings, the tax essentially shifts stochastic steady state, and with it the whole ergodic distribution, to a region of the state space, where it is very unlikely for a financial crisis to materialize. However, this is always welfare decreasing as shown in the first panel of column (a). At a first look somewhat surprisingly, it is possible to increase welfare by following a constant subsidy policy ($\tau_t = \tilde{\tau} > 1$). Likely this has to do with the fact that the stochastic steady state in the constrained efficient solution is characterized by higher savings due to the rebate externality. A subsidy does, however, entail even higher frequency of crisis (9.2%) than in the baseline calibration without macroprudential policy.

Column (b) shows the results for strict inflation targeting (SIT) where the macroprudential authority chooses to vary τ_t based on the credit-to-output gap. In particular, the figure shows negative values for ϕ_c meaning that a higher credit-to-output gap implies a lower

τ_t ($\tilde{\tau} = 1$ for simplicity). Such a policy is successful at reducing the frequency of crises and increasing welfare with the maximum at around $\phi_c = -0.12$. This highlights the importance of dynamically setting the macroprudential tax/subsidy over the credit cycle. As shown in column (a), a constant tax was always welfare decreasing, while a constant subsidy increased welfare but also increased the frequency of crises.

Column (c) shows how varying ϕ_a, the strength with which the central bank reacts to asset growth, interact with different values for ϕ_c, the strength with which the macroprudential authority reacts to the credit-to-output gap. While the welfare gains from leaning against the wind are a bit smaller when the macroprudential authority also reacts to the build-ups, it is still welfare improving for the checked parameter values. Note also that there seem to be important interactions between strict inflation targeting and macroprudential policy. While the parameter values for ϕ_c were always welfare improving under SIT (see column (b)), for the Taylor rules that don't react very strongly to inflation ($\phi_\pi = 1.5$ in column (c)) and to asset growth, welfare is substantially lower and the frequency of crisis substantially higher. This might have to do with the fact that in the run up to the crisis, the credit-to-output gap $\psi_t/\tilde{\psi}$ remains below 1 for longer under the baseline parametrization than under SIT or leaning against the wind (see panel (d) in Figure 5). Therefore, with some Taylor rule parameterizations the macroprudential authority might contribute to exacerbating the build-up by subsidizing savings in the run-up to the crisis and only relatively late switching to taxing savings.

5 Conclusions

I developed a New Keynesian model featuring endogenous build-ups of financial imbalances. To this end, I extended an otherwise standard New Keynesian model with a banking sector as in Boissay et al. (2016) and solved it using nonlinear solution techniques. The banking sector is characterized by frictions that can lead to freezes in the interbank market, or in other words, financial crises. The basic mechanism of Boissay et al. (2016) remains intact in this model, i.e. a sequence of positive productivity shocks can bring the economy closer to a region where even small negative productivity shocks or positive monetary policy shocks can lead to a financial crisis. The model is able to capture that financial crises often follow credit booms and does not require large exogenous shocks to generate financial crises.

In the framework developed in this paper, leaning against the wind is welfare improving as long as the macroprudential authority does not implement the optimal policy. The result is due to a failure of the divine coincidence in the presence of financial frictions in the banking sector, which introduces a tradeoff between price stability and financial stability for the central bank. The mechanism works by affecting the consumption smoothing decision of the household, which leads the household to accumulate less savings in response to productivity shocks. Thus, the interest rate policy of the central bank can in some cases prevent the economy from moving beyond its absorption capacity and can increase the stability of the financial sector. This leads to less frequent financial crises and higher welfare in comparison to cases where the central bank reacts less strongly (or not at all) to asset growth. It comes, however, at the cost of more volatile inflation. Crucially, a macroprudential authority that implements the optimal policy can overturn the result and restore the divine coincidence, making it optimal for the central bank to only be concerned with price stability again.

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A Derivations

A.1 Profit Maximization of Final Good Producer

The final good producer solves

$$\begin{aligned} \max_{\{\hat{y}_{it}\}} \quad & p_t \hat{y}_t - \int_0^1 p_{it} \hat{y}_{it} di \\ \text{s.t.} \quad & \hat{y}_t = \left(\int_0^1 \hat{y}_{it}^{\frac{\varepsilon-1}{\varepsilon}} di \right)^{\frac{\varepsilon}{\varepsilon-1}} . \end{aligned}$$

The first-order condition of this problem for each intermediate good i is

$$p_t \frac{\varepsilon}{\varepsilon - 1} \hat{y}_t^{\frac{1}{\varepsilon}} \frac{\varepsilon - 1}{\varepsilon} \hat{y}_{it}^{-\frac{1}{\varepsilon}} - p_{it} = 0 \, .$$

Rearranging yields the demand of the final good producer for good i

$$\hat{y}_{it} = \left(\frac{p_{it}}{p_t} \right)^{-\varepsilon} \hat{y}_t \, .$$

A.2 Cost Minimization of Intermediate Good Producers

Cost minimization problem of intermediate good producers

$$\begin{aligned} \min \quad & (1 - \bar{v}) \left[(r_t^k + \delta - 1) k_{it} + w_t n_{it} \right] \\ \text{s.t.} \quad & \hat{y}_{it} = z_t k_{it}^{\alpha} n_{it}^{1-\alpha} \, . \end{aligned}$$

From the first order conditions we have

$$\begin{aligned} n_{it} &= \left(\frac{1-\alpha}{\alpha} \frac{r_t^k + \delta - 1}{w_t} \right)^{\alpha} \frac{\hat{y}_{it}}{z_t} \\ k_{it} &= \left(\frac{\alpha}{1-\alpha} \frac{w_t}{r_t^k + \delta - 1} \right)^{1-\alpha} \frac{\hat{y}_{it}}{z_t} \end{aligned}$$

which implies that minimal cost $C(\hat{y}_{it})$ for producing an amount $\hat{y}_{it}$ is

$$C(\hat{y}_{it}) = (1 - \bar{v}) \left[(r_t^k + \delta) \left(\frac{\alpha}{1-\alpha} \frac{w_t}{r_t^k + \delta - 1} \right)^{1-\alpha} \frac{\hat{y}_{it}}{z_t} + w_t \left(\frac{1-\alpha}{\alpha} \frac{r_t^k + \delta - 1}{w_t} \right)^{\alpha} \frac{\hat{y}_{it}}{z_t} \right] .$$

Furthermore, the marginal cost of producing an additional unit is

$$m_t = \frac{dC}{d\hat{y}_{it}} = \frac{C(\hat{y}_{it})}{\hat{y}_{it}}$$

which can be rewritten as

$$\begin{aligned}
m_t &= (1-\bar{v}) \left(\frac{1-\alpha}{\alpha} \frac{r_t^k + \delta - 1}{w_t} \right)^{\alpha} \frac{1}{z_t} \left((r_t^k + \delta - 1) \frac{\alpha}{1-\alpha} \frac{w_t}{r_t^k + \delta - 1} + w_t \right) \\
&= (1-\bar{v}) \left(\frac{1-\alpha}{\alpha} \frac{r_t^k + \delta - 1}{w_t} \right)^{\alpha} \frac{1}{z_t} \frac{w_t}{1-\alpha} \\
&= \frac{1-\bar{v}}{z_t} \left(\frac{r_t^k + \delta - 1}{\alpha} \right)^{\alpha} \left(\frac{w_t}{1-\alpha} \right)^{1-\alpha} .
\end{aligned}$$

Note that the marginal cost are the same for all intermediate good producers.

A.3 Optimality Conditions of the Household

As discussed in Section 2.1, the problem of the household is

$$\begin{aligned}
&\max_{\{c_t, n_t, a_t, b_t\}_{t=0}^{\infty}} \mathrm{E}_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{c_t^{1-\sigma}}{1-\sigma} - \chi \frac{n_t^{1+\nu}}{1+\nu} \right) \\
&\text{s.t.} \quad c_t + a_t + b_t = w_t n_t + r_t^a a_{t-1} + \frac{R_{t-1}}{\pi_t} b_{t-1} + \Pi_t + \Theta_t + \Xi_t + \mathcal{T}_t \,.
\end{aligned}$$

The first order conditions of this problem for $t = 0, 1, \ldots$ are

$$\begin{aligned}
\beta^t c_t^{-\sigma} &= \lambda_t \\
\beta^t \chi n_t^{\nu} &= w_t \lambda_t \\
\lambda_t &= \mathrm{E}_t \left(\lambda_{t+1} \frac{R_t}{\pi_{t+1}} \right) \\
\lambda_t &= \mathrm{E}_t \left(\lambda_{t+1} r_{t+1}^a \right)
\end{aligned}$$

where λ_t is the Lagrange multiplier. Combining the FOC's yields the optimality conditions of the household

$$\begin{aligned}
\chi n_t^{\nu} &= w_t c_t^{-\sigma} \\
c_t^{-\sigma} &= \beta \mathrm{E}_t \left(c_{t+1}^{-\sigma} \frac{R_t}{\pi_{t+1}} \right) \\
c_t^{-\sigma} &= \beta \mathrm{E}_t \left(c_{t+1}^{-\sigma} r_{t+1}^a \right) .
\end{aligned}$$

The optimal decision of the housheold is characterized by two Euler equations and an intratemporal condition characterizing optimal labor supply.

A.4 Firm Price Setting (New Keynesian Phillips Curve)

As discussed in Section 2.2.2, the problem of the intermediate good producer is

$$\max_{p_{ik}} \mathrm{E}_t \sum_{k=t}^{\infty} q_{t,k} \left[\left(\frac{p_{ik}}{p_k} - m_t \right) \left(\frac{p_{ik}}{p_k} \right)^{-\varepsilon} \hat{y}_k - \frac{\theta}{2} \left(\frac{p_{ik}}{p_{ik-1}\tilde{\pi}} - 1 \right)^2 \hat{y}_k \right]$$

where $q_{t,t+1} = \beta \left(\frac{c_{t+1}}{c_t} \right)^{-\sigma}$, $q_{t,t} = 1$ and $q_{t,k} = \prod_{j=t+1}^{k} q_{j-1,j}$ is the stochastic discount factor and real marginal cost, m_t, follow from a cost minimization problem (see Appendix A.2).

The first order condition of this problem is

$$\mathrm{E}_t \left[q_{t,k} \left((1-\varepsilon) \left(\frac{p_{ik}}{p_k} \right)^{-\varepsilon} \frac{\hat{y}_k}{p_k} + \varepsilon m_k \left(\frac{p_{ik}}{p_k} \right)^{-\varepsilon-1} - \theta \left(\frac{p_{ik}}{p_{ik-1}\tilde{\pi}} - 1 \right) \frac{1}{p_{ik-1}\tilde{\pi}} \hat{y}_k \right) \right.$$
$$\left. - q_{t,k+1} \theta \left(\frac{p_{ik+1}}{p_{ik}\tilde{\pi}} - 1 \right) \left(- \frac{p_{ik+1}}{p_{ik}^2 \tilde{\pi}} \right) \hat{y}_{k+1} \right] = 0 \, .$$

Using the fact that all intermediate good producers are identical, we have in equilibrium that $p_{ik} = p_k$ for all i. Thus, by additionally setting $t = k$ we have

$$\left[(1-\varepsilon) \frac{\hat{y}_t}{p_t} + \varepsilon m_t \frac{\hat{y}_t}{p_t} - \theta \left(\frac{\pi_t}{\tilde{\pi}} - 1 \right) \frac{1}{p_{t-1}\tilde{\pi}} \hat{y}_t \right]$$
$$+ \mathrm{E}_t \left[q_{t,t+1} \theta \left(\frac{\pi_{t+1}}{\tilde{\pi}} - 1 \right) \frac{1}{p_t} \frac{\pi_{t+1}}{\tilde{\pi}} \hat{y}_{t+1} \right] = 0 \, .$$

Dividing by $\frac{\hat{y}_t}{p_t}$ and rearranging yields the New Keynesian Phillips curve

$$\left(\frac{\pi_t}{\tilde{\pi}} - 1 \right) \frac{\pi_t}{\tilde{\pi}} = \mathrm{E}_t \left[q_{t,t+1} \left(\frac{\pi_{t+1}}{\tilde{\pi}} - 1 \right) \frac{\pi_{t+1}}{\tilde{\pi}} \frac{\hat{y}_{t+1}}{\hat{y}_t} \right] + \frac{\varepsilon}{\theta} \left(m_t - \frac{\varepsilon - 1}{\varepsilon} \right) .$$

A.5 Intermediation costs

Intermediation costs are defined analogous to the return on assets, we have that

$$\Xi_t = \begin{cases} a_{t-1} r_t^k \int_{\bar{p}_t}^1 (1-p) \frac{d\mu(p)}{1-\mu(\bar{p}_t)} & \text{if an equilibrium with trade exists}\, , \\ a_{t-1} r_t^k \int_{q_t}^1 (1-p) d\mu(p) & \text{otherwise}\, . \end{cases}$$

where $q_t = \frac{\gamma}{r_t^k}$.

In the case that an equilibrium with trade in the interbank exists, we can rewrite Ξ_t as follows

$$\begin{aligned}\Xi_t &= a_{t-1} r_t^k \int_{\bar{p}_t}^1 (1-p) \frac{d\mu(p)}{1-\mu(\bar{p}_t)} \\ &= a_{t-1} \left(\underbrace{r_t^k \int_{\bar{p}_t}^1 \frac{1}{1-\mu(\bar{p}_t)} d\mu(p)}_{=1} - \underbrace{r_t^k \int_{\bar{p}_t}^1 p \frac{d\mu(p)}{1-\mu(\bar{p}_t)}}_{=\hat{r}_t^a} \right) \\ &= a_{t-1} \left(r_t^k - \hat{r}_t^a \right) .\end{aligned}$$

If an equilibrium with trade in the interbank market does not exists, we have

$$\begin{aligned}\Xi_t &= a_{t-1} r_t^k \int_{q_t}^1 (1-p) d\mu(p) \\ &= a_{t-1} \left(\underbrace{r_t^k \int_{q_t}^1 1 d\mu(p)}_{=1-\mu\left(\frac{\gamma}{r_t^k}\right)} - \underbrace{r_t^k \int_{q_t}^1 p d\mu(p)}_{=\hat{r}_t^a - \gamma\mu\left(\frac{\gamma}{r_t^k}\right)} \right) \\ &= a_{t-1} \left(r_t^k - \hat{r}_t^a \right) - \mu\left(\frac{\gamma}{r_t^k}\right) a_{t-1} \left(r_t^k - \gamma \right) \\ &= a_{t-1} \left(r_t^k - \hat{r}_t^a \right) + \underbrace{\left(1 - \mu\left(\frac{\gamma}{r_t^k}\right)\right) a_{t-1}}_{=k_t} \left(r_t^k - \gamma \right) - a_{t-1} \left(r_t^k - \gamma \right) \\ &= a_{t-1} \left(r_t^k - \hat{r}_t^a \right) - (a_{t-1} - k_t) \left(r_t^k - \gamma \right) .\end{aligned}$$

Note that this equation holds, both, when there is and when there is no trade in the interbank market, since it collapses to the equation with trade in the interbank market when $k_t = a_{t-1}$. Thus, we have in general that

$$\Xi_t = \left(r_t^k - \hat{r}_t^a \right) a_{t-1} - \left(r_t^k - \gamma \right) (a_{t-1} - k_t) .$$

A.6 Optimality Conditions

The following conditions determine the solution of the model

$$\chi n_t^{\nu} = w_t c_t^{-\sigma} \qquad \text{(Labor FOC)}$$

$$c_t^{-\sigma} = \beta \mathrm{E}_t \left(c_{t+1}^{-\sigma} \frac{R_t}{\pi_{t+1}} \right) \qquad \text{(Euler equation for bonds)}$$

$$c_t^{-\sigma} = \beta \mathrm{E}_t \left(c_{t+1}^{-\sigma} r_{t+1}^a \right) \qquad \text{(Euler equation for deposits)}$$

$$\left(\frac{\pi_t}{\tilde{\pi}} - 1 \right) \frac{\pi_t}{\tilde{\pi}} = \mathrm{E}_t \left(q_{t,t+1} \left(\frac{\pi_{t+1}}{\tilde{\pi}} - 1 \right) \frac{\pi_{t+1}}{\tilde{\pi}} \frac{\hat{y}_{t+1}}{\hat{y}_t} \right) + \frac{\varepsilon}{\theta} \left(m_t - \frac{\varepsilon - 1}{\varepsilon} \right) \qquad \text{(Firm price setting)}$$

$$\hat{y}_t = z_t k_t^{\alpha} n_t^{1-\alpha} \qquad \text{(Production function)}$$

$$y_t = \hat{y}_t + (\gamma + \delta - 1)(a_{t-1} - k_t) \qquad \text{(Total output)}$$

$$\log z_t = \rho_z \log z_{t-1} + e_t \qquad \text{(Productivity process)}$$

$$m_t = \frac{1}{z_t}\left(\frac{r_t^k + \delta - 1}{\alpha}\right)^{\alpha}\left(\frac{w_t}{1-\alpha}\right)^{1-\alpha} \qquad \text{(Real marginal cost)}$$

$$\frac{k_t}{n_t} = \frac{\alpha}{1-\alpha}\frac{w_t}{r_t^k + \delta - 1} \qquad \text{(Capital-labor ratio)}$$

$$R_t = \tilde{R}\left(\frac{\pi_t}{\tilde{\pi}}\right)^{\phi_\pi}\left(\frac{a_t}{a_{t-1}}\right)^{\phi_a} \qquad \text{(Taylor rule)}$$

$$\tau_t = \tilde{\tau}\left(\frac{\psi_t}{\tilde{\psi}}\right)^{\phi_c} \qquad \text{(Macroprudential rule)}$$

$$\psi_t = \frac{k_t}{y_t} \qquad \text{(Credit-output ratio)}$$

$$x_t = a_t - (1-\delta)a_{t-1} \qquad \text{(Law of motion for “potential capital”)}$$

$$y_t = c_t + x_t \qquad \text{(Resource constraint)}$$

$$b_t = 0 \qquad \text{(Bond market)}$$

The equilibrium conditions for the banking sector depend on if there is an equilibrium with trade in the interbank market or not (see Section 2.3.3 and 2.6.1 for details). If an equilibrium with trade does exist, the following conditions determine the solution

$$\mu\left(\frac{\rho_t}{r_t^k}\right) = \left[1 - \mu\left(\frac{\rho_t}{r_t^k}\right)\right]\frac{\rho_t - \gamma}{\gamma\vartheta} \qquad \text{(Interbank market)}$$

$$k_t = a_{t-1} \qquad \text{(Corporate loan market)}$$

$$r_t^a = \tau_{t-1} r_t^k \int_{\bar{p}_t}^{1} p \frac{d\mu(p)}{1 - \mu(\bar{p}_t)} \qquad \text{(Deposit rate)}$$

On the other hand, if an equilibrium with trade does not exist, we have that the solution is determined by

$$\rho_t = \gamma \qquad \text{(Interbank market)}$$

$$k_t = \left[1 - \mu\left(\frac{\gamma}{r_t^k}\right)\right] a_{t-1} \qquad \text{(Corporate loan market)}$$

$$r_t^a = \tau_{t-1} r_t^k \left[q_t \mu(q_t) + \int_{q_t}^{1} p\, d\mu(p)\right] \qquad \text{(Deposit rate)}$$

where $q_t = \frac{\gamma}{r_t^k}$.

Endogenous variables are c_t, n_t, b_t, k_t, a_t x_t, y_t, $\hat{y}_t$, z_t, m_t, π_t, τ_t, ψ_t, w_t, R_t, ρ_t, r_t^k, and r_t^a. Exogenous variables are e_t, z_t, a_0 and z_0.

A.7 Constrained Efficient Real Model

The model setup is the same as described in Section 2 except that there are no price adjustment costs, i.e $\theta = 0$. The social planner solves the same problem as the representative household, except that the planner also takes into account how the savings decision affects the corporate loan rate and takes into account that intermediation costs are rebated back to him/her. Essentially, this boils down to maximizing utility not only subject to the budget constraint but also all equilibrium conditions summarized in Appendix A.6 (except for the Euler equations).

The problem can be substantially simplified by combining some of these conditions. In particular, we can rewrite the budget constraint as follows

$$
\begin{aligned}
c_t + a_t + b_t &= w_t n_t + r_t^a a_{t-1} + \frac{R_{t-1}}{\pi_t} b_{t-1} + \Pi_t + \Theta_t + \Xi_t + \mathcal{T}_t \\
&= w_t n_t + \underbrace{\hat{r}_t^a \tau_{t-1}}_{=r_t^a} a_{t-1} + \frac{R_{t-1}}{\pi_t} b_{t-1} + \underbrace{(1-m_t)\hat{y}_t}_{=\Pi_t+\Theta_t} \\
&+ \underbrace{\left(r_t^k - \hat{r}_t^a\right) a_{t-1} - \left(r_t^k - \gamma\right)(a_{t-1} - k_t)}_{=\Xi_t} \\
&+ \underbrace{(1-\tau_{t-1})\,\hat{r}_t^a a_{t-1} - \bar{v}\left[(r_t^k + \delta - 1)k_t + w_t n_t\right]}_{=\mathcal{T}_t} \\
&= w_t n_t + r_t^k k_t + \frac{R_{t-1}}{\pi_t} b_{t-1} + (1-m_t)\hat{y}_t + \gamma\,(a_{t-1} - k_t) \\
&- \bar{v}\left[(r_t^k + \delta - 1)k_t + w_t n_t\right] \\
&= (1-\bar{v})\left[(r_t^k + \delta - 1)k_t + w_t n_t\right] + (1-\delta)k_t \\
&+ \frac{R_{t-1}}{\pi_t} b_{t-1} + (1-m_t)\hat{y}_t + \gamma\,(a_{t-1} - k_t) \\
&= m_t \hat{y}_t + (1-m_t)\hat{y}_t + (1-\delta)k_t + \gamma\,(a_{t-1} - k_t) + (1-\delta)a_{t-1} + \frac{R_{t-1}}{\pi_t} b_{t-1}\,.
\end{aligned}
$$

Finally, using the fact that $b_t = 0$ for all t and $\hat{y}_t = z_t k_t^\alpha n_t^{1-\alpha}$, we have that

$$
c_t + a_t = z_t k_t^\alpha n_t^{1-\alpha} + (1-\delta)k_t + \gamma\,(a_{t-1} - k_t)\;, \tag{10}
$$

which is the budget constraint in Definition 3.1.

Note that we can further rewrite this if we wanted to. We have that

$$
c_t + a_t = \underbrace{z_t k_t^\alpha n_t^{1-\alpha} + (\gamma + \delta - 1)(a_{t-1} - k_t)}_{=y_t} + (1-\delta)a_{t-1}\,,
$$

which is simply the resource constraint of this economy.

Since $\theta = 0$, the New Keynesian Phillips curve in equation (1) collapses to

$$m_t = \frac{\varepsilon - 1}{\varepsilon} \,.$$

Furthermore, from the first-order conditions of the cost minimization problem of intermediate good producers (see Appendix A.2) one can show that

$$\begin{aligned} r_t^k &= \frac{\alpha}{1-\bar{v}} z_t m_t \left(\frac{k_t}{n_t}\right)^{\alpha-1} - \delta + 1 \,, \\ w_t &= \frac{1-\alpha}{1-\bar{v}} z_t m_t \left(\frac{k_t}{n_t}\right)^{\alpha} \,. \end{aligned}$$

Since there is a production subsidy $\bar{v} = 1 - \frac{\varepsilon-1}{\varepsilon}$ and $m_t = \frac{\varepsilon-1}{\varepsilon}$, we have that the factor costs of production simplify to

$$\begin{aligned} r_t^k &= \alpha z_t \left(\frac{k_t}{n_t}\right)^{\alpha-1} - \delta + 1 \,, \\ w_t &= (1-\alpha) z_t \left(\frac{k_t}{n_t}\right)^{\alpha} \,, \end{aligned} \tag{11}$$

which are the standard firm FOCs with a Cobb-Douglas production function. Combining the expression for w_t with the first order condition for labor $\chi n_t^{\nu} = w_t c_t^{-\sigma}$ yields

$$n_t = \left[\frac{1-\alpha}{\chi} z_t\right]^{\frac{1}{\nu+\alpha}} c_t^{-\frac{\sigma}{\nu+\alpha}} k_t^{\frac{\alpha}{\nu+\alpha}} \,. \tag{12}$$

The only remaining equations relevant for the social planner problem are then equations (4), (10), (11), and (12), which are all used in Definition 3.1.

B A New Keynesian Model with Capital

In the following, I show the setup and optimality conditions of the standard New Keynesian. This model is used as a reference for some of the IRFs that are shown in Section 4.2 and for the welfare comparison in Section 4.5.

B.1 Model Setup

Household. The household chooses $\{c_t, n_t, k_t, b_t\}_{t=0}^{\infty}$ to solve the following problem

$$\max_{\{c_t,n_t,k_t,b_t\}_{t=0}^{\infty}} \mathrm{E}_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{c_t^{1-\sigma}}{1-\sigma} - \chi \frac{n_t^{1+\nu}}{1+\nu} \right)$$
$$\text{s.t.} \quad c_t + k_t + b_t = w_t n_t + r_t^k k_{t-1} + \frac{R_{t-1}}{\pi_t} b_{t-1} + \Pi_t + \Theta_t + \mathcal{T}_t$$

Firms. The intermediate good producers face Rotemberg adjustment cost and choose prices in each period t to solve the following problem

$$\max_{p_{ik}} \mathrm{E}_t \sum_{k=t}^{\infty} q_{t,k} \left[\left(\frac{p_{ik}}{P_k} - m_t \right) \left(\frac{p_{ik}}{p_k} \right)^{-\varepsilon} y_k - \frac{\theta}{2} \left(\frac{p_{ik}}{p_{ik-1}\tilde{\pi}} - 1 \right)^2 y_k \right]$$

where $q_{t,t+1} = \beta \left(\frac{c_{t+1}}{c_t} \right)^{-\sigma}$, $q_{t,t} = 1$ and $q_{t,k} = \prod_{j=t+1}^{k} q_{j-1,j}$ is the stochastic discount factor.

The production function of intermediate good producers is

$$y_t = z_t k_{t-1}^{\alpha} n_t^{1-\alpha}$$

and log TFP $\log z_t$ follows an AR(1) process

$$\log z_t = \rho_z \log z_{t-1} + e_t\,.$$

Costs minimization yields that real marginal costs are

$$m_t = \frac{1}{z_t} \left(\frac{r_t^k + \delta - 1}{\alpha} \right)^{\alpha} \left(\frac{w_t}{1-\alpha} \right)^{1-\alpha}.$$

Government. Bonds are in zero net supply. Thus, $b_t = 0$ for all t.

Monetary Policy. The central bank follows a Taylor rule

$$R_t = \tilde{R} \left(\frac{\pi_t}{\tilde{\pi}} \right)^{\phi_\pi} \left(\frac{k_t}{k_{t-1}} \right)^{\phi_y}$$

where $\tilde{R}$ and $\tilde{\pi}$ are the steady-state nominal interest rate and inflation, respectively.

Resource constraint. Since the price adjustment costs, the profits of firms and macroprudential taxes are redistributed to households, the resource constraint for this economy is

$$y_t = c_t + x_t$$

where $x_t = k_t - (1 - \delta)k_{t-1}$ are gross additions to the capital stock.

B.2 Optimality Conditions

The following conditions determine the solution of the model

$$\chi n_t^\nu = w_t c_t^{-\sigma} \quad \text{(Labor FOC)}$$

$$c_t^{-\sigma} = \beta \mathrm{E}_t \left(c_{t+1}^{-\sigma} \frac{R_t}{\pi_{t+1}} \right) \quad \text{(Euler equation for bonds)}$$

$$c_t^{-\sigma} = \beta \mathrm{E}_t \left(c_{t+1}^{-\sigma} r_{t+1}^k \right) \quad \text{(Euler equation for capital)}$$

$$\left(\frac{\pi_t}{\tilde{\pi}} - 1 \right) \frac{\pi_t}{\tilde{\pi}} = \mathrm{E}_t \left(q_{t,t+1} \left(\frac{\pi_{t+1}}{\tilde{\pi}} - 1 \right) \frac{\pi_{t+1}}{\tilde{\pi}} \frac{y_{t+1}}{y_t} \right) + \frac{\varepsilon}{\theta} \left(m_t - \frac{\varepsilon - 1}{\varepsilon} \right) \quad \text{(Firm price setting)}$$

$$y_t = z_t k_{t-1}^\alpha n_t^{1-\alpha} \quad \text{(Production function)}$$

$$\log z_t = \rho_z \log z_{t-1} + e_t \quad \text{(Productivity process)}$$

$$m_t = \frac{1}{z_t} \left(\frac{r_t^k + \delta - 1}{\alpha} \right)^\alpha \left(\frac{w_t}{1 - \alpha} \right)^{1-\alpha} \quad \text{(Real marginal cost)}$$

$$\frac{k_{t-1}}{n_t} = \frac{\alpha}{1 - \alpha} \frac{w_t}{r_t^k + \delta - 1} \quad \text{(Capital-labor ratio)}$$

$$R_t = \tilde{R} \left(\frac{\pi_t}{\tilde{\pi}} \right)^{\phi_\pi} \left(\frac{y_t}{\tilde{y}} \right)^{\phi_y} \exp(\xi_t) \quad \text{(Taylor rule)}$$

$$x_t = k_t - (1 - \delta)k_{t-1} \quad \text{(Law of motion for capital)}$$

$$y_t = c_t + x_t \quad \text{(Resource constraint)}$$

$$b_t = 0 \quad \text{(Bond market)}$$

Endogenous variables are c_t, n_t, b_t, k_t, x_t, y_t, z_t, m_t, π_t, w_t, R_t, and r_t^k. Exogenous variables are e_t, z_t, k_0 and z_0.

B.3 Log-linearized Optimality Conditions

Log-linearization around the steady state yields

$$\nu\hat{n}_t = \hat{w}_t - \sigma\hat{c}_t \qquad \text{(Labor FOC)}$$

$$-\sigma\hat{c}_t = -\sigma \mathrm{E}_t\left(\hat{c}_{t+1}\right) + \hat{R}_t - \mathrm{E}_t\left(\hat{\pi}_{t+1}\right) \qquad \text{(Euler equation for bonds)}$$

$$-\sigma\hat{c}_t = -\sigma \mathrm{E}_t\left(\hat{c}_{t+1}\right) + \mathrm{E}_t\left(\hat{r}^k_{t+1}\right) \qquad \text{(Euler equation for capital)}$$

$$\hat{\pi}_t = \frac{\varepsilon - 1}{\theta}\hat{m}_t + \beta \mathrm{E}_t\left(\hat{\pi}_{t+1}\right) \qquad \text{(Firm price setting)}$$

$$\hat{y}_t = \hat{z}_t + \alpha\hat{k}_{t-1} + (1-\alpha)\hat{n}_t \qquad \text{(Production function)}$$

$$\hat{z}_t = \rho_z\hat{z}_{t-1} + e_t \qquad \text{(Productivity process)}$$

$$\hat{m}_t = -\hat{z}_t + \alpha\frac{1}{1+\beta(\delta-1)}\hat{r}^k_t + (1-\alpha)\hat{w}_t \qquad \text{(Real marginal cost)}$$

$$\hat{k}_{t-1} - \hat{n}_t = \hat{w}_t - \frac{1}{1+\beta(\delta-1)}\hat{r}^k_t \qquad \text{(Capital-labor ratio)}$$

$$\hat{R}_t = \phi_\pi\hat{\pi}_t + \phi_y\hat{y}_t + \xi_t \qquad \text{(Taylor rule)}$$

$$\delta\hat{x}_t = \hat{k}_t - (1-\delta)\hat{k}_{t-1} \qquad \text{(Law of motion for capital)}$$

$$\hat{y}_t = \frac{c}{y}\hat{c}_t + \frac{x}{y}\hat{x}_t \qquad \text{(Resource constraint)}$$

Note that the log-linearized solution itself is used as an initial guess for the nonlinear solution of this New Keynesian model with capital.

C Solution Algorithm

The solution algorithm is based on Richter et al. (2014). In particular, I use a policy function iteration approach that uses linear interpolation for states that are off the grid. It follows the steps described in Algorithm 1.

Algorithm 1 (Solution Algorithm)**.**

1. *Define grids of points for the state variables* $a_{t-1} \in [a_{min}, a_{max}]$ *and* $z_t \in [z_{min}, z_{max}]$
2. *Make a guess for policy functions* $a'(a_{t-1}, z_t)$, $\pi(a_{t-1}, z_t)$ *and* $c(a_{t-1}, z_t)$. *I set the intial guess to the respective policies of the log-linear NK model with capital.*
3. *For each grid point* (a_{t-1}, z_t), *use a nonlinear solver to find the policy variables* (a_t, π_t, c_t) *that satisfy the Euler equations and the firm pricing equation. The solver calls a function that determines the equilibrium allocations by*
   (a) *Solving for time t variables using all equilibrium conditions (except those that contain expectations)*
   (b) *Computing* $t + 1$ *values for policy variables using linear interpolation (based on the current guess for the policy functions)*
   (c) *Solving for the remaining* $t + 1$ *variables and computing the expectation using the* $t + 1$ *values for the policy variables*
   ⇒ *Finally, the function returns the error in Euler equations and firm price setting equation to the solver*
4. *Update the policy functions* $a'(a_{t-1}, z_t)$, $\pi(a_{t-1}, z_t)$ *and* $c(a_{t-1}, z_t)$ *using the policy variables determined by the solver for each grid point*

Iterate on steps 3 and 4 until the mean squared error in policy functions between successive iterations is less than a given degree of precision.

To further improve the accuracy of the solution around the discontinuity, I compute two separate policy functions for each of the three policy variables over the whole state space, which are patched together when evaluating expectations. In one it is imposed that the interbank market works and in the other it is imposed that the interbank market does not work.[22] This avoids large approximation errors near the discontinuity which would otherwise arise due to the linear interpolation of off grid values. A similar approach is employed by Gust et al. (2017) to solve a model with a zero lower bound on nominal interest rates.

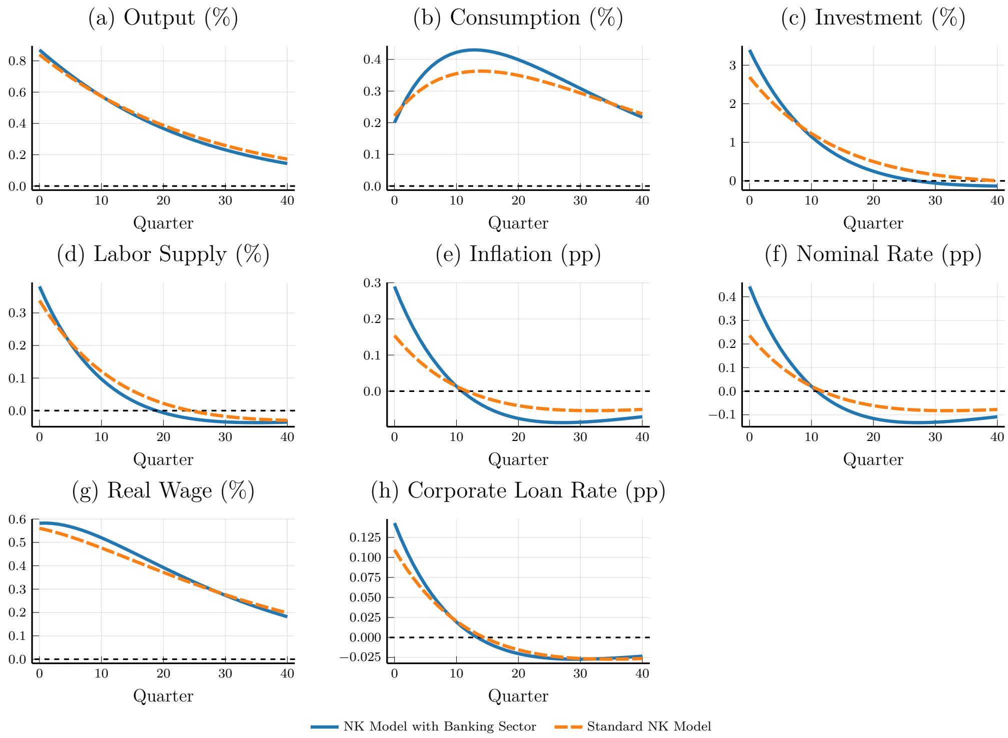
[22]This requires, however, to take a stance on how the interbank market rate is determined in the part of the state space that does not support an equilibrium with trade in the interbank market. For relatively dense grids it has been proven acceptable to assume that $\rho_t = \bar{\rho}$, i.e. the interbank market is stuck at the threshold value.

Note that in the RBC model of Boissay et al. (2016) the only policy variable was the choice of savings for next period. In the NK version of the model, the policy variables are $\{a_t, \pi_t, c_t\}$. All other variables can be derived from the state variables and their associated policy variables. Thus, finding a solution to the model boils down to finding the policy variables for each combination of state variables.

To solve the constrained efficient model, I use value function iteration on the grid of state variables. I use linear interpolation to evaluate policies off the grid and cubic spline interpolation to interpolate the value function off the grid. In this case, it has proven to be useful to start from a very coarse grid and successively refine the grid to improve the accuracy of the solution.

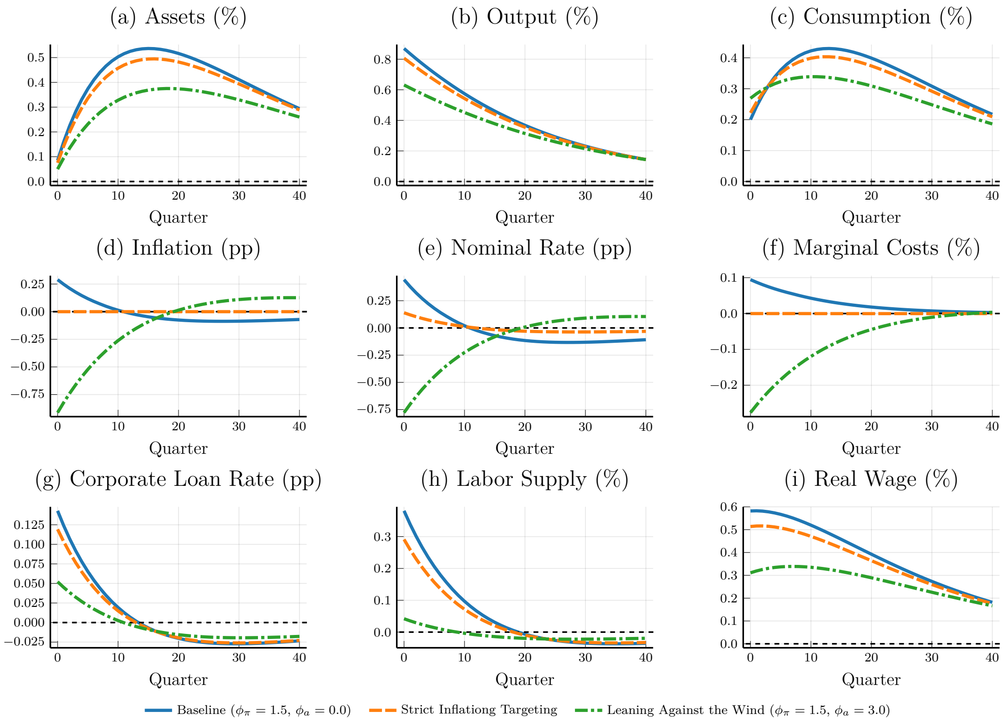
D Additional Figures

Figure 9: Comparison of Impulse Response Functions: Productivity (TFP) Shock



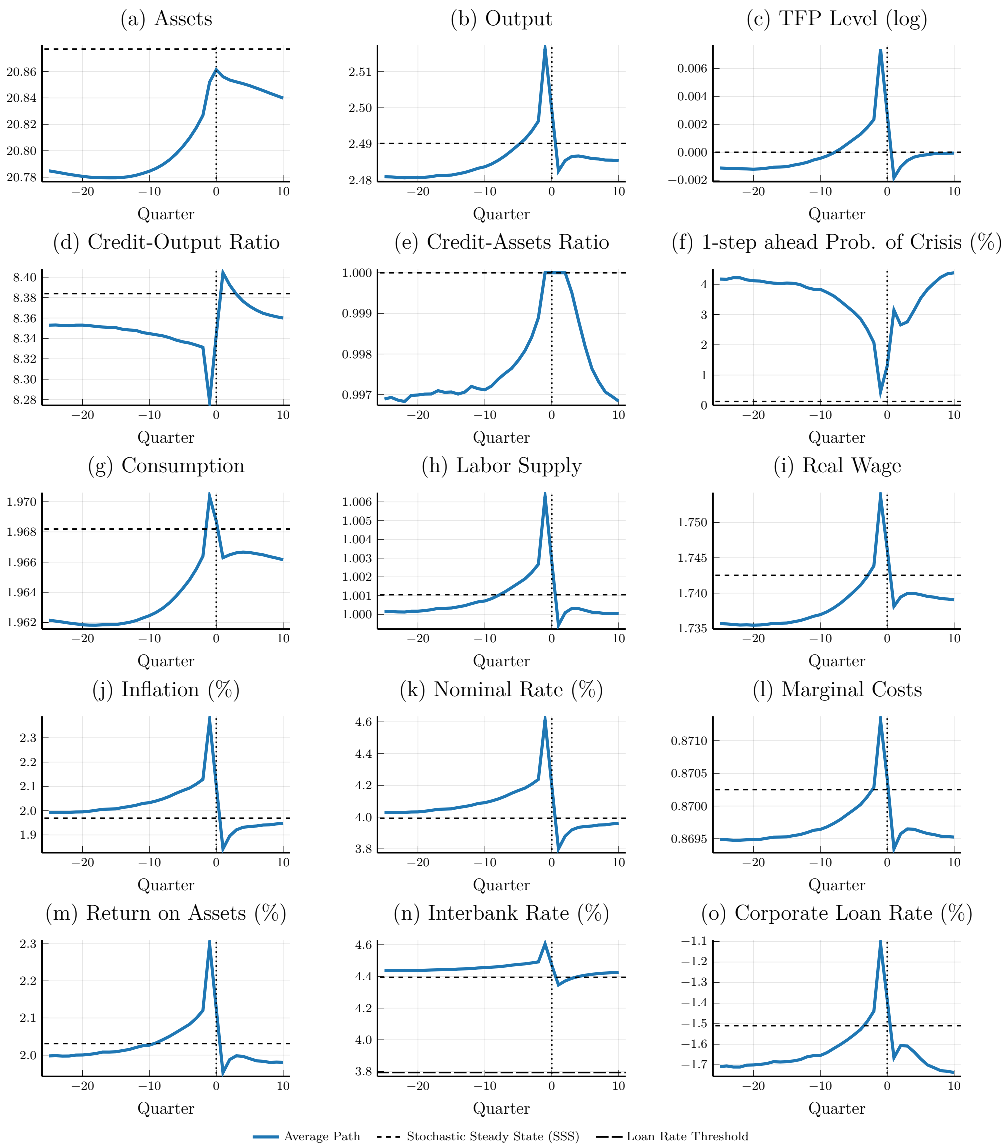
Notes: IRFs are in response to a one standard deviation productivity (TFP) shock. See Appendix B for details on the model setup of the Basic New Keynesian model with Capital.

Figure 10: Impulse Response Functions under Alternative Monetary Policy Specifications



Notes: IRFs are in response to a one standard deviation productivity (TFP) shock.

Figure 11: Typical Path to Recessions



Notes: Based on simulation of the model for 500,000 periods. Recessions are identified at least two consecutive periods with negative growth in output without there being also a financial crisis. In the figure a Recession starts at $t = 0$.