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Abstract

We examine the *social* and *agent-specific* welfare effects of monetary and macroprudential policy in a four-agent estimated macroeconomic model, consisting of *'banked simple households'*, *'underbanked simple households'*, *'firm owners'*, and *'bank owners'*. Optimal capital requirement and loan loss provisions ratios, are shown to improve all agent-specific and social welfare, but imply smaller gains for simple households and *firm owners* that rely on credit. Countercyclical capital buffers support *firm owners* and *bank owners*, with smaller gains for the two simple households. Countercyclical loan loss provisions improve social welfare only for specific shocks and benefit the 'simple underbanked household' and 'firm-owners' at the expense of 'bank-owners' and 'banked simple households'. Coordination between monetary and macroprudential policies yields higher social welfare than no coordination.

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The views expressed in this paper are authors' own and they do not necessarily represent the views of the institutions they are affilicted to.

1 Introduction

In response to the 2008 financial crisis, that reduced consumer confidence and real wages and resulted in a sustained economic recession, there has been a surge in the number of policy and academic papers exploring potential macroprudential policies. Most of these papers focus on the welfare of 'borrowers' and 'savers' and relate, predominantly, to the housing market. One of the main challenges of splitting the economy into pure 'borrowers' and 'savers', is that if all interest-earning agents are lumped as 'savers', then a simple household earning just a deposit rate is clustered in the same group as financial investors and bankers who may be earning loan rates, equity rates and other portfolio returns.[1] Moreover, macroprudential policies that derive welfare gains for savers, may conclude that they benefit mutually wealthy bankers and simple deposit holding households. This is in contrast to the wide debate that followed the global financial crisis, that wanted to separate the simple household from the bankers. The macroprudential policy implications of this stark distinction between 'borrowers' and 'savers', can become more relevant when the policy focus moves away from the housing market to overall economic activity and different types of shocks to those affecting the housing market.

In this paper we shift the focus of macroprudential policy away from the usual emphasis on 'borrowers' and 'savers' and the housing market, to different agent types and the overall production in the economy. We introduce a four-agent New Keynesian DSGE model, to examine the welfare implications of monetary and macroprudential policy for, *'firm owners'*, *'bank owners'* and *'simple households'*, where the latter is further categorised into *'banked simple households'* and '*underbanked simple households'*. Using data from Compustat and the Survey of Consumer Finances, *firm owners* are represented by the share of the US economy that are shareholders of non-financial firms; *bank owners* by the share of the US economy that are shareholders of all credit intermediation and related financial services; and *simple households* by the remaining share of the population that have no shares in any sector. Using data from the National Survey of Unbanked and Underbanked Households, we categorise *simple households* into *banked simple households'*, those who do not own either firms or banks but have savings and *'underbanked simple households'*, those who are similar to the former type, but have very little or no access to banking services or savings and thus resemble non-Ricardian hand-to-mouth households.[2]

Based on these population shares, we develop a DSGE model where each of the four utility maximizing agents has a unique income stream. The model features nominal, real and financial frictions, two layers of endogenous probability of default, for borrowers and banks, and a *deposit*

[1] A recent example of this type of clustering is the 'patient dynasty' in Mendicino et al. (2018).
[2] The four agent types are described in more detail in section 3.

insurance scheme financed by all agents.[3] It also accounts for trend inflation, trend growth and stochastic growth shocks. The model is first estimated to US quarterly data for the period 1985 Q1 to 2016 Q4, using Bayesian techniques, and then its estimates are used to examine the welfare effects of monetary and macroprudential policy for the four types of agents separately and for the aggregate economy as a whole. Our four-agent estimated model, shows investment shocks to be the most important contributor to volatility in GDP growth, (27.41%) with productivity shocks being the second most important (22.92%). Financial risk shocks explain approximately 20% of GDP volatility over the period examined, a value twice as large as the 10% reported in Smets and Villa (2016),[4] but still lower than the approximately 60% suggested in Christiano, Motto, and Rostagno (2014).[5] The model can be used to examine a number of policy questions. We focus on the interaction of monetary policy, (optimal interest rate rules), and macroprudential policy, in the form of optimal *bank capital requirement* ratios and *countercyclical capital buffer* rules. We also examine the effects of the optimal *loan loss reserves to total loans* ratio (LLP ratio) and the role of *dynamic loan loss provisions*, (dynamic LLP). Finally, we examine the effects of non-coordinated responses between the monetary and macroprudential authorities.

The results indicate that the social optimal bank *capital requirement ratio*, (CRR) is 12.6%. This is 2.1% higher than the current CRR ratio set by Basel III, and 4.6% higher than that of Basel II. It is also 3.6% higher than the optimal CRR of 9% suggested in Mendicino et al. (2019), that use a 'borrower-saver' focused welfare analysis, although it is lower than the stricter regulatory requirements suggested in some other studies.[6] Unlike the bulk of the 'borrower-saver' literature, where 'savers' usually benefit and 'borrowers' lose from stricter macroprudential policy, in this model the welfare effects are very asymmetric across the four agents considered. Increasing the capital requirement ratio up to approximately 12.2% is shown to raise the welfare of all four agents in this model, although not equally, with smaller gains for simple households and business owners who rely on credit. Stricter capital requirements, above that ratio, are shown to harm 'firm-owners' and 'simple households', while still benefit 'bank owners', because although such policy reduces loans, it increases the share of bank capital in funding loans for investment projects. At higher CRR, (above 25.9%), bank owners are shown to be harmed too, as at such very strict levels of macroprudential regulation, loans fall dramatically and the economy enters a long phase of dampened economic activity.

Countercyclical capital buffers are also shown to increase social welfare, but again very

[3]Extending our model to account for housing can also include a probability of default of the mortgage borrowers as it is the focus in Clerc et al. (2015) and Mendicino et al. (2018), but this is beyond the scope of this paper.
[4]It is the cumulative contribution of wealth and risk premium shocks in the above study.
[5]In that study this includes the contribution of news shocks.
[6]See, for example, Admati et al. (2010), and Karmakar (2016).

asymmetrically across the four agents. Such policy is shown to benefit the 'firm-owners' and to a lesser degree the 'bank-owners', but it implies much smaller welfare gains to the two simple household types. The shocks for which countercyclical capital buffers matter the most, are productivity and credit risk shocks. For productivity shocks the highest welfare gains are achieved by the 'firm owners', whereas for credit risk shocks such policy benefits the 'bank owners' the most. The 'underbanked simple households', whose only income is wages, are shown to make small welfare gains during productivity shocks, but following credit risk shocks they are the only agent not to gain from such policy. Interestingly, for a number of other shocks, such as monetary policy, investment prices, fixed production costs, technological growth, or net worth transfer shocks, the model indicates that countercyclical capital buffers cannot make a sizeable net contribution to social welfare, in addition to what is already provided by optimal monetary policy (see also Angelini, Neri, and Panetta (2014) and Quint and Rabanal (2014)).

The results also suggest an optimal LLP ratio of 6.3%, which is substantially higher to the average ratio of 2.03% in the US banking system for the period examined. Similar high values are indicated for the optimal ratios of all four individual agent-types in the model, with the lowest, 6.0%, being that for 'firms-owners' whose wealth relies on loans, and the highest 7% for bank-owners, who have the most to lose from banks defaulting. For the simple households this ratio lies in between these two, with the 'banked' households who are more exposed to bank risk, at a higher level (6.8%), than that of the 'underbanked' households, (6.3%). In general, loan loss provisions are shown to insulate the economy from credit risk and reduce substantially the default probability of the bank. They also reduce the cost of deposit insurance, the policy rate and the real deposit rate. These effects increase, up to approximately a 5-6% LLP ratio, the consumption and welfare of all agents, as well as aggregate consumption and social welfare. However, at higher ratios loan loss provisions are shown to reduce substantially loans and consumption, at both individual and aggregate levels, and thus economic growth (Laeven and Majnoni (2003)), resulting in this model in a fall in agent-specific and social welfares.

Dynamic LLP, responding countercyclically to expected non-performing loans, can make a significant net contribution to social welfare, but only if they are activated for shocks that affect expected loan losses and thus the performance of firms, (shocks to, productivity, net transfers to entrepreneurs, and stochastic growth shocks). However, in normal times they are shown to make no net welfare contribution to optimal monetary policy. This result is consistent with the fact that banks usually hold a very low level of loan loss provisions, but loan reserves increased rapidly in response to the 2008 financial crisis and even more so following the 2019 pandemic, suggesting a dynamic loan loss response. Overall, *dynamic countercyclical capital* *buffers* and, to some extent *dynamic* LLP, are shown to reduce the volatility of interest rates and increase social welfare. However, unlike *dynamic countercyclical capital buffers* that are shown to support mostly, 'firm-owners' and 'bank owners', *dynamic* LLP benefit the 'underbanked simple household' and 'firm-owners' at the expense of 'banked households' and 'bank owners'. A fundamental difference between the two is that a higher CRR does not necessarily imply a decrease in loans, as long as this ratio can be satisfied by more bank capital. This also means that a higher CRR can boost the power and welfare of bank owners. However, a higher LLP ratio (all else remaining unchanged), implies a direct decrease in bank loans, to buffer against potential loan losses. This implies less profits to banks, but also a lower level of required bank capital, as there is a decrease in loans. Thus unlike the effects of the CRR, a higher LLP ratio implies that bank owners lose part of their bank profits and capital share. Overall, as this paper shows, either higher CRR or LLP ratios, reduce the default probability of banks. This ensures a flow of loans to the real sector which benefit families and households. Although in this paper, a higher LLP ratio may imply that 'banked simple households' may also lose some welfare, as the reduction in loans is met by a decrease in the demand for both bank capital and deposits. Finally, the paper shows that although coordinated policies are not always Pareto superior to non-coordinated policies, coordination results in a higher social welfare than no coordination.

The rest of the paper is structured as follows. Section 2 discusses the related literature. Section 3 describes the theoretical framework of the four-agent DSGE model. Section 4, discusses the information used in the calibration and estimation of the model and presents the estimation results. Section 5, examines the welfare effects of the monetary and macroprudential policies considered and summarises the mains results. Section 6 examines the role of non-coordination between monetary and macroprudential policies, and 7 concludes.[7]

2 Related literature

Although this paper introduces a new policy framework, based on four agents that are different to pure 'borrowers' or 'savers', our results can still be placed within the literature that examines how the interaction of monetary and macroprudential policy affect different agents and social welfare. The bulk of this literature builds on the two-agent model, ('patient' and 'impatient'), by Iacoviello (2005), that focuses on housing assets. Iacoviello (2015) extends this by incorporating a utility maximising banker to evaluate and estimate how financial shocks can affect the real sector. This 'borrower-saver' framework has since been extended to account explicitly for the role of macroprudential and monetary policy rules, in a closed economy, (Rubio (2011), Lambertini,

[7]Other model details, proofs and simulations are provided in the supplementary Online Technical Appendix.

Mendicino, and Punzi (2013), Rubio and Carrasco-Gallego (2014, 2016)) and also in two-country models, (Rubio (2014), Brzoza-Brzezina, Kolasa, and Makarski (2015)). Some recent papers have extended this framework to examine the effects of endogenous default in two-sector, or multi-sector economies. For example, Quint and Rabanal (2014) adapt the Bernanke, Gertler, and Gilchrist (1999) (BGG) financial accelerator model to a two-sector estimated housing model and show that a stricter CRR reduces macroeconomic volatility and it increases the welfare of 'savers'. Similar results are shown in Clerc et al. (2015) and Mendicino et al. (2018), who use a model with several wealth channels and three layers of default, calibrated to the Euro Area. Some of these papers show that at low levels of bank capital regulation both savers and borrowers gain welfare, but as the CRR approaches the minimum value of Basel II, (8%), or become stricter, aggregate welfare gains are attributed only to savers, (Lambertini, Mendicino, and Punzi (2013), Mendicino et al. (2018)). Overall, there seems to be a growing consensus in the literature that tighter macroprudential policy supports the welfare of savers and although it makes borrowers worse off, it increases social welfare overall. An attempt to measure the welfare of bankers separately, within the Iacoviello (2015) 'borrower-saver' framework, is provided in Rubio and Carrasco-Gallego (2016, 2017). They show that although a stricter CRR results in a trade-off between borrowers and savers, the welfare effects move in the opposite direction, with borrowers having a positive second-order effect, whereas savers and bankers a negative one.

The results on *countercyclical capital buffers* vary significantly in the literature, although this is also subject to the policy rule used. Most of the related literature uses countercyclical capital rules that respond to either, credit deviations from steady state, (Quint and Rabanal (2014), Rubio and Carrasco-Gallego (2014, 2016)), Bekiros, Nilavongse, and Uddin (2018)), or to the credit-output ratio (Angelini, Neri, and Panetta (2014), Quint and Rabanal (2014)). Most of the papers that use the former type, as we also employ in this paper, find that such rules benefit the savers more than the borrowers, (Quint and Rabanal (2014), Rubio and Carrasco-Gallego (2014)). This is also supported by Mendicino et al. (2018) where countercyclical capital buffers respond to deviations of the expected default risk of each borrower-type from their steady-state values. However, some papers support the opposite view, that such rules promote the 'borrowers' more than the 'savers' (Lambertini, Mendicino, and Punzi (2013), Rubio and Carrasco-Gallego (2016)), and they can harm bankers (Rubio and Carrasco-Gallego (2016)). The general message from this literature, including this paper, is that countercyclical capital requirements help reduce interest rate volatility, increase social welfare and make the economy more resilient to shocks.

The literature appears to shed less light on the role of *loan loss provisions*, (LLP). In practice, dynamic LLP, were first introduced in Spain in 2000, when its economy had reached the lowest

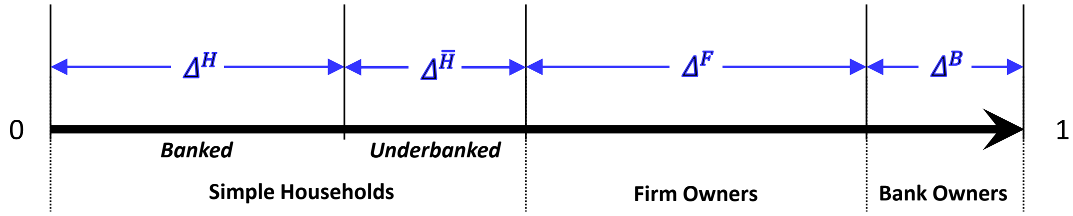
LLP to loans ratio and the highest cyclicality of LLP among OECD countries; they have also been used by some Latin American countries, (Bolivia, Chile, Colombia, Mexico, Peru and Uruguay). The limited empirical evidence we have on dynamic LLP supports its use. Saurina (2009) shows that the introduction a fast credit growth in the 1990s resulted in an increased risk and higher loan losses in Spain, but following the introduction of loan provisions in 2000, Spain experienced a strong credit expansion with a reduced level of procyclicality and non-performing loans, up to the housing market crisis in 2007. Using counterfactual simulations, Wezel, Chan-Lau, and Columba (2012) also provide strong support for dynamic LLP as a countercyclical buffer building tool that can reduce banks' probability of default.[8] More recently, Olszak, Roszkowska, and Kowalska (2018) using individual bank data from over 65 countries also show that dynamic LLP are effective in reducing the procyclicality of loan losses. Both these results are consistent with the findings in our model, where the introduction of LLP are shown to reduce risk and the probability of default of banks and the procyclicality of loans. There is also limited theoretical work on the role of the LLP for social welfare, and even less so for the welfare of heterogeneous agents, as we examine here. The few papers that exist focus largely on the role of dynamic LLP and examine mainly aggregate welfare effects. In this literature dynamic LLP follow rules that usually target expected loan losses (Bouvatier and Lepetit (2012), Agénor and Da Silva (2017)). Since our model is driven by the endogenous default probabilities of firms and banks, we employ a dynamic LLP rule that responds to deviations of expected 'non-performing loans', which are subject to the expected probability of default of borrowers.

3 The Four-Agent DSGE Model

We consider an economy that is populated by four different types of agents: simple households, consisting of *banked simple households* and *underbanked simple households*, *non-financial firm owners* and *bank owners*. The families of these four agent types are distributed in space $[0, 1]$, with 'banked simple households' distributed between $[0, \varDelta^H]$, underbanked simple households between $[\varDelta^H, \varDelta^H + \varDelta^{\overline{H}}]$, non-financial 'firm owners' between $[\varDelta^H + \varDelta^{\overline{H}}, \varDelta^H + \varDelta^{\overline{H}} + \varDelta^F]$, and 'bank owners' between $[\varDelta^H + \varDelta^{\overline{H}} + \varDelta^F, 1]$, where their size is given by, $\varDelta^H$, $\varDelta^{\overline{H}}$, $\varDelta^F$, and $\varDelta^B \left(= 1 - \varDelta^H - \varDelta^{\overline{H}} - \varDelta^F\right)$ respectively, as illustrated in figure 1. To keep the four agent types consistent and comparable, we assume that all family members of each agent type derive utility from consumption and leisure, they can all have access to financial markets (except the underbanked simple households), they all hold deposits in banks, and for simplicity, they all

[8]Other studies that also use counterfactual simulations produce similar results, Balla and McKenna (2009) and Wezel (2010).

Figure 1: Distribution of Agents



work in the production sector that produces all consumption and investment goods.[9] However, the levels of consumption, leisure and deposits for each agent type are different due to their idiosyncratic budget constraints, consisting of unique types of incomes streams. Deposits are guaranteed, up to a fixed level, by a government monitored *deposits insurance scheme*, and so for simplicity they are treated as the 'risk-free' asset. *Banked simple households*, have no ownership in either firms or banks, and thus their only income source is their wages and the interest income from their deposits. *Underbanked simple households* are similar to banked simple households, but they are assumed to have little or no access to banking, thus their behaviour is similar to non-Ricardian households who consume their disposable income from wages (hand-to-mouth). *Firm owners* are the owners of all non-financial firms in the economy, producing consumption and investment goods. The non-financial sector consists of a multitude of entrepreneurs managing risky investment projects, many monopolistic competitive intermediate goods producing firms, a competitive final goods producer, and a competitive capital goods producer. Entrepreneurs are modelled similar to Bernanke, Gertler, and Gilchrist (1999) and Christiano, Motto, and Rostagno (2014), however, all their financial transactions are made with the 'firm owner' (rather than the household as in those models). They use their net worth and loans from banks to purchase capital from capital producers and provide capital services to the intermediate goods producing firms for a rental income. 'Firm owners' provide an initial lump sum transfer to entrepreneurs, and they receive a proportion of entrepreneurs' wealth at the end of each period. Entrepreneurial projects experience idiosyncratic shocks, thus their return on capital and their loans, carry a risk which is factored in by banks when deciding the loan interest rate. The used capital stock is sold back to capital goods producers and newly produced capital is purchased in each period (Carlstrom, Fuerst, and Paustian (2016)). 'Firm owners' receive, profits from all intermediate goods firms, profits from capital producers and net transfers from entrepreneurs.

[9]The assumption that all agents work in the production sector is also to keep the model closer to the way we disaggregate the data, since people working in one sector cannot be restricted to also owning that sector. (i.e. anyone working in the banking sector may hold non-financial firm shares and similarly any firms or individuals working in the non-financial firm sector may hold bank shares). Another issue arising in assuming that agents work only in their respective sector, is the difficulty in obtaining data on wages for work-from-home households and for different levels of bank workers. Thus, with no loss in generality, we assume that all agents receive the same wage and focus on their other income streams that are specific to their type.

Bank owners are the owners of the financial sector (banks). They provide bank capital to banks, for which they receive a risky return. As the shareholders of all banks, they also receive any profits made by banks. Banks raise loan funds from bank deposits, (from all agents other than 'underbanked simple household'), and from bank capital provided by 'bank owners', subject to the *bank capital requirement ratio* and their own *loan loss provisions.* Banks also carry a risk of default and their default probability is endogenously affected by the size of the risk shock, their loan return, the deposit rate, and monetary and macroprudential policy responses. The production and labour markets are characterised by differentiation and price and wage stickiness, as employed widely in the literature.[10] In this model labour markets are differentiated within each agent-type, but through a two-stage aggregation (via two labour contactors, one at the agent-type family level and another at the economy-wide level) they result into a homogenous labour bundle, where all members of the four agent-type families earn the same average wage. Finally, there is a monetary authority that undertakes monetary and macroprudential policies and a government whose main role is limited to setting fiscal policy in a way that satisfies the safety of deposits through its *deposits insurance scheme.*

3.1 Banked Simple Households

The expected lifetime utility of each member h, of the 'banked simple household' family H is[11]

$$\mathbb{E}_t \sum_{s=0}^{\infty} \left(\beta^H\right)^s \left\{ \mathcal{U}\left(c^H_{h,t+s}, c^H_{t+s-1}\right) - \mathcal{V}\left(n^H_{h,t+s}\right) \right\}, \tag{1}$$

where, $c^H_{h,t}$ and $n^H_{h,t}$ are the consumption and labour hours of member h, respectively, β^H is the discount factor and $\mathbb{E}_t(\cdot)$ is the expectations operator. $\mathcal{U}(\cdot)$ and $\mathcal{V}(\cdot)$ define preferences over consumption and leisure, respectively, that are assumed to be similar across all four agents:

$$\mathcal{U}\left(c^H_{h,t}, c^H_{t-1}\right) = \log\left(c^H_{h,t} - \varsigma c^H_{t-1}\right), \tag{2}$$

$$\mathcal{V}\left(n^H_{h,t}\right) = \psi_n \frac{\left(n^H_{h,t}\right)^{1+\eta}}{1+\eta}, \tag{3}$$

[10] Christiano, Eichenbaum, and Evans (2005), Faia and Monacelli (2007), An and Schorfheide (2007).

[11] Capital letter superscripts, $X = H, \overline{H}, F, B$, denote the respective agent-type families, whereas lower case subscripts $x = h$, $\overline{h}$, f, b, denote individual family members in their respective agent-type family. So, $c^H_{h,t}$ is the consumption of the banked simple household member h in agent type family H; c^H_t is the equilibrium *per capita* level of consumption of banked simple households; $\Delta^H c^H_t$ is the aggregate consumption of all banked simple households and c_t is aggregate consumption. The aggregate equilibrium is described in section 3.12.

where, ς, is external habit persistence in consumption, $\psi_n > 0$ and η is the inverse of the Frisch elasticity of labour supply.[12] The budget constraint of the 'banked simple household' is,

$$c^H_{h,t} \leqslant n^H_{h,t} \frac{W^H_{h,t}}{P_t} - d^H_{h,t} \left(1 + \frac{\kappa_D}{2} \left(\frac{d^H_{h,t}}{c^H_t} - \frac{d^H}{c^H}\right)^2\right) + \frac{\widetilde{R}^D_t d^H_{h,t-1}}{\pi_t} - \tau^H_{h,t}, \tag{4}$$

where, $W^H_{h,t}$ is the nominal wage rate received by banked household member h, P_t is the aggregate price level, π_t is the gross inflation rate, $d^H_{h,t}$ is deposits, $\tau^H_{h,t}$ is a lump-sum tax, and $\widetilde{R}^D_t$ is the average gross nominal return on deposits, explained below. There is an adjustment cost, κ_D, when agents deviate from their steady state deposits-to-consumption ratio.[13] Each 'banked simple household' chooses, consumption ($c^H_{h,t}$), nominal wages ($W^H_{h,t}$), and deposits ($d^H_{h,t}$), to maximise (1), subject to (4). At the symmetric, per capita equilibrium, we derive:[14]

$$\mathcal{U}^H_{c,t} \left[1 + \frac{\kappa_D}{2} \left(\frac{d^H_t}{c^H_t} - \frac{d^H}{c^H}\right)^2 + \kappa_D \left(\frac{d^H_t}{c^H_t} - \frac{d^H}{c^H}\right) \frac{d^H_t}{c^H_t}\right] = \beta^H \mathbb{E}_t \left\{\mathcal{U}^H_{c,t+1} \frac{\widetilde{R}^D_{t+1}}{\pi_{t+1}}\right\}, \tag{5}$$

where $\mathcal{U}^H_{c,t}$ is the marginal utility of banked simple households' current consumption,

$$\mathcal{U}^H_{c,t} = \frac{S^U_t}{c^H_t - \varsigma c^H_{t-1}}. \tag{6}$$

3.2 Underbanked Simple Households

The expected lifetime utility of each member $\overline{h}$, of the 'underbanked simple households' family $\overline{H}$, is modelled similar to 'hand-to-mouth' consumers in the fiscal policy related literature. Accordingly, each member consumes their entire wage income, net of taxes, in each period:[15]

$$\mathbb{E}_t \sum_{s=0}^{\infty} \left(\beta^{\overline{H}}\right)^s \left\{\mathcal{U}\left(c^{\overline{H}}_{\overline{h},t+s}, c^{\overline{H}}_{t+s-1}\right) - S^N_{t+s}\, \mathcal{V}\left(n^{\overline{H}}_{\overline{h},t+s}\right)\right\}, \tag{7}$$

subject to the budget constraint:

$$c^{\overline{H}}_{\overline{h},t} \leqslant n^{\overline{H}}_{\overline{h},t} \frac{W^{\overline{H}}_{\overline{h},t}}{P_t} - \tau^{\overline{H}}_{\overline{h},t}, \tag{8}$$

where, $c^{\overline{H}}_{\overline{h},t}$ is consumption, $n^{\overline{H}}_{\overline{h},t}$ is the quantity of hours worked, $W^{\overline{H}}_{\overline{h},t}$ is the corresponding nominal wage rate, and $\tau^{\overline{H}}_{\overline{h},t}$ is a lump-sum tax. Wage setting is discussed in section 3.10.

[12]The parameters ψ_n and η are also assumed to be common across all agent types.
[13]The assumption of family specific adjustment costs allows us to derive explicit demand for deposits for each family that are required for deriving aggregate deposits, (see also Mumtaz and Theodoridis (2017)).
[14]For more details see in the Online Technical Appendix.
[15]This is written as a life-time utility maximisation problem because of wage-setting and wage stickiness.

3.3 Non-Financial Firm Owners

Each member f, of the 'non-financial firm owners' family F, maximises:

$$\mathbb{E}_t \sum_{s=0}^{\infty} \left(\beta^F\right)^s \Big\{ \mathcal{U}\left(c^F_{f,t+s}, c^F_{t+s-1}\right) - \mathcal{V}\left(n^F_{f,t+s}\right) \Big\}, \tag{9}$$

subject to their budget constraint:

$$c^F_{f,t} \leqslant n^F_{f,t} \frac{W^F_{f,t}}{P_t} - d^F_{f,t} \left(1 + \frac{\kappa_D}{2}\left(\frac{d^F_{f,t}}{c^F_t} - \frac{d^F}{c^F}\right)^2\right) + \frac{\widetilde{R}^D_t d^F_{f,t-1}}{\pi_t} + \Pi^F_{f,t} + \Pi^K_{f,t} + \Pi^E_{f,t} - \tau^F_{f,t}, \tag{10}$$

where $c^F_{f,t}$, $n^F_{f,t}$, $d^F_{f,t}$ and $W^F_{f,t}$, are consumption, labour hours, deposits and the nominal wage of 'firm owner' f, respectively. As 'firm owners' also receive profits from intermediate goods producing firms, $\Pi^F_{f,t}$, and capital producers, $\Pi^K_{f,t}$, and net transfers from entrepreneurs, $\Pi^E_{f,t}$, while they pay a lump sum tax, $\tau^F_{f,t}$. Each firm owner chooses, $c^F_{f,t}$, $W^F_{f,t}$ and $d^F_{f,t}$, to maximise (9), subject to (10). At the per capita symmetric equilibrium we obtain,

$$\mathcal{U}^F_{c,t} = \frac{S^U_t}{c^F_t - \varsigma c^F_{t-1}}, \tag{11}$$

$$\mathcal{U}^F_{c,t}\left[1 + \frac{\kappa_D}{2}\left(\frac{d^F_t}{c^F_t} - \frac{d^F}{c^F}\right)^2 + \kappa_D\left(\frac{d^F_t}{c^F_t} - \frac{d^F}{c^F}\right)\frac{d^F_t}{c^F_t}\right] = \beta^F \mathbb{E}_t\left\{\mathcal{U}^F_{c,t+1}\frac{\widetilde{R}^D_{t+1}}{\pi_{t+1}}\right\}. \tag{12}$$

3.4 Bank Owners

Each member b, of the 'bank owners' family B, maximises their expected lifetime utility,

$$\mathbb{E}_t \sum_{s=0}^{\infty} \left(\beta^B\right)^s \Big\{ \mathcal{U}\left(c^B_{b,t+s}, c^B_{t+s-1}\right) - \mathcal{V}\left(n^B_{b,t+s}\right) \Big\}, \tag{13}$$

subject to their budget constraint,

$$\begin{aligned} c^B_{b,t} \leqslant n^B_{b,t} \frac{W^B_{b,t}}{P_t} - d^B_{b,t} \left(1 + \frac{\kappa_D}{2}\left(\frac{d^B_{b,t}}{c^B_t} - \frac{d^B}{c^B}\right)^2\right) + \frac{\widetilde{R}^D_t d^B_{b,t-1}}{\pi_t} - \left(e^B_{b,t} + \zeta\frac{\mu^*_{z,t} e^B_{b,t-1}}{\pi_t}\right) \\ + \frac{\left(1-\Theta_t\right) R^E_t e^B_{b,t-1}}{\pi_t} + \Pi^B_{b,t} - \tau^B_{b,t}, \end{aligned} \tag{14}$$

where $c^B_{b,t}$, $d^B_{b,t}$, $n^B_{b,t}$ and $W^B_{b,t}$, are consumption, deposits, labour hours, and the nominal wage rate of bank owner b, respectively. Bank owners also provide banks with equity, (bank capital), in real terms $e^B_{b,t}$. We assume bank equity adjustment costs that increase proportionally to changes in economic activity, $\mu^*_{z,t}$, where ζ regulates the size of these costs.[16] As with 'the banked simple households' and 'firm owners', 'bank owners' also receive a deposit return, and as with all four types of families they too receive the same wage and pay their respective lump-sum tax, $\tau^B_{b,t}$. In addition, they receive, a bank equity return, R^E, with a probability, $1-\Theta_t$, where Θ_t is the bank default probability (derived below). At the end of each period each member of the 'bank owners' family also receives any profits by banks, $\Pi^B_{b,t}$.[17] Each bank owner chooses $c^B_{b,t}$, $W^B_{b,t}$, $d^B_{b,t}$ and $e^B_{b,t}$, to maximise (13), subject to (14). From the first order conditions we obtain:

$$\mathcal{U}^B_{c,t} = \frac{S^U_t}{c^B_t - \varsigma c^B_{t-1}}, \tag{15}$$

$$\mathcal{U}^B_{c,t}\left[1 + \frac{\kappa_D}{2}\left(\frac{d^B_t}{c^B_t} - \frac{d^B}{c^B}\right)^2 + \kappa_D\left(\frac{d^B_t}{c^B_t} - \frac{d^B}{c^B}\right)\frac{d^B_t}{c^B_t}\right] = \beta^B \mathbb{E}_t\left\{\mathcal{U}^B_{c,t+1}\frac{\widetilde{R}^D_{t+1}}{\pi_{t+1}}\right\}, \tag{16}$$

$$\mathcal{U}^B_{c,t} = \beta^B \mathbb{E}_t\left\{\mathcal{U}^B_{c,t+1}\frac{R^E_{t+1}\left(1-\Theta_{t+1}\right)}{\pi_{t+1}}\right\} - \zeta\beta^B\mathbb{E}_t\left\{\mathcal{U}^B_{c,t+1}\frac{\mu^*_{z,t+1}}{\pi_{t+1}}\right\}, \tag{17}$$

where, $\mathcal{U}^B_{c,t}$ is the marginal utility of consumption of bank owners. From the above first order conditions we derive the required equity rate:

$$R^E_{t+1} = \mathbb{E}_t\left\{\frac{\widetilde{R}^D_{t+1}}{\left(1-\Theta_{t+1}\right)}\left(1 + \frac{\kappa_D}{2}\left(\frac{d^B_t}{c^B_t} - \frac{d^B}{c^B}\right)^2 + \kappa_D\left(\frac{d^B_t}{c^B_t} - \frac{d^B}{c^B}\right)\frac{d^B_t}{c^B_t}\right)^{-1} + \frac{\zeta\mu^*_{z,t+1}}{\left(1-\Theta_{t+1}\right)}\right\}. \tag{18}$$

Equation (18), shows the equity rate to be positively related to the deposit rate, the probability of bank default, Θ_t, and economic growth, $\mu^*_{z,t+1}$.

3.5 Entrepreneurs

3.5.1 Earnings of Entrepreneurs

The behaviour of entrepreneurs follows a variation of Bernanke, Gertler, and Gilchrist (1999) and Christiano, Motto, and Rostagno (2014), where there exists a large number of entrepreneurs, each managing a risky capital project, although here entrepreneurial projects are owned by non-financial 'firms owners'. Each $\mathcal{N}$-type entrepreneur combines net worth $\mathcal{N}$, with loans $B^{\mathcal{N}}_t$ from banks, to purchase capital $K^{\mathcal{N}}_t$ from capital producers at per unit price Q_t: $Q_t K^{\mathcal{N}}_t = \mathcal{N} + B^{\mathcal{N}}_t$. If the distribution of entrepreneurs is $h_t(\mathcal{N})$, the aggregate levels of capital stock K_t, loans B_t, and net worth $\mathcal{N}_t$, are $K_t = \int_0^\infty K^{\mathcal{N}}_t h_t(\mathcal{N})\,d\mathcal{N}$, $B_t = \int_0^\infty B^{\mathcal{N}}_t h_t(\mathcal{N})\,d\mathcal{N}$, and $\mathcal{N}_t = \int_0^\infty \mathcal{N} h_t(\mathcal{N})\,d\mathcal{N}$.

[16]This assumption implies a positive correlation between bank equity returns and economic activity which improves the estimation of the model.

[17]Since we assume that banks break even in each state of the economy, at equilibrium bank profits are zero.

After they purchase new capital, entrepreneurs experience an idiosyncratic shock, which converts capital into $\varepsilon K_t^{\mathcal{N}}$ units; ε is an idiosyncratic risk shock, drawn from a unit mean log-normal distribution with standard deviation, σ_t^{ε}; $\log\left[\sigma_t^{\varepsilon}\right] = \left(1-\rho^{\sigma^{\varepsilon}}\right)\log\left[\sigma^{\varepsilon}\right] + \rho^{\sigma^{\varepsilon}}\log\left[\sigma_{t-1}^{\varepsilon}\right] + \epsilon_t^{\sigma^{\varepsilon}}$, where $\epsilon_t^{\sigma^{\varepsilon}} \sim \mathcal{N}\left(0, \left[\sigma^{\sigma^{\varepsilon}}\right]^2\right)$. After observing period $t+1$ shocks, entrepreneurs choose the capital utilisation rate $u_{t+1}^{\mathcal{N}}$ to provide capital services, $\overline{k}_{t+1}^{\mathcal{N}} = u_{t+1}^{\mathcal{N}}\varepsilon K_t^{\mathcal{N}}$, to intermediate firms at the competitive real rental rate r_{t+1}^K. Following Schmitt-Grohé and Uribe (2012), the rate of capital depreciation $\delta\left(u_t^{\mathcal{N}}\right)$ is a function of the utilisation rate, $\delta\left(u_t^{\mathcal{N}}\right) = \delta_0 + \delta_1\left(u_t^{\mathcal{N}}-1\right) + \frac{\delta_2}{2}\left(u_t^{\mathcal{N}}-1\right)^2$; δ_0, $\delta_1 > 0$. At the end of period $t+1$, entrepreneur $\mathcal{N}$ sell their remaining capital $\left(1-\delta\left(u_{t+1}^{\mathcal{N}}\right)\right)\varepsilon K_t^{\mathcal{N}}$, to capital producers at Q_{t+1}. The equilibrium average return on capital is,

$$R_{t+1}^K = \frac{P_{t+1}r_{t+1}^K u_{t+1} + Q_{t+1}\left[1-\delta\left(u_{t+1}\right)\right]}{Q_t}, \tag{19}$$

where, $r_{t+1}^K = q_{t+1}\delta'\left(u_{t+1}^{\mathcal{N}}\right)$, and $q_t = Q_t/P_t$ is the real price of capital. The default condition of the entrepreneur is, $\varepsilon R_{t+1}^K Q_t K_t^{\mathcal{N}} < R_{t+1}^{L\mathcal{N}} B_t^{\mathcal{N}}$, where $R_{t+1}^{L\mathcal{N}}$ is the state contingent loan rate. The default probability of the entrepreneur is,

$$\Phi_{t+1}^{\mathcal{N}} = F_E\left(\varepsilon_{t+1}^{*\mathcal{N}}, \sigma_t^{\varepsilon}\right) = \int_{\underline{\varepsilon}}^{\varepsilon_{t+1}^{*\mathcal{N}}} f_E\left(\varepsilon, \sigma_t^{\varepsilon}\right) d\varepsilon,$$

where, $\varepsilon_{t+1}^{*\mathcal{N}}$ is the cut-off point of the idiosyncratic risk shock and $f_E\left(\varepsilon, \sigma_t^{\varepsilon}\right)$, and $F_E\left(\varepsilon, \sigma_t^{\varepsilon}\right)$, are, its probability density and cumulative distribution functions, respectively.[18] The average capital income seized by the bank at default is, $\int_{\underline{\varepsilon}}^{\varepsilon_{t+1}^{*\mathcal{N}}} \varepsilon R_{t+1}^K Q_t K_t^{\mathcal{N}} f_E\left(\varepsilon, \sigma_t^{\varepsilon}\right) d\varepsilon = G_E\left(\varepsilon_{t+1}^{*\mathcal{N}}, \sigma_t^{\varepsilon}\right) R_{t+1}^K Q_t K_t^{\mathcal{N}}$, where, $G_E\left(\varepsilon_{t+1}^{*\mathcal{N}}, \sigma_t^{\varepsilon}\right) = \int_{\underline{\varepsilon}}^{\varepsilon_{t+1}^{*\mathcal{N}}} \varepsilon\ f_E\left(\varepsilon, \sigma_t^{\varepsilon}\right) d\varepsilon$. The average return that the bank could receive from entrepreneur $\mathcal{N}$ is, $\left\{\varepsilon_{t+1}^{*\mathcal{N}}\left[1-F_E\left(\varepsilon_{t+1}^{*\mathcal{N}}, \sigma_t^{\varepsilon}\right)\right] + G_E\left(\varepsilon_{t+1}^{*\mathcal{N}}, \sigma_t^{\varepsilon}\right)\right\}\ R_{t+1}^K Q_t K_t^{\mathcal{N}}$. Thus, we can define the gross *share of capital income received by banks* as

$$\Gamma_E\left(\varepsilon_{t+1}^{*\mathcal{N}}, \sigma_t^{\varepsilon}\right) = \varepsilon_{t+1}^{*\mathcal{N}}\left[1-F_E\left(\varepsilon_{t+1}^{*\mathcal{N}}, \sigma_t^{\varepsilon}\right)\right] + G_E\left(\varepsilon_{t+1}^{*\mathcal{N}}, \sigma_t^{\varepsilon}\right), \tag{20}$$

and *the share of income received by the entrepreneur* as, $1-\Gamma_E\left(\varepsilon_{t+1}^{*\mathcal{N}}, \sigma_t^{\varepsilon}\right)$.

3.5.2 Participation Constraint of the Bank

Banks incur a monitoring cost, μ, as with the lenders in Carlstrom and Fuerst (1997), and Bernanke, Gertler, and Gilchrist (1999). If, $\widetilde{R}_{t+1}$ is the minimum return the bank expects for participating in the loan contract (derived in section 3.6), then its participation constraint is,

$$\int_{\varepsilon_{t+1}^{*\mathcal{N}}}^{\overline{\varepsilon}} R_{t+1}^{L\mathcal{N}} B_t^{\mathcal{N}}\ f_E\left(\varepsilon, \sigma_t^{\varepsilon}\right) d\varepsilon + (1-\mu)\int_{\underline{\varepsilon}}^{\varepsilon_{t+1}^{*\mathcal{N}}} \varepsilon R_{t+1}^K Q_t K_t^{\mathcal{N}}\ f_E\left(\varepsilon, \sigma_t^{\varepsilon}\right) d\varepsilon \geqslant \widetilde{R}_{t+1} B_t^{\mathcal{N}}.$$

[18] Since we consider a log-normal distribution, $\underline{\varepsilon} = 0$ and $\overline{\varepsilon} \to \infty$.

By using the functional forms defined earlier, defining leverage as, $L_t^{\mathcal{N}} = \frac{Q_t K_t^{\mathcal{N}}}{\mathcal{N}} = \frac{\mathcal{N}+B_t^{\mathcal{N}}}{\mathcal{N}}$, and assuming perfectly competitive banks that break-even, the participation constraint is

$$\left[\Gamma_E\left(\varepsilon_{t+1}^{*\mathcal{N}}, \sigma_t^{\varepsilon}\right) - \mu G_E\left(\varepsilon_{t+1}^{*\mathcal{N}}, \sigma_t^{\varepsilon}\right)\right] R_{t+1}^K L_t^{\mathcal{N}} = \widetilde{R}_{t+1}\left(L_t^{\mathcal{N}} - 1\right). \tag{21}$$

3.5.3 The Optimisation Problem of the Entrepreneur

The objective of entrepreneur $\mathcal{N}$ is to maximise $\max_{\left\{L_t^{\mathcal{N}}, \varepsilon_{t+1}^{*\mathcal{N}}\right\}} \mathbb{E}_t\left\{\left[1 - \Gamma_E\left(\varepsilon_{t+1}^{*\mathcal{N}}, \sigma_t^{\varepsilon}\right)\right] R_{t+1}^K \mathcal{N} L_t^{\mathcal{N}}\right\}$, subject to (21), by choosing loans and the cut-off point of the idiosyncratic risk shock, taking all other quantities as given. From the first order conditions, of the entrepreneur's problem,

$$\mathbb{E}_t\left\{\begin{array}{l}\left[1 - \Gamma_E\left(\varepsilon_{t+1}^{*}, \sigma_t^{\varepsilon}\right)\right] R_{t+1}^K \\ \quad + \left[\frac{\Gamma_E'\left(\varepsilon_{t+1}^{*}, \sigma_t^{\varepsilon}\right)}{\Gamma_E'\left(\varepsilon_{t+1}^{*}, \sigma_t^{\varepsilon}\right) - \mu G_E'\left(\varepsilon_{t+1}^{*}, \sigma_t^{\varepsilon}\right)}\right]\left[\left[\Gamma_E\left(\varepsilon_{t+1}^{*}, \sigma_t^{\varepsilon}\right) - \mu G_E\left(\varepsilon_{t+1}^{*}, \sigma_t^{\varepsilon}\right)\right] R_{t+1}^K - \widetilde{R}_{t+1}\right]\end{array}\right\} = 0, \tag{22}$$

$$\left[\Gamma_E\left(\varepsilon_{t+1}^{*}, \sigma_t^{\varepsilon}\right) - \mu G_E\left(\varepsilon_{t+1}^{*}, \sigma_t^{\varepsilon}\right)\right] R_{t+1}^K L_t = \widetilde{R}_{t+1}\left(L_t - 1\right). \tag{23}$$

3.5.4 Evolution of Aggregate Net Worth of Entrepreneurs

At the end of the period, each entrepreneur transfers a stochastic proportion, $1 - \Lambda_{t+1}$, of their assets, $V_{t+1}^{\mathcal{N}}$ to their respective firm owners, while the firm owners also provide entrepreneur a fixed lump-sum transfer $\Omega^{E^{\mathcal{N}}}$ in support of their projects. Aggregating over all entrepreneurs,

$$\mathbb{N}_{t+1} = \Lambda_{t+1}\left[1 - \Gamma_E\left(\varepsilon_{t+1}^{*}, \sigma_t^{\varepsilon}\right)\right] \frac{R_{t+1}^K q_t K_t}{\pi_{t+1}} + z_{t+1}^{*}\Omega^E. \tag{24}$$

where, $q_t K_t = L_t \mathbb{N}_t$, and $\mathbb{N}_t = \mathcal{N}_t / P_t$ is the real quantity of net worth. Thus the aggregate net transfer from all entrepreneurs to the entire family of 'firm owners' is,

$$\Pi_t^E = (1 - \Lambda_t)\left[1 - \Gamma_E\left(\varepsilon_t^{*}, \sigma_{t-1}^{\varepsilon}\right)\right] \frac{R_t^K q_{t-1} K_{t-1}}{\pi_t} - z_t^{*}\Omega^E.$$

3.6 Banks

Within the financial sector there exists a continuum of identical competitive banks, $i \in [0, 1]$. The balance sheet of any given bank i can be written in nominal terms as

$$B_{i,t}\left(1 - LLP_{i,t}\right) = D_{i,t} + E_{i,t}, \tag{25}$$

where $E_{i,t}$, $D_{i,t}$ and $B_{i,t}$ are the nominal levels of bank capital, deposits, and loans, respectively, and $LLP_{i,t}$ is the ratio of the level of loan loss provisions to total loans. Deposits are funded by all agent types (less underbanked households), for the risk-free return, R_t^D. However, the actual deposit rate received by depositors is the average deposit return, $\widetilde{R}_t^D$, (derived below), which may differ from R_t^D due to the possibility of default by banks and the presence of a deposit insurance scheme. Bank capital is funded only by bank owners, and carries a risk but also a higher expected return than deposits, as shown in (18). Since it is an expensive form of raising funds, banks require it only to meet the regulatory $CRR_t \equiv \gamma_t$:

$$\gamma_t = \frac{E_{i,t}}{B_{i,t}}, \quad or \quad E_{i,t} = \gamma_t B_{i,t}, \tag{26}$$

Individual banks experience IID idiosyncratic shocks ω on the return of their loan portfolio. This layer of idiosyncrasy aims to capture risks that are specific to banks and thus affect their loan return, but are not directly related to the idiosyncratic risk of borrowers (Clerc et al. (2015), Mendicino et al. (2018), Mendicino et al. (2019)).[19] Since the entrepreneur's participation constraint is binding, the average return earned by bank i on its loan portfolio is $\widetilde{R}_{t+1} B_{i,t}$. However, at adverse states, this may not be sufficient to cover its promised deposit liabilities, $R_t^D D_{i,t}$, forcing the bank to bankruptcy. Since bank capital holders are not entitled to payments during bank defaults, the defaulting condition of the bank is, $\omega \widetilde{R}_{t+1} B_{i,t} < R_t^D D_{i,t}$. Using (25) and (26) that imply, $D_{i,t} = B_{i,t}(1 - LLP_{i,t} - \gamma_t)$, the symmetric cut-off point of the bank is,[20]

$$\omega_{t+1}^* = \frac{R_t^D [1 - LLP_t - \gamma_t]}{\widetilde{R}_{t+1}}. \tag{27}$$

and the default probability of the bank is

$$\Theta_t \equiv \int_{\underline{\omega}}^{\omega_{t+1}^*} f_B(\omega, \sigma^\omega)\, d\omega = F_B(\omega_{t+1}^*, \sigma^\omega),$$

where $f_B(\cdot)$ and $F_B(\cdot)$ are the probability density function and the cumulative distribution of the bank's idiosyncratic shock ω, respectively. The distribution of ω is assumed to be log-normal with unit mean and standard deviation of σ^ω. Thus, the break-even condition of the bank is:

Average Loan Income - Average Deposit Cost - Average Bank Capital Cost

- Average LLP Cost - Other Fixed Costs = 0

$$\textit{Average Loan Income} = \int_{\underline{\omega}}^{\overline{\omega}} \left[\omega \widetilde{R}_{t+1} B_{i,t}\right] f_B(\omega, \sigma^\omega)\, d\omega = \widetilde{R}_{t+1} B_{i,t}$$

[19] Such idiosyncratic risk shocks can include direct shocks to the loan return received by banks, miscalculations, IT-system based risk, operational issues, bank geographical specialisations shocks, etc.

[20] With no loss in generality, we assume that at the symmetric equilibrium all banks set the same LLP_t ratio.

$$\mathit{Average\ Deposit\ Cost} = \underbrace{\int_{\omega_{t+1}^*}^{\overline{\omega}} \left[R_t^D D_{i,t}\right] \ f_B\left(\omega, \sigma^\omega\right) d\omega}_{\text{Non-default states}} + \underbrace{\int_{\underline{\omega}}^{\omega_{t+1}^*} \left[\omega \widetilde{R}_{t+1} B_{i,t}\right] \ f_B\left(\omega, \sigma^\omega\right) d\omega}_{\text{Default states}}$$

$$\mathit{Average\ Bank\ Capital\ Cost} = \underbrace{\int_{\omega_{t+1}^*}^{\overline{\omega}} \left[R_{t+1}^E E_{i,t}\right] \ f_B\left(\omega, \sigma^\omega\right) d\omega}_{\text{Non-default states}} + \underbrace{\int_{\underline{\omega}}^{\omega_{t+1}^*} \left[0\right] \ f_B\left(\omega, \sigma^\omega\right) d\omega}_{\text{Default states}}$$

$$\mathit{Average\ LLP\ Cost} = \widetilde{R}_{t+1} LLP_t B_{i,t}$$

$$\mathit{Other\ Fixed\ Costs} = \varrho B_{i,t}, \quad \varrho > 0$$

The cost of holding loan loss provisions ($LLP_t B_{i,t}$), is set equal to $\widetilde{R}_{t+1}$, that is, equal to the minimum income expected to be earned on these forgone loans, (opportunity cost), and this cost is passed on to borrowers. Using this information we can write,

$$\widetilde{R}_{t+1} B_{i,t} = \left[R_t^D D_{i,t}\left(1 - F_B\left(\omega_{t+1}^*, \sigma^\omega\right)\right) + \widetilde{R}_{t+1} B_{i,t} G_B\left(\omega_{t+1}^*, \sigma^\omega\right)\right] + R_{t+1}^E E_{i,t}\left(1 - F_B\left(\omega_{t+1}^*, \sigma^\omega\right)\right) + \widetilde{R}_{t+1} LLP_t B_{i,t} + \varrho B_{i,t}. \tag{28}$$

$$F_B\left(\omega_{t+1}^*, \sigma^\omega\right) = \int_{\underline{\omega}}^{\omega_{t+1}^*} f_B\left(\omega, \sigma^\omega\right) d\omega, \tag{29}$$

$$G_B\left(\omega_{t+1}^*, \sigma^\omega\right) = \int_{\underline{\omega}}^{\omega_{t+1}^*} \omega \ f_B\left(\omega, \sigma^\omega\right) d\omega, \tag{30}$$

Using the cut-off condition, (27), the bank's minimum expected loan return for participation is,

$$\widetilde{R}_{t+1} = R_t^D \frac{\left(1 - LLP_t - \gamma_t\right)}{\left(1 - LLP_t\right)} \left(1 - F_B\left(\omega_{t+1}^*, \sigma^\omega\right) + \frac{G_B\left(\omega_{t+1}^*, \sigma^\omega\right)}{\omega_{t+1}^*}\right) + \frac{\varrho}{\left(1 - LLP_t\right)} + \frac{\left(1 - F_B\left(\omega_{t+1}^*, \sigma^\omega\right)\right) R_{t+1}^E \gamma_t}{\left(1 - LLP_t\right)}. \tag{31}$$

3.7 Average Deposit Return and the Deposit Insurance Scheme

The government runs a deposit insurance scheme, where a fraction κ of deposits is insured and receive the promised repayment of R_t^D, (as in Mendicino et al. (2018)). The remaining proportion of deposits, $1 - \kappa$, is uninsured and receives R_t^D, if the bank does not default, while it receives the net amount of collateral seized, (available income from loans, $\omega \widetilde{R}_{t+1} B_{i,t}$, net of monitoring costs), if the bank defaults. Thus, the average return received by deposit holders is,

$$\widetilde{R}_{t+1}^D D_t = \kappa R_t^D D_t + (1 - \kappa)\left[\int_{\omega_{t+1}^*}^{\overline{\omega}} R_t^D D_t f_B\left(\omega, \sigma^\omega\right) d\omega + \left(1 - \mu^B\right) \int_{\underline{\omega}}^{\omega_{t+1}^*} \omega \widetilde{R}_{t+1} B_t \ f_B\left(\omega, \sigma^\omega\right) d\omega\right],$$

where, μ^B is a monitoring cost.[21] The amount that needs to be funded by the government, denoted in real terms by g_t^{DIA}, is

$$P_{t+1}g_{t+1}^{DIA} = \widetilde{R}_{t+1}^D D_t - \left[\int_{\omega_{t+1}^*}^{\overline{\omega}} R_t^D D_t f_B\left(\omega, \sigma^\omega\right) d\omega + \left(1 - \mu^B\right) \int_{\underline{\omega}}^{\omega_{t+1}^*} \omega \widetilde{R}_{t+1} B_t \; f_B\left(\omega, \sigma^\omega\right) d\omega\right],$$

which, using similar steps as above, can be written, in real terms for period t, as

$$g_t^{DIA} = \kappa\left[\omega_t^* - \Gamma_B\left(\omega_t^*, \sigma^\omega\right) + \mu^B G_B\left(\omega_t^*, \sigma^\omega\right)\right] \widetilde{R}_t \frac{b_{t-1}}{\pi_t}. \tag{32}$$

where, $\Gamma_B\left(\omega_{t+1}^*, \sigma^\varepsilon\right) = \omega_{t+1}^*\left[1 - F_B\left(\omega_{t+1}^*, \sigma^\omega\right)\right] + G_B\left(\omega_{t+1}^*, \sigma^\omega\right)$.

3.8 Goods Production

The production sector consists of a competitive final goods producer and an infinite number of intermediate goods firms $j \in [0,1]$, that transfer profits to the 'firm-owners'. The final goods producer aggregates intermediate goods $y_{j,t}$ using the technology, $y_t = (\int_0^1 y_{j,t}^{(\frac{\lambda_p - 1}{\lambda_p})} dj)^{(\frac{\lambda_p}{\lambda_p - 1})}$ where, $\lambda_p > 1$. The demand for a each intermediate good j, is $y_{j,t} = y_t\left(\frac{P_{j,t}}{P_t}\right)^{-\lambda_p}$, where $P_t = (\int_0^1 P_{j,t}^{1-\lambda_p} dj)^{(\frac{1}{1-\lambda_p})}$ is the average price index. Following Christiano, Motto, and Rostagno (2014), an existing one-to-one technology converts final goods into consumption goods and another technology converts one unit of final goods into $\Upsilon^t \mu_{\Upsilon,t}$ units of investment goods; $\Upsilon > 1$ is the deterministic growth rate of investment technology and $\mu_{\Upsilon,t}$ is an investment price shock, where, $\log\left(\mu_{\Upsilon,t}\right) = \rho^{\mu_\Upsilon} \log\left(\mu_{\Upsilon,t-1}\right) + \epsilon_t^{\mu_\Upsilon}$; $\epsilon_t^{\mu_\Upsilon}$ is normally distributed with zero mean and standard deviation σ_{μ_Υ}. The equilibrium prices of consumption and investment goods are, P_t and $\frac{P_t}{\Upsilon^t \mu_{\Upsilon,t}}$, respectively. The production technology of each intermediate goods firm j is,

$$y_{j,t} = A_t\left(\bar{k}_{j,t}\right)^\alpha \left(z_t n_{j,t}\right)^{(1-\alpha)} - z_t^* \Psi_t, \tag{33}$$

where, $\bar{k}_{j,t}$ and $n_{j,t}$ are capital services and labour hours from all four agents, respectively. A_t is a stationary technology shock, where, $\ln\left(A_t\right) = \rho^A \ln\left(A_{t-1}\right) + \epsilon_t^A$; ϵ_t^A is normally distributed with zero mean and standard deviation σ_A. Total fixed production costs, Ψ_t, are proportional to the average trend growth in technology, $z_t^* = z_t \Upsilon^{\left(\frac{\alpha}{1-\alpha}\right)t}$. The change in this trend is, $\mu_{z,t}^* = \frac{z_t^*}{z_{t-1}^*} = \mu_{z,t} \Upsilon^{\left(\frac{\alpha}{1-\alpha}\right)}$, where $z_t = \mu_{z,t} z_{t-1}$, and $\log\left(\mu_{z,t}\right) = \rho^{\mu_z} \log\left(\mu_{z,t-1}\right) + \epsilon_t^{\mu_z}$; $\epsilon_t^{\mu_z}$ is normally distributed with zero mean and standard deviation σ_{μ_z}. Following Andreasen (2012), Ψ_t, is stochastic, where $\ln\left(\Psi_t\right) = \left(1 - \rho^\Psi\right) \ln\left(\Psi_t\right) + \rho^\Psi \ln\left(\Psi_{t-1}\right) + \epsilon_t^\Psi$; ϵ_t^Ψ is normally distributed with zero mean and standard deviation σ_Ψ. Each firm's total variable costs are, $tc_{j,t} = r_t^K\, \overline{k}_{j,t} + w_t\, n_{j,t}$,

[21] This captures costs like legal fees, checking accounts of defaulted banks, etc.

its real marginal cost is, $mc_{j,t} = \frac{\left(r_t^K\right)^{(\alpha)} \; (w_t)^{(1-\alpha)}}{(z_t)^{(1-\alpha)} \; A_t \; (\alpha)^{(\alpha)} \; (1-\alpha)^{(1-\alpha)}}$, where w_t is the average real wage rate and $\frac{\bar{k}_{j,t}}{n_{j,t}} = \left(\frac{w_t^h}{r_t^K}\right)\left(\frac{\alpha}{1-\alpha}\right)$. Each firm j sets prices as in Calvo (1983), where a fraction ω_p of firms index their prices to gross inflation, $\pi_{t-1}^{\iota_p}\pi^{1-\iota_p}P_{j,t-1}$, where ι_p denotes price indexation:

$$\max_{P_{j,t}} \left[\mathbb{E}_t \left\{ \left(\beta^F \omega_p\right)^s \; \frac{\mathcal{U}_{c,t+s}^F}{\mathcal{U}_{c,t}^F} \Pi_{j,t+s}^F \right\}\right]$$

$$\text{subject to, } \Pi_{j,t}^F = \frac{P_{j,t}}{P_t} y_{j,t} - tc_{j,t}, \text{ and } \forall t, \quad y_{j,t+s} = y_{t+s}\left(\frac{P_{j,t+s}}{P_{t+s}}\right)^{-\lambda_p}$$

where $\left(\beta^F \omega_p\right)^s \; \frac{\mathcal{U}_{c,t+s}^F}{\mathcal{U}_{c,t}^F}$ is the stochastic discount factor of non-financial 'firm owners'. Using, $\partial\left(tc_{j,t+s}\right)/\partial y_{j,t+s} = mc_{j,t+s}$, the first order condition is,

$$0 = \mathbb{E}_t \sum_{s=0}^{\infty} (\beta^F \omega_p)^s \mathcal{U}_{c,t+s}^F \left\{ \left(\frac{1}{P_{t+s}}\right) \left(P_{j,t+s} \frac{\partial y_{j,t+s}}{\partial P_{j,t}} + \frac{\partial P_{j,t+s}}{\partial P_{j,t}} y_{j,t+s} \right) - mc_{t+s} \frac{\partial y_{j,t+s}}{\partial P_{j,t}} \right\},$$

and using the Calvo assumptions, we can summarise price dynamics by the following relationships:

$$1 = (1-\omega_p)\left(p_t^*\right)^{1-\lambda_p} + \omega_p \left(\frac{\pi_{t-1}^{\iota_p}\pi^{1-\iota_p}}{\pi_t}\right)^{1-\lambda_p}, \tag{34}$$

$$Q3_t = \mathcal{U}_{c,t}^F \, y_t \, x_t + \beta^F \omega_p \mathbb{E}_t \left\{ Q3_{t+1} \left(\frac{\pi_t^{\iota_p}\pi^{1-\iota_p}}{\pi_{t+1}}\right)^{-\lambda_p} \right\}, \tag{35}$$

$$Q4_t = \mathcal{U}_{c,t}^F \, y_t + \beta^F \omega_p \mathbb{E}_t \left\{ Q4_{t+1} \left(\frac{\pi_t^{\iota_p}\pi^{1-\iota_p}}{\pi_{t+1}}\right)^{1-\lambda_p} \right\}, \tag{36}$$

$$p_t^* = \left(\frac{\lambda_p}{\lambda_p - 1}\right)\frac{Q3_t}{Q4_t}, \tag{37}$$

where p_t^* is the optimal aggregate price level and $Q3_t$ and $Q4_t$ are intermediate terms.

3.9 Capital Producers

A competitive capital producer purchases quantity $\mathbb{X}_t$ of used capital at $q_t\mathbb{X}_t$ from entrepreneurs and combines it with investment x_t, to produce new capital K_t, using the following technology:[22] $K_t = \mathbb{X}_t + S_t^I\left[1 - \frac{\xi_k}{2}\left(\frac{x_t}{x_{t-1}} - \mu_z^*\Upsilon\right)^2\right] x_t$, where ξ_k is an investment adjustments cost and S_t^I is an investment efficiency shock, that follows an AR(1) process, $\log\left(S_t^I\right) = \rho^I \log\left(S_{t-1}^I\right) + \epsilon_t^I$, where ϵ_t^I is normally distributed with zero mean and variance σ_I^2. The optimisation problem of the capital producer is, $\max_{\left\{x_{t+s},\ \mathbb{X}_{t+s}\right\}_{t=0}^{\infty}} \left[\mathbb{E}_t \sum_{s=0}^{\infty} \left(\beta^F\right)^s \left(\frac{\mathcal{U}_{c,t+s}^F}{\mathcal{U}_{c,t}^F}\right)\left(q_t K_t - q_t\mathbb{X}_t - \frac{x_t}{\Upsilon^t \; \mu_{\Upsilon,t}}\right)\right]$. As any quantity of used capital is found to be optimal for the capital producer, from market clearing,

[22] This is similar to Christiano, Motto, and Rostagno (2003) and Fernández-Villaverde (2010).

we get $\mathbb{X}_t = [1 - \delta(u_t)] K_{t-1}$. Thus, the evolution of capital stock can be written as,

$$K_t = [1 - \delta(u_t)] K_{t-1} + S_t^I \left[1 - \frac{\xi_k}{2}\left(\frac{x_t}{x_{t-1}} - \mu_z^* \Upsilon\right)^2\right] x_t. \tag{38}$$

Meanwhile, the first order condition with respect to investment is,

$$1 = \Upsilon^t \ \mu_{\Upsilon,t} \left\{ \begin{array}{c} q_t S_t^I \left[1 - \frac{\xi_k}{2}\left(\frac{x_t}{x_{t-1}} - \mu_z^* \Upsilon\right)^2 - \xi_k \left(\frac{x_t}{x_{t-1}} - \mu_z^* \Upsilon\right)\left(\frac{x_t}{x_{t-1}}\right)\right] \\ +\beta^F \mathbb{E}_t \left\{\frac{\mathcal{U}_{c,t+1}^F}{\mathcal{U}_{c,t}^F} q_{t+1} S_{t+1}^I \xi_k \left(\frac{x_{t+1}}{x_t} - \mu_z^* \Upsilon\right)\left(\frac{x_{t+1}}{x_t}\right)^2\right\} \end{array} \right\}. \tag{39}$$

3.10 Wage Setting

Wage setting is similar across all four agent-type families and follows a variant of Erceg, Henderson, and Levin (2000) and Christiano, Eichenbaum, and Evans (2005). Each member $x = h, \overline{h}, f, b$, of its respective family, $X = H, \overline{H}, F, B$, sets a wage rate for their differentiated labour services, $n_{x,t}^X$, which they provide to their family competitive labour contractor, who then combines all differentiated labour-types within that family into a homogeneous labour bundle, n_t^X. At the economy-wide level, a final labour contractor combines the labour bundles from all agent-type families into an economy-wide aggregate labour bundle n_t, that firms use as their input,

$$n_t = \Delta^H n_t^H + \Delta^{\overline{H}} n_t^{\overline{H}} + \Delta^F n_t^F + \Delta^B n_t^B, \tag{40}$$

where, $n_t^X = \left(\int_0^1 \left(n_{x,t}^X\right)^{\left(\frac{\lambda_w - 1}{\lambda_w}\right)} dx\right)^{\left(\frac{\lambda_w}{\lambda_w - 1}\right)}$, and $\lambda_w > 1$ is the elasticity of substitution between differentiated labour types. Since the aggregation technology results in the same homogeneous labour bundle across all four families, they are all perfect substitutes and receive the same wage,

$$W_t^H = W_t^{\overline{H}} = W_t^F = W_t^B = W_t. \tag{41}$$

Wages are sticky as in Erceg, Henderson, and Levin (2000), where a fraction, ω_w, have past wages indexed to past inflation and the growth rate (Smets and Wouters (2007), Christiano, Motto, and Rostagno (2014)). Denoting wage and growth indexation by ι_w and ι_μ, respectively, the wage dynamics for each family type $X = H, \overline{H}, F, B$, are as follows:

$$\left(w_t^X\right)^{1-\lambda_w} = \omega_w \left(\mathbb{Q}_t \ w_{t-1}^X\right)^{1-\lambda_w} + (1 - \omega_w)\left(w_t^{X*}\right)^{1-\lambda_w}, \tag{42}$$

$$w_t^{X*} = \left(\frac{\lambda_w}{\lambda_w - 1}\right) \frac{Q1_t^X}{Q2_t^X}, \tag{43}$$

$$Q1_t^X = n_t^X \left(\frac{w_t^X}{w_t^{X*}}\right)^{\lambda_w(1+\eta)} \mathcal{U}_{n,t}^X + \beta^X \omega_w \mathbb{E}_t \left\{ Q1_{t+1}^X \left(\mathbb{Q}_{t+1}\right)^{-\lambda_w(1+\eta)} \left(\frac{w_{t+1}^{X*}}{w_t^{X*}}\right)^{\lambda_w(1+\eta)} \right\}, \tag{44}$$

$$Q2_t^X = n_t^X \left(\frac{w_t^X}{w_t^{X*}}\right)^{\lambda_w} \mathcal{U}_{c,t}^X + \beta^X \omega_w \mathbb{E}_t \left\{ Q2_{t+1}^X \left(\mathbb{Q}_{t+1}\right)^{1-\lambda_w} \left(\frac{w_{t+1}^{X*}}{w_t^{X*}}\right)^{\lambda_w} \right\}, \tag{45}$$

$$\mathcal{U}_{n,t}^X = \psi_n \left(n_t^X\right)^{\eta}, \tag{46}$$

where, $\mathbb{Q}_t = \frac{\pi_{t-1}^{\iota_w} \pi^{1-\iota_w}}{\pi_t} \left(\mu_{z,t}^*\right)^{\iota_\mu} \left(\mu_z^*\right)^{1-\iota_\mu}$.

3.11 The Government Budget Constraint

The government uses tax revenues to fund its deposit insurance scheme, g_t^{DIA}, and an exogenous component of government expenditure, $z_t^* \widetilde{g}_t$, where $\ln\left(\widetilde{g}_t\right) = \left(1-\rho^G\right) \ln\left(\widetilde{g}\right) + \rho^G \ln\left(\widetilde{g}_{t-1}\right) + \epsilon_t^G$, $\epsilon_t^G \sim \mathcal{N}\left(0, \sigma_G^2\right)$, and at the steady state $\widetilde{g}_t$ equals a fixed share of the stationary steady state output, g_y. Thus the government budget constraint must satisfy, [23]

$$\overline{g}_t \equiv z_t^* \widetilde{g}_t + g_t^{DIA} = \tau_t. \tag{47}$$

Since lump-sum taxes are collected from all families, the total tax revenue is,

$$\tau_t = \Delta^H \tau_t^H + \Delta^{\overline{H}} \tau_t^{\overline{H}} + \Delta^F \tau_t^F + \Delta^B \tau_t^B. \tag{48}$$

3.12 Aggregate Equilibrium

In the aggregate equilibrium all individuals within each agent-type family consume similar quantities of consumption and hold similar quantities of income. Quantities of all variables are aggregated over the population share of each family, Δ^X, where, $X = H, \overline{H}, F, B$. Thus, given the symmetric *per capita* consumption levels of each family type, aggregate consumption is,

$$c_t = \Delta^H c_t^H + \Delta^{\overline{H}} c_t^{\overline{H}} + \Delta^F c_t^F + \Delta^B c_t^B,$$

where $\Delta^H + \Delta^{\overline{H}} + \Delta^F + \Delta^B = 1$. Similarly, given that underbanked simple households do not hold deposits, the clearing condition in the deposit market is, $d_t = \Delta^H d_t^H + \Delta^F d_t^F + \Delta^B d_t^B$. Market clearing requires that the aggregate demand for capital services and labour from intermediate firms is equal to their respective aggregate supply, $\int_0^1 \bar{k}_{j,t} dj = \bar{k}_t$, and $\int_0^1 n_{j,t} dj = n_t = \Delta^H n_t^H + \Delta^{\overline{H}} n_t^{\overline{H}} + \Delta^F n_t^F + \Delta^B n_t^B$. Thus aggregate production is, $y_t = \frac{(z_t)^{(1-\alpha)} A_t \left(\bar{k}_t\right)^{(\alpha)} (n_t)^{(1-\alpha)} - z_t^* \Psi_t}{V_t^P}$, where,

[23] Tildes above variables, $\widetilde{x}$, denote detrended variables, except $\widetilde{R}^D$ and $\widetilde{R}$, that denote average rates.

$V_t^p = (1-\omega_p)(p_t^*)^{-\lambda_p} + \left(\frac{\pi_{t-1}^{\iota_p}\pi^{1-\iota_p}}{\pi_t}\right)^{-\lambda_p}\omega_p V_{t-1}^p$, is a measure of price dispersion. The aggregate budget constraints of the four family types are:

Banked simple households:

$$\Delta^H c_t^H = \Delta^H n_t^H w_t^H - \Delta^H d_t^H \left(1 + \frac{\kappa_D^H}{2}\left(\frac{d_t^H}{c_t^H} - \frac{d^H}{c^H}\right)^2\right) + \Delta^H \frac{\widetilde{R}_t^D d_{t-1}^H}{\pi_t} - \Delta^H \overline{g}_t.$$

Underbanked simple households:

$$\Delta^{\overline{H}} c_t^{\overline{H}} = \Delta^{\overline{H}} n_t^{\overline{H}} w_t^{\overline{H}} - \Delta^{\overline{H}} \overline{g}_t.$$

Non-financial firm owners:

$$\Delta^F c_t^F = \Delta^F n_t^F w_t^F - \Delta^F d_t^F \left(1 + \frac{\kappa_D^F}{2}\left(\frac{d_t^F}{c_t^F} - \frac{d^F}{c^F}\right)^2\right) + \Delta^F \frac{\widetilde{R}_t^D d_{t-1}^F}{\pi_t} + \Pi_t^F + \Pi_t^K + \Pi_t^E - \Delta^F \overline{g}_t,$$

$$\begin{aligned}
\Pi_t^F &= y_t - r_t^K\ \overline{k}_t - w_t\ n_t,\\
\Pi_t^K &= q_t K_t - q_t\left[1-\delta(u_t)\right]K_{t-1} - \frac{x_t}{\Upsilon^t\ \mu_{\Upsilon,t}},\\
\Pi_t^E &= (1-\Lambda_t)\left[1-\Gamma_E\left(\varepsilon_t^*, \sigma_{t-1}^{\varepsilon}\right)\right]\frac{R_t^K q_{t-1}K_{t-1}}{\pi_t} - z_t^*\Omega_t.
\end{aligned}$$

Bank owners:

$$\Delta^B c_t^B = \left\{\begin{array}{c}\Delta^B n_t^B w_t^B - \Delta^B d_t^B\left(1 + \frac{\kappa_D}{2}\left(\frac{d_t^B}{c_t^B} - \frac{d^B}{c^B}\right)^2\right) + \Delta^B \frac{\widetilde{R}_t^D d_{t-1}^B}{\pi_t} - \left(e_t + \zeta\frac{\mu_{z,t}^* e_{t-1}}{\pi_t}\right)\\ + \frac{(1-\Theta_t)R_t^E e_{t-1}}{\pi_t} - \Delta^B \overline{g}_t.\end{array}\right\}$$

Finally, defining $gdp_t = c_t + \frac{x_t}{\Upsilon^t\ \mu_{\Upsilon,t}} + \overline{g}_t$, we can write the aggregate resource constraint as,

$$y_t = \left\{\begin{array}{l} gdp_t + \left\{\mu_t G_E\left(\varepsilon_t^*, \sigma_{t-1}^{\varepsilon}\right)\frac{R_t^K q_{t-1}K_{t-1}}{\pi_t}\right\} + \left\{\mu^B G_B\left(\omega_t^*, \sigma_{t-1}^{\omega}\right)\widetilde{R}_t \frac{b_{t-1}}{\pi_t}\right\}\\ + \left\{\Delta^H d_t^H \frac{\kappa_D^H}{2}\left(\frac{d_t^H}{c_t^H} - \frac{d^H}{c^H}\right)^2 + \Delta^F d_t^F \frac{\kappa_D^F}{2}\left(\frac{d_t^F}{c_t^F} - \frac{d^F}{c^F}\right)^2 + \Delta^B d_t^B \frac{\kappa_D}{2}\left(\frac{d_t^B}{c_t^B} - \frac{d^B}{c^B}\right)^2\right\}\\ + \left\{\varrho\frac{b_{t-1}}{\pi_t} + \zeta\frac{\mu_{z,t}^* e_{t-1}}{\pi_t} + \widetilde{R}_t\ LLP_{t-1}\frac{b_{t-1}}{\pi_t} - LLP_t b_t\right\} - g_t^{DIA}.\end{array}\right\}$$

3.13 Monetary and Macroprudential Policy

Following standard practice, monetary policy is implemented by a Taylor rule:

$$R_t = (R_{t-1})^{\rho^R}\left(R\left(\frac{\pi_t}{\pi}\right)^{\phi_\pi}\left(\frac{\widetilde{y}_t}{\widetilde{y}}\right)^{\phi_y}\right)^{1-\rho^R}\exp\left(\epsilon_t^R\right), \tag{49}$$

where here the nominal gross policy interest rate is equivalent to the fully covered (risk-free) deposit rate, $R_t^D = R_t$. $0 < \rho^R < 1$, ϕ_π,$\phi_y > 0$, and ϵ_t^R is a monetary policy shock which is normally distributed with zero mean and standard deviation σ_R.

Macroprudential policy is examined through variations in the fixed CRR, (γ), and also by using the following *countercyclical capital buffer* (CCyB) rule:

$$\gamma_t = \gamma \left(\frac{\widetilde{b}_t}{\widetilde{b}} \right)^{\gamma_{\widetilde{b}}}, \tag{50}$$

where, $\gamma_{\widetilde{b}} \geqslant 0$, is the responsiveness parameter to deviations of credit from its steady state.[24] In addition, we examine the effects of changes in the average fixed LLP ratio of banks, and also introduce a dynamic LLP_t rule, according to which banks adjust their loan loss provisions ratio in response to deviations of expected non-performing loans from their steady state:[25]

$$LLP_t = LLP \left(\frac{\Phi_{t+1}\widetilde{b}_t}{\Phi\widetilde{b}} \right)^{\alpha_{NPL}}, \tag{51}$$

where $\Phi_{t+1}\widetilde{b}_t$ represents expected non-performing loans and $\alpha_{NPL} \geqslant 0$, is the policy responsiveness parameter. The welfare implications of these rules are discussed in section 5.

4 Estimation

4.1 Methodology and Data

We estimate the non-linear, detrended version of the model using Bayesian estimation techniques, based on US quarterly data for the period, 1985:1-2016:4. For the estimation we use eleven observables: real GDP, aggregate real consumption, investment, aggregate labour hours, real wage rate, inflation, nominal interest rate, loan rate spread, relative price of investment, real net worth and real loans. We also consider two measurement errors on net worth and loans, as the model comprises nine shocks. The data used for all variables is taken from the Federal Reserve Bank of St. Louis. For the calibration of the population shares of the four agents, we use data from, Compustat, the Survey of Consumer Finances (SCF) and the National Survey of Unbanked and Underbanked Households of the Federal Deposit Insurance Corporation (FDIC).[26]

4.2 Calibrated Parameters

The calibrated parameter values are given in Table 1. The top panel reports common calibrated values used in the literature, while the bottom panel reports model-specific calibrated values that match observed data. The capital share of output, α, is 0.33, (Fernald (2014)), and the

[24] This countercyclical rule is shown to outperform other rules, (Bekiros, Nilavongse, and Uddin (2018)).
[25] We assume that at equilibrium, the same LLP is employed by all banks.
[26] For details see in the Technical Appendix.

Table 1: Calibrated Parameters

Parameter	Symbol	Value
Capital share of output	α	0.33
Depreciation rate	δ_0	0.025
Inverse of the Frisch elasticity of labour supply	η	1
Elasticity of substitution - intermediate goods	λ_p	6
Elasticity of substitution - member specific labour	λ_w	21
Monitoring costs: entrepreneurs	μ	0.21
Monitoring costs: banks	μ^B	0.21
Entrepreneur lump sum transfer	Ω	0.005
Share of simple households-banked	Δ^H	0.268
Share of simple households-underbanked	$\Delta^{\overline{H}}$	0.267
Share of firm owners	Δ^F	0.435
Share of bank owners	Δ^B	0.030
Share of total deposits that is insured	κ	0.79
Growth rate of labour augmenting integrated technology	μ_z	1.0024
Trend growth rate of investment-specific technological change	Υ	1.0026
Gross inflation	π	1.0054
Discount factor - same for all	β	0.99974
Bank capital required ratio	γ	0.105
Government expenditure to output ratio	g_y	0.214
Scale parameter of utility from leisure	ψ_n	22
Costs of adjusting bank capital, incurred by bank owners	ζ	0.01301
LLP to loans ratio	LLP	0.0203
Operational cost of loans - steady state	ϱ^L	0.00279
SD of banks idiosyncratic shock	σ^ω	0.04762
SD of entrepreneurs idiosyncratic shock	σ^ε	0.41810
Entrepreneur net worth transfer	Λ	0.9863
Deposits of all non-financial firm owners / total deposits	$\frac{\Delta^F d^F}{d}$	0.633
Deposits of all bank owners / total deposits	$\frac{\Delta^B d^B}{d}$	0.037

depreciation rate, δ_0, is 0.025 (Christiano, Eichenbaum, and Evans (2005), Bernanke, Gertler, and Gilchrist (1999)), so that annualised depreciation is 10%. The inverse of the Frisch elasticity of labour supply, η, is assumed to be 1, and the elasticity of substitution in the goods market, λ_p, and the labour market, λ_w, are taken as 6 and 21, so that their respective mark-ups are 20% and 5% percent. The monitoring cost parameter in the entrepreneurs' loan contract, μ, is 0.21 and the lump-sum transfer made by the non-financial firm owners to entrepreneurs, Ω, is 0.005, (Christiano, Motto, and Rostagno (2014)).[27] Further, following Mendicino et al. (2018), the monitoring cost in the banking sector, μ^B, is assumed to be equal to that of entrepreneurs. One of the main challenges of focusing on the welfare of our four different types of agents, is how to account for the population shares of these groups. This is a rather complicated issue, because individuals can be the holders of both financial and non-financial shares. To make some meaningful distinction between these different types of agents we classify them as follows: 'Bank owners' are anyone who holds shares of financial intermediation related firms, 'firm owners'

[27]The value for monitoring costs falls also within the plausible range, 0.20-0.36, of Carlstrom and Fuerst (1997), although it is higher than the 0.12 used by Bernanke, Gertler, and Gilchrist (1999).

are anyone who holds shares in non-financial firms, and finally we treat as 'simple households' anyone who does not have claims of ownership of any kind. Based on the data available in the 1989-2016 waves of the Survey of Consumer Finances (SCF), on average, 46.5% of households hold direct or indirect stocks, whereas the remaining 53.5% do not hold any stocks of any type.[28] Since both 'banked simple households' and 'underbanked simple households' do not hold any stocks, we treat this 53.5% as the share of all 'simple households' in the model. We then split the 46.5% share of households who hold direct or indirect stocks, into 'non-financial firm owners' and 'bank owners', depending on the share ownership. Based on data extracted from Compustat, the total number of common shareholders of firms falling into the "credit intermediation and related activities" category (*North American Industry Classification System (NAICS)*), as a percentage of the total number of common shareholders in firms falling into all non-farm categories, is 6.4%. Accordingly, we take 6.4% of the 46.5% (i.e. 3%), as the share of 'bank owners', $\mathit{\Delta}^B$, in the model, while the remaining 43.5% is taken as the share of 'non-financial firm owners', $\mathit{\Delta}^F$. Further, we take the share of unbanked and underbanked US households, given in the *National Survey of Unbanked and Underbanked Households*, (FDIC), as the share of 'underbanked' simple households, $\mathit{\Delta}^{\overline{H}}$, while the remaining share is taken as the share of 'banked' simple households, $\mathit{\Delta}^H = 1 - \mathit{\Delta}^{\overline{H}} - \mathit{\Delta}^F - \mathit{\Delta}^B$. Using the data reported in Demirgüç-Kunt, Kane, and Laeven (2014) for 2010, we calibrate the share of deposits that is insured, κ, to be 0.79. Conditional on the capital share of production, the two trend growth parameters are calibrated at $\mu_z = 1.0024$ and $\Upsilon = 1.0026$, so that the resulting balanced growth rate of the economy and investment growth rate match the quarterly growth rates of per capita real GDP and per capita real investment in the sample. Steady state gross inflation, π, is calibrated so that the annual net inflation matches the observed sample average. As all agent types receive the same deposit rate, their Euler equations in the steady state imply the same discount factor.[29] This common discount factor, β, is calibrated so that it matches the average effective federal funds rate, given the steady state values of inflation and the growth rate of the economy. The bank capital required ratio γ is 10.5%, as per Basel III guidelines. The ratio of government expenditure to output, g_y, is calibrated to match the government expenditure to GDP ratio in the data. ψ_n is set at 22, so that the average number of hours worked in the steady state is approximately equal to one third. The adjustment cost parameter on bank equity, ζ, is calibrated so that the bank equity spread is equal to the observed spread between return on bank equity and the 10-year treasury constant maturity rate. The loan loss provisions to loans ratio is set at $LLP = 0.0203$, to match the

[28] According to SCF, "Indirect holdings are those in pooled investment funds, retirement accounts, and other managed assets."

[29] This includes the underbanked simple households, who in the data holds little or no deposits, but could also have access to the economy-wide deposit rate.

Table 2: Steady State Model Fit (At Prior Mean Values)

Target	Model Definition	Model	Data
Nominal risk free policy rate	$400\ (R-1)$	3.77 %	3.77 %
Inflation	$400\ (\pi-1)$	2.15 %	2.15 %
Capital requirement ratio	$100\ \gamma$	10.50 %	10.50 %
GDP growth	$100\ (\mu_z^*-1)$	0.37 %	0.37 %
Investment growth	$100\ (\Upsilon\mu_z^*-1)$	0.63 %	0.63 %
Loan spread	$400\ \left(\frac{R^L}{R}-1\right)$	2.34 %	2.34 %
Bank capital spread	$400\ \left(\frac{R^E}{R}-1\right)$	5.96 %	5.96 %
LLP to loans	$100\ LLP$	2.03 %	2.03 %
Default probability of entrepreneurs	$400\ F_E\left(\varepsilon^*,\sigma^\varepsilon\right)$	2.20 %	2.20 %
Default probability of banks	$400\ F_B\left(\omega^*,\sigma^\omega\right)$	0.81 %	0.81 %
Loans to output	$100\ \frac{\tilde{l}}{\tilde{y}}$	253 %	251 %
Government expenditure to output	$100\ \frac{\tilde{g}}{\tilde{y}}$	21.5 %	21.5 %
Investment to output	$100\ \frac{\tilde{x}}{\tilde{y}}$	24.8 %	21.5 %

Note: Nominal risk free rate: average effective federal funds rate. GDP and Investment growth: average quarterly growth rates of real per capita GDP and per capita investment, respectively. Capital requirement ratio: as per Basel III guidelines. Loan spread: Baa *less* 10 year constant maturity treasury bill rate. Bank capital spread: average return on bank equity *less* 10 year constant maturity treasury bill rate. Default probability of entrepreneurs: average US corporate default rates (S&P Global Ratings). Default probability of banks: average of number of failed banks as a share of total banks (FDIC). Loans to output: non-financial sector loans as a share of GDP. Government expenditure to output: government consumption and investment as a share of GDP. Investment to output: investment as a share of GDP.

average of observed data on loan loss reserves to total loans for all US Banks. The parameter measuring other operational costs on loans, ϱ^L, is calibrated to enhance the matching of the loan rate spread to the observed spread between Moody's seasoned Baa corporate bond yield and the 10-year treasury constant maturity rate. The standard deviations of the two idiosyncratic shocks, σ^ε and σ^ω, are calibrated so as to match the default probability of entrepreneurs and banks in the model, to the default probability of average US corporate default rates (based on S&P Global Ratings) and the percentage of average number of failed banks to total banks, respectively. The share of net-worth transferred to firm owners, Λ, is calibrated to match the loans-to-GDP ratio in the data. The share of deposits of 'non-financial firm owners' to total deposits ($\frac{\Delta^F d^F}{d}$), and the corresponding ratio for 'bank owners' ($\frac{\Delta^B d^B}{d}$), are equal to the exogenous values, ϖ^F and ϖ^B, respectively, that match US financial accounts data. Finally, fixed production costs, Ψ, are endogenously calibrated so that steady state profits of intermediate firms are zero.

Table 2 shows that our parametrisation for the steady state matches the calibration targets closely for most of the variables. It also derives steady state per capita consumption values as follows: for 'underbanked simple households' $\tilde{c}^{\overline{H}} = 0.3467$, for 'banked simple households'

Table 3: Estimation Results

		Prior Distribution			Posterior Distribution			
		Dist.	Mean	Stdev.	Mean	Mode	[90% Conf.	Int.]
Deep structural parameters								
ω_p	Calvo price stickiness	beta	0.6600	0.1000	0.5399	0.5550	[0.4575	0.6223]
ω_w	Calvo wage stickiness	beta	0.6600	0.1000	0.8472	0.8417	[0.7976	0.8962]
ι_p	Price indexation to past inflation	beta	0.5000	0.1500	0.1802	0.1453	[0.0634	0.2935]
ι_w	Wage indexation to past inflation	beta	0.5000	0.1500	0.5749	0.5866	[0.3657	0.7908]
ι_μ	Wage indexation to growth	beta	0.5000	0.1500	0.8506	0.8643	[0.7776	0.9235]
Ψ_u	Capital utilisation cost elasticity	gamm	5.0000	1.0000	3.5552	3.4131	[2.2036	4.8809]
ξ_k	Investment adjustment costs	gamm	4.0000	1.0000	1.8693	1.8372	[1.3800	2.3302]
ς	Habit persistence	beta	0.5000	0.2000	0.8626	0.8723	[0.7833	0.9417]
ϕ_π	TR inflation response	norm	1.5000	0.2500	2.4049	2.3785	[2.1110	2.6953]
ϕ_y	TR output response	gamm	0.1300	0.1000	0.0216	0.0114	[0.0008	0.0413]
ρ^R	Monetary policy smoothing	beta	0.7500	0.1000	0.8848	0.8878	[0.8648	0.9053]
κ_D^{Est}	Deposits to cons. adj. costs	beta	0.5000	0.2500	0.1701	0.1492	[0.0590	0.2806]
Persistence parameters of shocks								
ρ^A	Aggregate productivity shock	beta	0.5000	0.2000	0.9670	0.9774	[0.9426	0.9924]
ρ^I	Investment shock	beta	0.5000	0.2000	0.9014	0.9182	[0.8608	0.9434]
ρ^G	Government expenditure shock	beta	0.5000	0.2000	0.9496	0.9564	[0.9166	0.9849]
$\rho^{\sigma^\varepsilon}$	Entr. idiosyncratic risk shock	beta	0.5000	0.2000	0.9219	0.9198	[0.8960	0.9486]
ρ^Ψ	Fixed costs shock	beta	0.5000	0.2000	0.8648	0.8666	[0.8197	0.9114]
ρ^{μ_z}	Persistent tech. growth shock	beta	0.5000	0.2000	0.0466	0.0321	[0.0062	0.0847]
ρ^{μ_Υ}	Investment price shock	beta	0.5000	0.2000	0.9578	0.9616	[0.9324	0.9840]
Standard deviations of shocks								
σ^A	Aggregate productivity shock	invg	0.0010	0.0200	0.0045	0.0045	[0.0036	0.0053]
σ^{MP}	Monetary policy shock	invg	0.0010	0.0200	0.0011	0.0011	[0.0010	0.0013]
σ^I	Investment shock	invg	0.0010	0.0200	0.0232	0.0222	[0.0191	0.0271]
σ^G	Government expenditure shock	invg	0.0010	0.0200	0.0175	0.0171	[0.0156	0.0193]
$\sigma^{\sigma^\varepsilon}$	Entr. idiosyncratic risk shock	invg	0.0010	0.0200	0.0560	0.0551	[0.0498	0.0621]
σ^Ψ	Fixed costs shock	invg	0.0010	0.0200	0.0517	0.0507	[0.0460	0.0570]
σ^{μ_z}	Persistent tech. growth shock	invg	0.0010	0.0200	0.0100	0.0097	[0.0086	0.0113]
σ^{μ_Υ}	Investment price shock	invg	0.0010	0.0200	0.0044	0.0044	[0.0040	0.0049]
σ^Λ	Entr. net worth transfer shock	invg	0.0010	0.0200	0.0050	0.0049	[0.0043	0.0056]
Standard deviations of measurement errors								
$ME_t^{\mathbb{N}^{obs}}$	Net worth growth	invg	0.0001	0.0200	0.0579	0.0570	[0.0517	0.0639]
$ME_t^{B^{obs}}$	Loan growth	invg	0.0001	0.0200	0.0117	0.0117	[0.0104	0.0131]

$\widetilde{c}^H = 0.3469$, for 'bank owners' $\widetilde{c}^B = 0.3475$, and for the 'non-financial firm owners' $\widetilde{c}^F = 0.3958$, which indicate that in terms of steady state per capita consumption, firm owners are the wealthiest family in the economy, whereas the underbanked simple households are the poorest.[30]

[30] These values are calculated with habits persistence set to 0.5, the prior mean used in the estimation.

Table 4: Unconditional Variance Decomposition

Variable	ϵ_t^A	ϵ_t^{MP}	ϵ_t^I	ϵ_t^G	$\epsilon_t^{\sigma^\varepsilon}$	ϵ_t^Ψ	$\epsilon_t^{\mu_z}$	$\epsilon_t^{\mu_\Upsilon}$	ϵ_t^Λ
Y_t^{obs}	22.92	3.08	27.41	9.24	19.39	2.28	10.12	0.77	4.79
C_t^{obs}	20.09	0.96	18.33	1.57	14.77	5.81	2.98	0.32	35.19
I_t^{obs}	17.73	5.80	37.82	0.13	28.83	0.56	3.55	1.93	3.65
w_t^{obs}	7.56	0.45	0.68	0.26	2.12	2.07	86.72	0.05	0.09
N_t^{obs}	16.45	4.45	33.04	3.38	23.85	13.60	3.57	0.70	0.96
$P_t^{I,obs}$	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00
B_t^{obs}	11.55	0.73	10.02	0.78	8.86	5.94	1.66	0.18	60.28
π_t^{obs}	32.64	5.00	11.07	1.52	35.82	11.29	1.75	0.27	0.65
R_t^{obs}	19.24	5.40	15.24	1.83	50.15	5.55	1.78	0.39	0.42
S_t^{obs}	3.60	0.59	6.77	0.43	84.91	2.50	0.50	0.45	0.27
$\mathbb{N}_t^{obs}$	1.46	7.04	40.51	0.05	39.40	0.54	1.09	2.47	7.45

ϵ_t^A: Aggregate productivity shock, ϵ_t^{MP}: Monetary policy shock, ϵ_t^I: Investment shock, ϵ_t^G: Government expenditure shock, $\epsilon_t^{\sigma^\varepsilon}$: Entrepreneur idiosyncratic risk shock, ϵ_t^Ψ: Fixed costs shock, $\epsilon_t^{\mu_z}$: Persistent technology growth shock, $\epsilon_t^{\mu_\Upsilon}$: Investment price shock, ϵ_t^Λ: Entrepreneur net worth transfer shock

4.3 Prior Distributions

The parameters related to the prior distributions of the estimation are consistent with those used widely in the literature.[31] When estimating the deposit to consumption adjustment cost parameter, κ_D, we transform it to $\kappa_D^{Est} = \frac{\kappa_D}{1+\kappa_D}$, so that it lies between 0 and 1, allowing us greater control over its possible parameter space.[32] Habit persistence follows a beta distribution with a mean of 0.5 and a standard deviation of 0.2. The prior distributions of the shocks are also consistent with most of these studies. For the persistence parameters of the shocks, we use a beta-distribution with a prior mean of 0.5 and standard deviation of 0.2, whereas for the standard deviations of shocks, we use an inverse gamma distribution with mean, 0.001 and standard deviation 0.02. The net worth transfer shock follows a white noise process, as in Christiano, Motto, and Rostagno (2014).

4.4 Posterior Distributions and Variance Decomposition

The main estimation results are given in Table 3, while Table 4 summarises the resulting unconditional variance decompositions. The structural parameter estimates are comparable to those reported in the literature. The results show considerable level of habit formation, while the adjustment costs related to the deposits-to-consumption ratio, are found to be relatively low.

[31]See for example, Smets and Wouters (2007), Justiniano, Primiceri, and Tambalotti (2010, 2011, 2013), Christiano, Motto, and Rostagno (2014), Iacoviello and Neri (2010), and Gerali et al. (2010)

[32]A similar transformation is used by Smets and Wouters (2007) for the elasticity of capital utilisation costs.

Although the behaviour of entrepreneurs in our model follows Christiano, Motto, and Rostagno (2014), our estimates of the contribution of financial risk shocks to GDP volatility, account for 19.39% of the variation in GDP growth, which is approximately one-third in size to that shown in their study, although it is almost double in size to the 10% reported in Smets and Villa (2016). The contribution of technology and investment shocks in our estimates are consistent with Smets and Villa (2016), where these shocks are shown to explain most of the variation in GDP growth.

5 Welfare Analysis

The welfare of each individual agent-type family, $X = H, \overline{H}, F, B$, is based on their expected lifetime utility, which can be expressed recursively as follows:[33]

$$\mathcal{W}_t^X = \log\left(c_t^X - \varsigma c_{t-1}^X\right) - \psi_n V_t^{wX} \frac{\left(n_t^X\right)^{1+\eta}}{1+\eta} + \beta^X \mathbb{E}_t\left(\mathcal{W}_{t+1}^X\right),$$

$$V_t^{wX} = (1-\omega_w)\left(\frac{w_t^{X*}}{w_t^X}\right)^{-\lambda_w(1+\eta)} + \left(\frac{\pi_{t-1}^{\iota_w}\pi^{1-\iota_w}}{\pi_t}\ \left(\mu_{z,t-1}^*\right)^{\iota_\mu}\left(\mu_z^*\right)^{1-\iota_\mu}\right)^{-\lambda_w(1+\eta)} \omega_w \left(\frac{w_t^X}{w_{t-1}^X}\right)^{\lambda_w(1+\eta)} V_{t-1}^{wX}.$$

For some meaningful measure of welfare, we also use a consumption equivalent measure:[34]

$$CE_o^X = \left[\exp\left(\left(1-\beta^X\right)\left(\mathcal{W}_o^X - \mathcal{W}_\star^X\right)\right) - 1\right] 100,$$

where, the subscripts o and $\star$ are the quantities of the policy under consideration and the reference policy, respectively.[35] Using these measures we compute social (aggregate) welfare, as a weighted sum of the total welfare in each agent-type family:[36]

$$\mathcal{W}_t = \vartheta^H \Delta^H \mathcal{W}_t^H + \vartheta^{\overline{H}} \Delta^{\overline{H}} \mathcal{W}_t^{\overline{H}} + \vartheta^F \Delta^F \mathcal{W}_t^F + \vartheta^B \Delta^B \mathcal{W}_t^B, \tag{52}$$

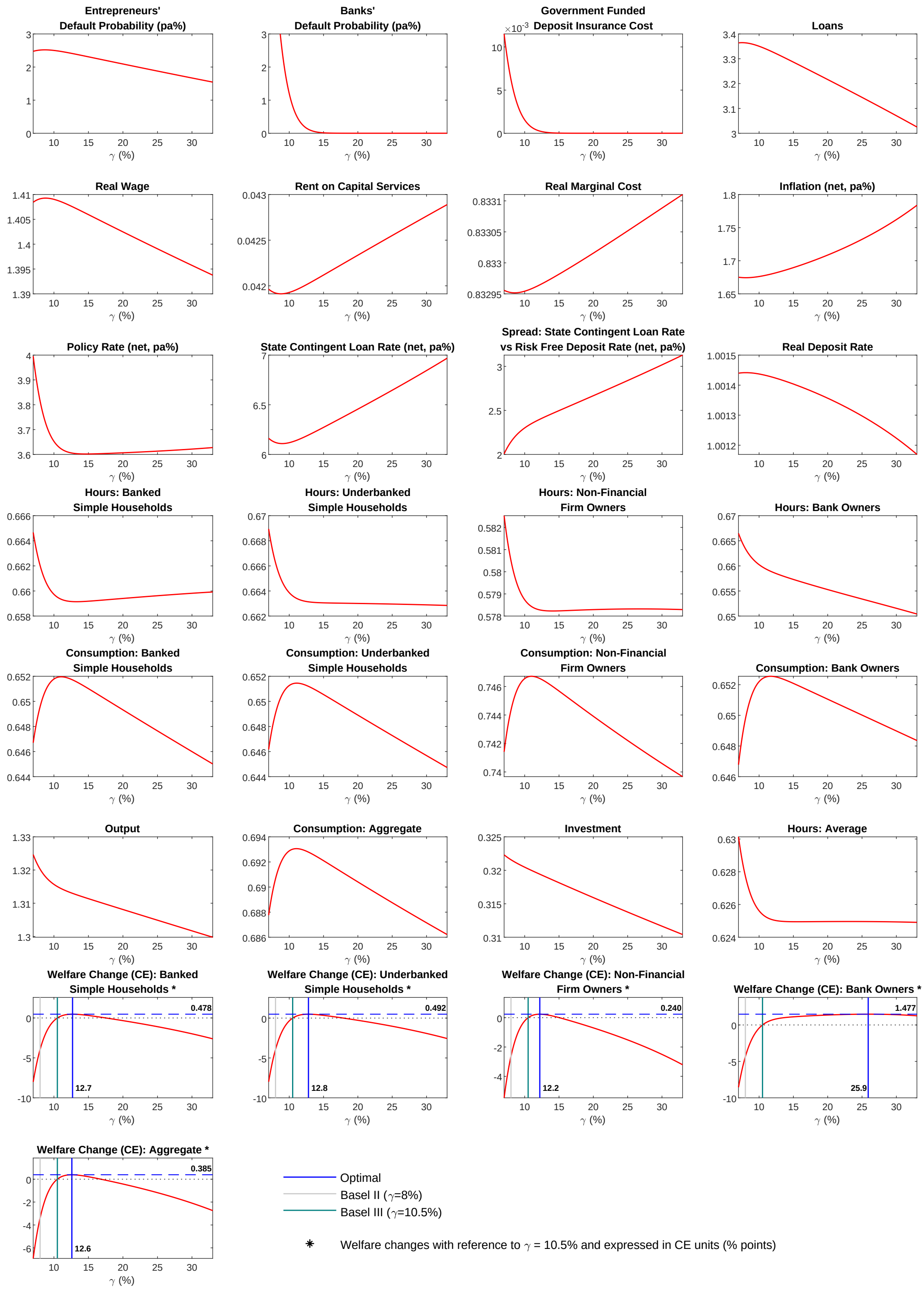
where, $\mathcal{W}_t$ is social welfare and ϑ^H, $\vartheta^{\overline{H}}$, ϑ^F and ϑ^B are the weights of each family respectively. Since all agents have access to the same deposit rate and discount factor, (see earlier), we adopt a common aggregation weighting used in the literature, where $\vartheta^X = 1-\beta$, for all the respective family types, $X = H, \overline{H}, F, B$.[37] Accordingly, the aggregate consumption equivalent measure is,

$$CE_o = \left[\exp\left(\left(\mathcal{W}_o - \mathcal{W}_\star\right)\right) - 1\right] 100,$$

where $\mathcal{W}_o$ and $\mathcal{W}_\star$, represent the aggregate welfare under each policy consideration.

[33] For details see in the Technical Appendix.
[34] See Schmitt-Grohé and Uribe (2007), Ascari and Ropele (2012), Rubio and Carrasco-Gallego (2014, 2016)
[35] Thus a positive value of CE_o^X indicates an increase in welfare from the reference policy for agent type X.
[36] See also Brzoza-Brzezina, Kolasa, and Makarski (2015).
[37] See, among others, Brzoza-Brzezina, Kolasa, and Makarski (2015), Lambertini, Mendicino, and Punzi (2013), Mendicino and Pescatori (2005), and Rubio and Carrasco-Gallego (2014, 2016, 2017). We have also considered steady state consumption shares for these weights and found the qualitative results to be robust.

Figure 2: Stochastic Means: Effects of Changes in Capital Requirement Ratio



5.1 Optimal Bank Capital Requirement Ratio

In this section we examine the welfare implications of the bank capital requirement ratio for each of the four agent-type families separately, and for social welfare. Figure 2 illustrates how different levels of the capital requirement ratio, γ, affect the stochastic means of key variables, when all other parameters are fixed at their estimated posterior mean and subject to all estimated shocks being active. The welfare results, (bottom two rows), are expressed in CE percentage points with reference to $\gamma = 10.5\%$, and thus represent net welfare changes in addition to those obtained by the Basel III capital requirement ratio of 10.5%.[38]

The results show that the social optimal CRR is 12.6%. This value is 2.1% higher than that implied currently by the Basel III Convention and implies a net increase in social welfare of 0.385% in CE units (quarterly). More importantly, in this model not all agent-types benefit equally from the social optimal CRR. For 'firm-owners' the optimal CRR appears to be the lowest of all four agents, at 12.2%, implying a net CE welfare increase of 0.24%, whereas that for 'bank owners' is the highest, at 25.9% with a net welfare increase of 1.477%. For the two simple household types, the optimal long-run CRR is similar, with 'banked households' at 12.7% and 'underbanked households' at 12.8%, values which imply a net welfare increase of 0.478% and 0.492%, respectively. Overall, given the relatively small share of 'bank owners' in the economy, the society's optimal weight is closer to that of the simple households, at $\gamma = 12.6\%$.

Interestingly, in this model it is the businesses ('firm-owners') that gain the least from a stricter CRR. 'Firm-owners' are both 'borrowers' and 'savers', but they are predominantly the main borrowers, as this model deviates from mortgage loans and borrowing focuses on the production sector. Thus, our results for the implication of the long-run CRR, are not inconsistent with earlier results in the 'borrower-saver' literature, that indicate that borrowers are worse-off from stricter macroprudential policy, although here we shed light on a number of new aspects. Also, unlike most of the literature that uses the 'borrower-saver' framework, where savers usually benefit and borrowers lose from stricter macroprudential policy, here we show that up to a certain level of bank capital requirements there are welfare gains to be made for all four agent types, but not equally across all of them, as explained above. Also, stricter bank capital regulation in this model is shown to reduce mainly the default probability of banks, although at higher levels, where loans are more restricted, it can also reduce the default probability of entrepreneurs.

Looking closer at the stochastic steady state effects of the model, increasing gradually (from low values) the CRR, the welfare of all agents is shown to initially increase, despite the resulting fall in aggregate demand and output. This is because increasing the CRR reduces the default

[38] Hence, in Figure 2, CE=0 at $\gamma = 10.5\%$.

probability of banks and the deposit insurance cost, while it initially increases the real wage and consumption of all four agent-types, reducing also their employment hours. However, higher values of the CRR, are shown to raise the loan spread and reduce investment and employment hours, of all agent-types, causing a fall in aggregate output. This also makes capital investment, which relies on borrowing, more expensive than labour, raising initially average real wages and increasing consumption for all four agent-types. The latter, however, reduces the average labour hours and amplifies the fall in output. The fall in aggregate demand, as investment and output fall, causes the rent on capital services, real marginal cost and prices to also fall, reducing also the policy rate and raising the real deposit rate.

Overall, in this model stricter macroprudential policy, in terms of a higher CRR, is shown to affect adversely the real economy and businesses that rely on credit, while benefit 'bank-owners' the most. For bank owners the optimal capital requirement ratio can afford to rise to much higher levels, (25.9%), before their welfare gains from such policy start to diminish. This result may initially look rather paradoxical, since credit banks were the most vocal against stricter bank capital controls during the financial crisis, however, here banks belong to bank-owners and their welfare relies on bank capital dividends. Stricter bank capital requirements imply a relatively higher share of bank capital required in funding bank activities and thus a higher share of bank dividends for bank owners. This results can also be explained by the fact that a higher CRR reduces the risk of bank default and thus provides a more stable environment for bank owners. However, stricter bank capital regulation, that is above 25.9% here, will start harming bank owners too, as loans fall dramatically and the economy enters a phase of long-run reduced economic activity.

5.2 Optimal Monetary Policy and Dynamic Bank Capital Requirements

In this section we examine the implications of monetary policy, both independently and in interaction with macroprudential policy, for the welfare of each agent type separately and for social welfare.[39] Table 5(a), reports the optimal combination of the interest rate rule under monetary policy alone, whereas Table 5(b) reports the optimal combinations of the Taylor rule and the countercyclical capital buffers (CCyB), (eq. 50). Welfare is measured in terms of CE units with reference to the optimal values derived from the optimal Taylor rule.

The results in Table 5 show that in terms of social welfare and when all shocks are activated (All or All§), the CCyB rule is welfare increasing, a result widely reported in the literature.[40]

[39]We consider plausible parameter spaces of $\phi_y \in [0, 1.0]$ and $\phi_\pi \in [1.5, 3.0]$, similar to Benes and Kumhof (2015) and Schmitt-Grohé and Uribe (2007), using the step size of each grid to be 0.1.

[40]In testing the CCyB rule, we restrict our grid search to very modest changes in γ_t. For example the optimal value of $\gamma_{\widetilde{b}_t} = 0.90$, in Table 5, implies a S.D. of 8% points, that is an increase of the CRR by 0.84, or from

Table 5: Optimal Monetary Policy and Countercyclical Bank Capital Buffers

(a) Optimal Taylor rule

	Optimal Parameters			CE vs Optimal TR (% Points)**					SD (% Points)	
Shock	ϕ_π	ϕ_y	$\gamma_{\widetilde{b}_t}$	BH	UBH	F	B	Social	$\widehat{R}_t$	$\widehat{\gamma}_t$
All	3.0	0.2	-	-	-	-	-	-	0.662	-
ϵ^A	1.5	0.0	-	-	-	-	-	-	0.211	-
ϵ^{MP}	3.0	1.0	-	-	-	-	-	-	0.146	-
ϵ^I	1.7	0.7	-	-	-	-	-	-	0.250	-
ϵ^G	1.8	0.1	-	-	-	-	-	-	0.057	-
$\epsilon^{\sigma^\varepsilon}$	3.0	0.3	-	-	-	-	-	-	0.446	-
ϵ^Ψ	2.2	1.0	-	-	-	-	-	-	0.114	-
ϵ^{μ_z}	3.0	0.0	-	-	-	-	-	-	0.071	-
ϵ^{μ_Υ}	3.0	0.2	-	-	-	-	-	-	0.018	-
ϵ^Λ	2.8	0.1	-	-	-	-	-	-	0.061	-

(b) Optimal Taylor rule and CCyB responses to credit deviations from trend (eq. 50)

	Optimal Parameters			CE vs Optimal TR (% Points)**					SD (% Points)	
Shock	ϕ_π	ϕ_y	$\gamma_{\widetilde{b}_t}$	BH	UBH	F	B	Social	$\widehat{R}_t$	$\widehat{\gamma}_t$
All	3.0	0.1	0.9	0.0142	0.0174	0.3334	0.1980	0.1593	0.628	8.029
All§	3.0	0.1	1.1	0.1376	0.1624	0.3190	0.3870	0.2306	0.582	9.285
ϵ^A	1.5	0.0	1.0	0.0784	0.1706	0.2342	0.2005	0.1744	0.256	5.078
ϵ^{MP}	3.0	1.0	0.0	-	-	-	-	-	0.146	-
ϵ^I	1.7	0.7	0.6	0.0032	0.0045	0.0026	-0.0039	0.0030	0.242	1.056
ϵ^G	1.8	0.1	1.2	-0.0010	0.0116	0.0066	-0.0020	0.0056	0.066	1.454
$\epsilon^{\sigma^\varepsilon}$	3.0	0.3	1.5	0.0852	-0.0035	0.0225	0.1301	0.0356	0.417	3.969
ϵ^Ψ	2.2	1.0	0.0	-	-	-	-	-	0.114	-
ϵ^{μ_z}	3.0	0.0	0.1	0.0019	-0.0009	-0.0000	0.0062	0.0004	0.073	0.390
ϵ^{μ_Υ}	3.0	0.2	0.0	-	-	-	-	-	0.018	-
ϵ^Λ	2.8	0.1	0.0	-	-	-	-	-	0.061	-

All: All nine shocks activated. All§: Only shocks with non-zero CCyB responses activated. CE: Welfare difference in terms of consumption equivalent units against optimal monetary policy, in percentage points. BH: Banked Simple Households, UBH: Underbanked Simple Households, F: Non-Financial Firm Owners, B: Bank Owners. Parameter spaces: $\phi_\pi \in \{1.50, 1.60, \ldots, 3.00\}$, $\phi_y \in \{0.00, 0.10, \ldots, 1.00\}$, $\gamma_{\widetilde{b}_t} \in \{0.00, 0.10, \ldots, 5.00\}$.

However, when we look at the welfare effects of each of the four agents individually, the results are very asymmetric and they can move even in the opposite direction to that suggested by the literature, particularly for specific type of shocks. Countercyclical buffers are shown to benefit the 'firm-owners' the most, with second best the 'bank-owners', while they make a much smaller welfare contribution to the simple households. This result differs to the existing literature, since firms-owners here are also the main borrowers, and the bulk of literature reports 'savers' to gain the most from such policy. When we allow only shocks for which the CCyB rule has a non-zero contribution, the ranking of welfare gains changes with the 'bank-owner' benefiting the most from macroprudential policy, with 'firm-owners' being a close second best, whereas again the welfare gains of the two simple households are approximately half that of the

$\gamma_t = 10.5\%$ to 11.34%.

former two. In either of these two cases (All or All§), the banked simple household appears to gain a little less than the underbanked simple household. This is because dynamic CRR rules stabilise real wages (the only income of the underbanked family), but they also increase bank capital requirements pro-cyclically to loans, which reduces the relative contribution of deposits, to that of bank capital, in funding loans, reducing the relative income share of depositors. In terms of the nature of shocks, it is shown that the second largest welfare gain to productivity shocks, (that dominate all shocks), is during credit risk shocks ($\epsilon^{\sigma^{\varepsilon}}$). However, the welfare gains here are again asymmetric, with the 'bank-owners' benefiting the most from countercyclical buffer policy, then the 'banked simple households' and least the 'firm-owners'. Interestingly, the results suggest that the 'underbanked simple household' not only does not gain from such policy but loses welfare. Intuitively, this is because during financial shocks that threaten banks, the whole society is taxed to raise funds towards the government's deposit insurance scheme, but the 'underbanked simple household' has much less to benefit from financial stability compared to the banked household, but also to entrepreneurs who are the main borrowers in this model. Finally, the results in Table 5 show that for four types of shocks: monetary policy, fixed production costs, investment price and net worth transfer shocks, an optimal Taylor rule is sufficient, as there are no further welfare gains to be made from countercyclical buffers.[41]

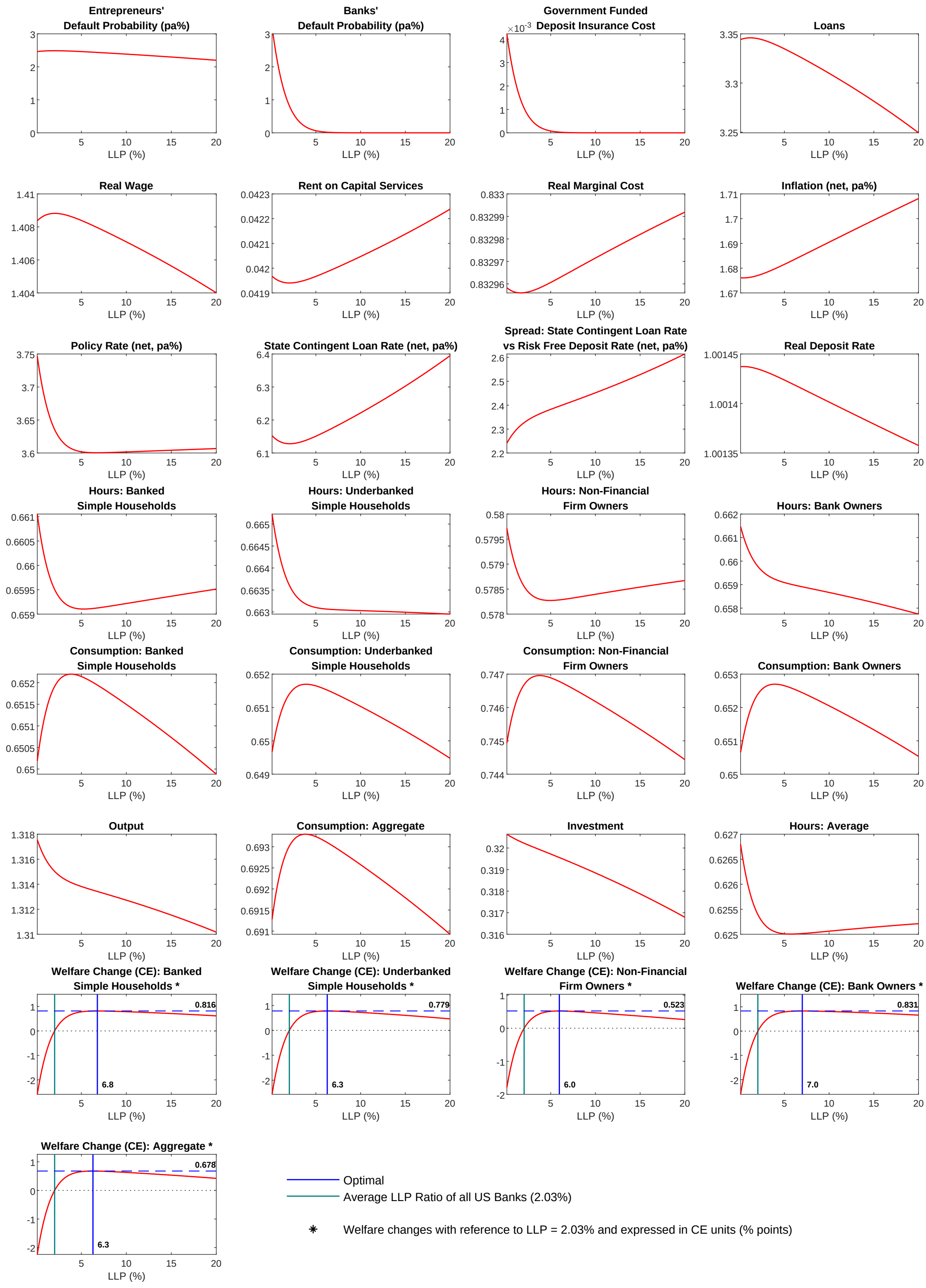
5.3 Optimal Loan Loss Provisions Ratio

Figure 3, reports the stochastic means of key variables for different values of the loan loss provision ratio (LLP), and the welfare implications for each agent-type separately and for social welfare.[42] As with a stricter CRR, a higher LLP is shown to insulate the economy from credit risk and reduce the default probability of the bank, the cost of deposit insurance, the policy rate and the real deposit rate. As a result, increasing LLP gradually, is shown to initially increase the consumption levels of all four agent types and aggregate consumption, which is also reflected in an increase is agent-specific and social welfare, up to approximately 6.0%. However, at higher levels loan loss provisions are shown to reduce substantially, loans and consumption, at both individual and aggregate levels, and thus economic growth. As with the optimal CRR, the optimal level of the LLP ratio is different for the four agents, with the lowest, 6.0%, being that for 'firms-owners', whose wealth relies on loans, and the highest 7% for bank-owners, who have the most to lose from banks defaulting. For the simple households the optimal LLP ratio lies somewhere in between these two. Since the 'banked' households are more exposed to bank risk,

[41]This result is consistent with the findings in Quint and Rabanal (2014) although in their study the largest welfare gains from macroprudential policy are achieved during risk shocks, as their focus is on house mortgages.

[42]For our analysis we assume that at equilibrium all banks set the same loan loss reserves ratio.

Figure 3: Stochastic Means: Effects of Changes in the *Loan Loss Provisions* Ratio



their optimal ratio, 6.8% is slightly higher than that of the 'underbanked' households which is 6.3%. Overall, one of the most striking results here, is that the society's optimal LLP ratio is 6.3%, which is substantially higher to the average 2.03% applied in the US banking system.

Table 6: Optimal Monetary Policy and Dynamic Loan Loss Provisions

Optimal Policy Parameters: Taylor Rule and Dynamic Loan Loss Provisions (eq. 51)											
	Optimal Parameters			CE vs Optimal TR (% Points)**					SD (% Points)	
Shock	ϕ_π	ϕ_y	α_{NPL}	BH	UBH	F	B	Social	$\widehat{R}_t$	$\widehat{LLP}_t$
All	3.00	0.20	0.00	-	-	-	-	-	0.662	-
All§	3.00	0.10	1.10	-0.3045	0.4885	0.2589	-0.1533	0.1564	0.444	60.609
ϵ^A	1.50	0.00	2.00	-0.0607	0.4459	0.3728	0.0085	0.2650	0.279	53.772
ϵ^{MP}	3.00	1.00	4.00	-0.0183	0.0180	0.0126	-0.0292	0.0045	0.082	14.359
ϵ^I	1.60	0.70	0.20	-0.0140	0.0141	0.0044	-0.0103	0.0016	0.244	7.299
ϵ^G	1.50	0.20	4.00	-0.3201	0.3492	0.0240	-0.3115	0.0082	0.133	56.370
$\epsilon^{\sigma^\varepsilon}$	3.00	0.30	0.00	-	-	-	-	-	0.446	-
ϵ^Ψ	2.20	1.00	0.00	-	-	-	-	-	0.114	-
ϵ^{μ_z}	1.50	0.00	4.00	-0.1058	0.4565	0.3280	-0.0829	0.2335	0.063	52.714
ϵ^{μ_Υ}	3.00	0.20	0.00	-	-	-	-	-	0.018	-
ϵ^Λ	1.50	1.00	4.00	-0.8631	1.6404	0.2825	-0.6342	0.3062	0.287	96.775

All: All nine shocks activated. All§: Only shocks with non-zero LLP responses activated. CE: Welfare difference in terms of consumption equivalent units against optimal monetary policy, (percentage points). BH: Banked Simple Households, UBH: Underbanked Simple Households, F: Non-Financial Firm Owners, B: Bank Owners. Parameter spaces: $\phi_\pi \in \{1.50, 1.60, \ldots, 3.00\}$, $\phi_y \in \{0.00, 0.10, \ldots, 1.00\}$, $\alpha_{NPL} \in \{0.00, 0.10, \ldots, 4.00\}$.

5.4 Optimal Monetary Policy and Dynamic Loan Loss Provisions

In this section we examine the welfare effects of optimal monetary policy in combination with a dynamic loan loss provisions rule, as described in equation (51). Table 6, shows that dynamic loan loss provisions responding countercyclically to expected non-performing loans, can make a net contribution to social welfare, only if it is activated for shocks that affect the performance of firms and the entrepreneurs. Such policy is shown to benefit the 'underbanked' household and 'firm owners' the most, at the expense of 'banked households' and 'bank owners'. This is because unlike stricter bank capital regulation that raises the share of bank capital and thus benefits the 'bank owners', with dynamic loan loss provisions the banking sector builds buffers to protect against a potential default of firms, by directly reducing a share of their potential loans, which in turns also reduces their required level of bank capital and deposits. Such policy reduces loans and economic activity and dampens the volatility of interest rates and equity returns, but benefits firms and their share holders by increasing the probability of credit continuing to flow from banks to firms. This benefits both production and the simple underbanked household, whose only income is wages from firms, but reduces the welfare of 'banked households' and 'bank owners'.

6 Non-Coordinated Policies

In this section we examine the case of non-coordinated policies between the monetary and macroprudential authorities. In earlier papers, non-coordination is captured by assuming two separate loss functions, or splitting the policy objective function, where the monetary authority focuses on stabilising inflation and output, whereas the macroprudential authority aims at financial stability, (see, among others, Angelini, Neri, and Panetta (2014), Rubio (2014), and Rubio and Yao (2020)). However, in our paper, the policy objective is represented by the social welfare of the economy, where there are four distinct agent types. The approach where both policy makers jointly choose policy parameters to optimise the policy objective, as in section 5, represents the case of coordination among the two policymakers. However, in such a framework it is less clear how the policy objective should be split between these two authorities to examine non-coordination. There are four agent-type families: 'non-banked simple households' and 'banked simple households' (simple deposit holders), 'firm owners' and 'bank capital owners', but only the latter two are exposed to financial market volatility. Firm owners are the only credit holders in this model and they also hold firm shares. Bank owners hold all bank shares and supply bank capital. We believe that a meaningful way of splitting the policy objective in such a framework, is for the monetary policy to represent all the simple households, and the macroprudential authority to represent the interests of firm owners and bank owners, that hold all credit, shares and bank capital. Accordingly, the welfare objectives considered in the non-coordinated policy scenario for the monetary authority, $\mathcal{W}_t^{NC^{Mon}}$, and the macroprudential authority, $\mathcal{W}_t^{NC^{MacPru}}$, are [43]

$$\mathcal{W}_t^{NC^{Mon}} = (1-\beta^H)\left(\frac{\Delta^H}{\Delta^H+\Delta^{\overline{H}}}\right)\mathcal{W}_t^H + \left(1-\beta^{\overline{H}}\right)\left(\frac{\Delta^{\overline{H}}}{\Delta^H+\Delta^{\overline{H}}}\right)\mathcal{W}_t^{\overline{H}} \tag{53}$$

$$\mathcal{W}_t^{NC^{MacPru}} = (1-\beta^F)\left(\frac{\Delta^F}{\Delta^F+\Delta^B}\right)\mathcal{W}_t^F + (1-\beta^B)\left(\frac{\Delta^B}{\Delta^F+\Delta^B}\right)\mathcal{W}_t^B. \tag{54}$$

The results show that that for the case of countercyclical bank capital buffers, coordinated policies, illustrated earlier in table 5, are superior to non-coordinated policies, shown in Table 7, and this is irrespective of the shock affecting the economy, which is consistent with some of the earlier literature (Angelini, Neri, and Panetta (2014a)). Further, our results highlight that the distributive effects of welfare may also change when the two policies are non-coordinated. For example, when we consider the case where all shocks are activated, simple households loose welfare during non-coordinated policies amidst a relatively stronger macroprudential response,

[43] More details and alternative aggregate welfare functions are considered in the Online Technical Appendix.

whereas during coordinated policies none of the families record welfare losses, where in both cases welfare changes are derived in comparison to the case of monetary policy acting alone. However, we observe that welfare improvements enjoyed by firm and bank owners are higher under non-coordinated than coordinated policies. Therefore, coordinated policies do not correspond to

Table 7: Optimal Policy Parameters: Non-Coordinated Responses

Optimal Taylor rule and CCyB responses to credit deviations from trend (eq. 50)

	Optimal Parameters			CE vs Optimal TR (% Points)**					SD (% Points)	
Shock	ϕ_π	ϕ_y	$\gamma_{\widetilde{b}_t}$	BH	NBH	F	B	Social	$\widehat{R}_t$	$\widehat{\gamma}_t$
All	3.0	0.1	1.2	-0.0912	-0.0012	0.3540	0.3089	0.1383	0.630	11.006
ϵ^A	1.5	0.0	1.1	0.0686	0.1710	0.2377	0.2057	0.1736	0.261	5.597
ϵ^{MP}	3.0	1.0	0.0	-	-	-	-	-	0.146	-
ϵ^I	1.8	1.0	0.8	0.0017	0.0011	0.0010	-0.0068	0.0010	0.265	1.284
ϵ^G	1.7	0.1	1.3	-0.0020	0.0127	0.0064	-0.0026	0.0056	0.065	1.582
$\epsilon^{\sigma^\varepsilon}$	3.0	0.3	1.5	0.0852	-0.0035	0.0225	0.1301	0.0356	0.417	3.969
ϵ^Ψ	3.0	0.0	0.7	-0.0178	-0.0120	0.0071	0.0156	-0.0044	0.159	1.473
ϵ^{μ_z}	3.0	0.0	0.1	0.0019	-0.0009	-0.0000	0.0062	0.0004	0.073	0.390
ϵ^{μ_Υ}	3.0	0.2	0.0	-	-	-	-	-	0.018	-
ϵ^Λ	3.0	0.1	0.1	-0.0052	-0.0002	-0.0022	0.0012	-0.0024	0.061	0.202

All: All nine shocks activated. CE: Welfare difference in terms of consumption equivalent units against optimal monetary policy, (percentage points). BH: Banked Simple Households, UBH: Underbanked Simple Households, F: Non-Financial Firm Owners, B: Bank Owners. Parameter spaces: $\phi_\pi \in \{1.50, 1.60, \dots, 3.00\}$, $\phi_y \in \{0.00, 0.10, \dots, 1.00\}$, $\gamma_{\widetilde{b}_t} \in \{0.00, 0.10, \dots, 5.00\}$.

a Pareto superior outcome, compared to non-coordinated policies in this paper, although overall, they do result in a higher social welfare.

7 Concluding Comments

This paper introduces a model that allows us to study the welfare implications of monetary and macroprudential policy on four different types of agents, to the pure 'borrowers' or 'savers' used widely in the literature. In this model, the 'simple banked household' would have to be clustered together with banks and 'bank-owners' to make up 'savers'. Also, since we deviate from the housing market, based on the assumption that any of these four agents could also be paying mortgages, our 'borrowers' would then be mainly entrepreneurs, who belong to the 'firm-owners', whereas the 'simple underbanked household', that is estimated to make up approximately 26.7% of the US economy, would be left completely out of a 'borrower-saver' analysis.

Macroprudential regulation is shown to reduce the default probability of banks and potentially that of firms that rely on credit. Insulating the banking sector from credit risk is a feature which has been at the core of macroprudential policy design in practice, however it is an effect often missing in the bulk of the related DSGE literature that examine macroprudential policy.[44] The framework introduced here can be used for a number of macroeconomic policy experiments, although here it is used to examine monetary and macroprudential policy.

The results indicate a slightly stricter bank capital requirement ratio than the current ratio implemented according to Basel III, and a substantially higher optimal loan loss provisions ratio than the average ratio held overall by US banks. In terms of welfare specific to the heterogeneous agents considered, the results suggest that stricter macroprudential policy, in terms of higher capital requirement or loan loss provisions ratios, can support all four agents, but more so the 'bank owners' than the 'simple households' and businesses that rely on credit. Dynamic countercyclical capital buffers are also shown to support all four agent types, but the welfare gains for 'bank owners' and 'firms owners' are much larger than those for the simple households. The results also suggest that countercyclical loan loss provisions can make a net welfare improvement, over optimal monetary policy, but only for specific types of shocks that destabilise repayments of loans. For those shocks, countercyclical loan loss provisions are shown to protect the 'simple underbanked household' and 'firm-owners', at the expense of the financial system: banks, 'bank owners' and 'banked simple households'. Finally, the paper indicates that coordination between monetary and macroprudential policies results in higher social welfare, although this may not always be Pareto optimal with respect to non-coordinated outcomes.

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[44] A notable exception in this literature is Mendicino et al. (2018).

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