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Systemic risk, countercyclical capital, and stress tests:

Macroprudential policy in a macroeconomic model

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Abstract
The financial crisis has shown that better macroprudential regulation is needed to counteract systemic risk in the financial system. In addition to the Basel III requirements, macroprudential stress tests are being developed to address system-wide imbalances. However, while recent research has advanced the modelling of financial frictions and the empirical analysis of macroprudential policy, modelling of macroprudential tools such as capital requirements and stress tests has barely progressed. Therefore, I assess the effectiveness of stress tests and countercyclical capital buffers using a macroeconomic model, where systemic risk creates crises. To analyse macroprudential policy, I perform a welfare analysis where a financial authority targets leverage. I find that macroprudential policy increases welfare through reducing systemic risk and raising total wealth. A regime with only countercyclical capital requirements raises welfare more than a regime with only stress tests, but a combined regime is best, raising welfare by 3.23%.

Keywords: Countercylical capital requirements, DSGE modelling, Macroprudential policy, Stress tests, Systemic risk
JEL classification: E13, E44, E58, G01, G28

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List of Abbreviations

bp	basis point (10^{-4})
CCyB	Countercyclical capital buffer
DSGE	Dynamic stochastic general equilibrium
DW2014	Dewachter and Wouters (2014)
ECB	European Central Bank
FOC	First order condition
GDP	Gross domestic product
HK2014	He and Krishnamurthy (2014)
IRF	Impulse response function
TFP	Total factor productivity

List of Symbols

Variables

A_t	Technology
B_t	Bonds
C_t	Consumption
D_t^K	Dividends of capital producer
D_t	Dividends of goods producer
H_t	Housing stock
i_t	Investment rate
K_t	Capital stock
p_t	Price of housing
q_t	Price of capital
r_t^H	Rental rate on housing
r_t	Risk-free interest rate
R_t	Return on assets
$\tilde{R}_t$	Return on equity
U_t	Household utility

V_t	Equity
W_t	Household wealth
Y_t	Output
α_t^{FI}	Leverage ratio (assets over equity)
ω_t	Misspricing of risk
τ_t^{CCyB}	Macroprudential CCyB tool: tax on debt
τ_t^{ST}	Macroprudential stress test tool: tax on risk-weighted assets
ε_t	Reputation

Parameters

$\bar{A}$	Productivity constant
l	Household wage share
m	Intermediary risk aversion
α_ε	Leverage constant
β	Household discount rate
δ	Capital depreciation rate
η	Intermediary exit rate
κ	Adjustment costs for capital investment
λ	Minimum debt-to-wealth fraction
θ	Household expenditure share on housing
ε_{MIN}	Minimum intermediary reputation

Shocks

σ_t^A	Technology shock
σ_t^K	Capital efficiency shock

1 Introduction

When the financial crisis hit markets in 2007–2008, financial regulations were crude. To achieve financial stability, policymakers relied on microprudential regulation, based on the soundness of individual financial institutions. Such policy quickly emerged as insufficient to guarantee financial stability in an environment marked by a tightly interconnected financial system that relies on outside financing and provides essential real economy services. Now, a widely held belief is that the financial architecture is inherently fragile and externalities can have systemic impacts on financial intermediation and the functioning of the economy (Adrian, Covitz, & Liang, 2015).

As a result, macroprudential policy has been proposed to take into perspective the macroeconomic environment, the interconnection between the financial sector and the real economy, and the central role of financial intermediaries. The purpose of such policy is to address the contribution of systemic risk to the real economy and improve system-wide stability. For example, countercyclical capital buffers (CCyBs) impose an additional capital requirement on banks that increases with the economy's leverage (Rubio & Carrasco-Gallego, 2016). Lately, stress tests are becoming more and more important: European Central Bank (ECB) Vice President Constâncio (2017) argues for macroprudential stress tests to assess system-wide risk, thereby increasing the quality of assets at financial intermediaries.

While financial authorities are increasingly relying on macroprudential policies, formal economic analysis of such policies is still in its infancy. To analyse what type of policy benefits the economy, widely used New Keynesian dynamic stochastic general equilibrium (DSGE) models[1] provide a "lab economy" for economists to experiment with. These models demonstrate the general equilibrium effects of small shocks on different macroeconomic and financial variables. Considering the empirical evidence of financial market imperfections, researchers have started to explicitly model financial frictions in DSGE models.

Similarly, in this paper, I extend the model presented by He and Krishnamurthy (2014, hereafter HK2014) that includes issues of macroprudential concern, in particular endogenously generated systemic risk. Systemic risk is created when the financial sector faces disruptions that trigger adverse effects in the real economy.[2] The model is built with some microfoundations but is intentionally kept simple to

[1] DSGE models are a class of macroeconomic models used in academia and central banking to analyse the effects of policies. See Smets and Wouters (2003) or Christiano, Eichenbaum, and Evans (2005) for a standard New Keynesian DSGE model.

[2] Although there is no consensus on the definition of systemic risk, the ECB (2018b) establishes: "Systemic risk can best be described as the risk that the provision of necessary financial products and services by the financial system will be impaired to a point where economic growth and welfare may be materially affected".

use advanced solution techniques that capture the time-varying characteristics of systemic risk and accommodate its non-linear behaviour, an important feature for assessing financial regulations (Mendoza, 2016). In more detail, my model focuses on systemic risk generated by two financial frictions: First, there is a separation between ownership and management of financial intermediaries; Second, I employ an equity constraint similar to HK2014 and Dewachter and Wouters (2014, hereafter DW2014), which allows for a transition from normal times to recessions. The equity constraint prevents financial intermediaries from raising additional equity during recessions. This increases the need for intermediaries to finance investments with debt, increasing leverage and risk premia. Additionally, intermediaries do not internalise household risk preferences for investment, which leads to a misspricing of risk.

With the model generating systemic risk, representing a world where financial crises happen endogenously, I can perform a welfare analysis of two different macroprudential policy tools: CCyBs and stress tests. There is a growing literature assessing macroprudential tools in macroeconomic models with financial frictions. Laséen, Pescatori, and Turunen (2017) derive an optimal CCyB that is welfare enhancing vis-à-vis a simple monetary policy rule and Rubio and Carrasco-Gallego (2016) find a loan-to-value ratio that increases welfare. Clerc et al. (2015) demonstrate that there is a minimum capital requirement improving welfare. However, little progress has been made to analyse macroprudential stress tests à la Constâncio (2017). CCyBs and stress tests are implemented in my model as tax rates on debt and assets, respectively. The objective of this study is to determine the welfare effects of these two macroprudential policy tools and in particular to establish whether one improves welfare more than the other.

My contribution to the literature is as follows. First, I extend HK2014's model to analyse an economy where two assets are held in equilibrium instead of only one. Second, I model both CCyBs and stress tests as tax rates to find numerically the welfare maximising macroprudential policy tool that approximates the optimal macroprudential policy rate. It should be seen as complementary to Laséen et al. (2017), who focus on the advantage of CCyBs over monetary policy, and Clerc et al. (2015), who focus on default and minimum capital requirements.

The rest of this thesis is structured as follows. In Section 2, I motivate my research and place it into the related literature. Then, I introduce the model in Section 3 and I show how it creates systemic risk and matches the data. In Section 4, I derive the optimal macroprudential policy and I search for the welfare maximising numerical approximation of the optimal rate. Section 5 concludes.

2 Background and related literature

In this section, I motivate my study and relate it to two strands of current research. For one, my thesis builds on the literature on macroeconomic modelling with financial frictions, and second, I add to the debate of how macroprudential policy reactions to financial instability should look like.

2.1 Financial frictions in macroeconomic models

Introducing financial frictions in standard macroeconomic models has been crucial to understand financial crises. While Brunnermeier, Eisenbach, and Sannikov (2013) provide a comprehensive survey of the literature on macroeconomics with financial frictions, I limit this section to the important developments required to understand my model. Some researchers model a limited capital market, while others limit access to credit markets due to contract or information failures, for example. It is important to distinguish between financial risk that is exogenous and imposed on the model from the outside, and endogenous risk that arises due to agents' decisions.

Examples of early work with exogenous financial frictions in macroeconomic models included the financial accelerator, where Bernanke, Gertler, and Gilchrist (1999) develop an amplification channel for macroeconomic shocks propagating into credit markets. Kiyotaki and Moore (1997) similarly create large business cycle fluctuations via small shocks that propagate through imperfect credit markets. These models focus on the dynamics around the non-stochastic steady state and are unable to generate results for an economy in a recession, for instance.

More recent papers converge on generating endogenous systemic risk. Here, macroeconomic models either incorporate capital constraints on financial intermediaries or the possibility of default as an important factor for explaining the emergence of risk in the financial system. For instance, Gertler and Karadi (2011) develop a standard DSGE model with a collateral-constrained financial sector, exploiting the effects of default on collateral. Clerc et al. (2015) develop a model with three layers of default that generates financial amplification of shocks through a net worth channel. Gilchrist and Zakrajšek (2012) determine that investors become more risk averse when their capital becomes impaired, which then translates into higher bond premia and lower supply of credit. Adrian and Boyarchenko (2012) develop a risk-bearing funding constraint for the intermediaries that generates procyclical leverage and procyclical dynamics of credit. However, these models only incorporate first-order effects, which do not take into account risk amplification inherent to the global dynamics of more sophisticated models with time-varying systemic risk, which is needed to analyse macroprudential regulations (Mendoza, 2016).

The literature studying the global dynamics of models with financial frictions has been growing for the last decade and is where this thesis fits in. Examples include HK2014, DW2014, Brunnermeier and Sannikov (2014), and Danielsson, Shin, and Zigrand (2011), who work on models with endogenous and time-varying risk. They solve these models either using global solution methods or higher-order perturbation methods.

HK2014 introduce a macroeconomic model that includes systemic risk where financial intermediation can be disrupted and feedback channels amplify distress in the real economy back to the financial sector. This model allows the analysis of the stochastic distribution of the economy where some states feature systemic risk. In particular the transition from normal states to risky states is in focus. To get systemic risk, HK2014 introduce an equity constraint that is only binding when trust in financial intermediaries falls below a certain threshold, which means that the model analysis requires global solution methods. DW2014 take these insights and propose a perturbation based approach to get endogenous financial risk in standard macro models. They replace the equity constraint with a continuously binding and differentiable function, gaining computation time while retaining important model characteristics. The method developed by DW2014 has been crucial for the model of Laséen et al. (2017) as well as my own model to be solvable with Dynare's available perturbation methods.

Similarly, Brunnermeier and Sannikov (2014) and Danielsson et al. (2011) develop models that integrate balance sheet constraints to create endogenous financial risk. However, the use of global solution methods to solve the model with occasionally binding constraints faces the same limitations as HK2014 for implementing the procedures in larger macro models. Favilukis, Ludvigson, and Van Nieuwerburgh (2017) use numerical solution techniques to solve a similar setup in a model with a large state vector, however their iterative procedure is very time-consuming.

Recent research also incorporates time-varying risk premia, which are a key channel in my model. De Graeve, Dossche, Emiris, Sneessens, and Wouters (2010) investigate the time-varying nature of asset price risk in a DSGE model that differentiates shareholders, bondholders, and workers. They discuss the link between macroeconomic frictions and asset price risk, but they do not consider financial constraints. In a related exercise, by introducing housing and default of borrowers backed with housing collateral, Iacoviello (2015) demonstrates the importance of housing loans to the financial business cycle. Housing redistribution leads banks to deleverage and produce a credit crunch, which propagates to the real economy. While this model captures the gross domestic product (GDP) slump in Europe after the financial crisis well, it is unable to create systemic risk.

Solving economic models with endogenous risk using higher-order perturbation methods has seen a growing interest. DW2014 develop a third-order perturbation solution that can be integrated into larger models. De Graeve et al. (2010) also use third-order perturbation methods to investigate time-varying risk. Perturbation-based approximations are faster, but lose some accuracy compared to global methods. With new advances in computational macroeconomics, this tradeoff is appropriate for my model. As such, I benefit from the methods developed by Fernández-Villaverde, Guerrón-Quintana, Rubio-Ramírez, and Uribe (2011), who concentrate on exogenous shocks and stochastic volatility, and Born and Pfeifer (2014), who dig further into the appropriate methodology when risk is positive and time-varying.

2.2 Macroprudential policy to address systemic risk

Macroprudential policy was devised as a complementary tool to microprudential policy that prevents the systemic build up of financial risk. Microprudential policy has an idiosyncratic focus on the survival of individual financial institutions (Crocket, 2000), whereas macroprudential policy has a system-wide focus on the stability of the entire system.

In regards to achieving a stable financial system, the mainstream view of central bank intervention before the financial crisis deemed the use of interest rate policy to curb financial exuberance costly and ineffective (Bernanke & Gertler, 2001). Policymakers thought microprudential regulations, mainly implemented outside the central banking framework, would guarantee financial stability (Borio, 2003). However, in Bernanke et al. (1999) and related research, asset price deviations are assumed from fundamentals, so that financial frictions are exogenous, which has been substantially criticised.

After the crisis, this neglect on behalf of central bankers came under the focus of researchers. As a result, two discussions emerged: First, the debate on the ability of interest rate policy to counteract asset price build-up, and second, the debate on how macroprudential tools prevent financial instability. Finocchiaro and Grodecka (2018) provide an overview of macroprudential tools that have been implemented since the crisis and Akinci and Olmstead-Rumsey (2018) try to empirically asses some of these tools. Regulation on the loan-to-value ratio imposes quantity restrictions on credit suppliers and credit takers. Therefore, it can for example be seen as protection for homeowners taking out loans. Amortisation rules specify the repayment of loans and affects the speed of deleverage. Loan-to-income regulations impose a hard limit on borrowing in relation to consumers income. Capital regulation is widely used and imposes requirements on financial intermediaries' capital reserves. For example, a CCyB imposes an additional capital requirement when system-wide leverage is high and a "Global Systemically Important Bank" surcharge imposes an additional capital requirement on the world's biggest banks. Stress tests allow the financial authority to review financial institutions reactions to severe crises and therefore induce higher quality asset holdings.

Empirically, Cerutti, Claessens, and Laeven (2017) document the use of various macroprudential policies in a sample of 119 countries and find that policies have an effect on the development of credit and housing markets, dampening the financial cycle. Akinci and Olmstead-Rumsey (2018) show that macroprudential policies in advanced economies have primarily targeted the housing sector, which seems more effective and leading to lower credit growth, house credit growth, and house price appreciation, especially in economies with a large dependency on bank finance. Thus, when modelling macroprudential policies, it seems useful to incorporate a housing sector. Additionally, Bruno, Shim, and Shin (2017) suggest that macroprudential policy is more successful when complementing monetary policy by reinforcing monetary tightening rather than working in opposite directions.

Through a DSGE model, Woodford (2012) presents the idea of extending inflation targeting rules with financial stability concerns. However, the solution techniques used remove non-linear dynamics which are important for accurately assessing welfare. Svensson (in press) argues that macroprudential regulations are welfare improving, in particular when compared to surprise monetary policy announcements, and that the empirical experience of the Swedish central bank to lean against financial variables during the early 2010s proved insufficient. Laséen et al. (2017) use a model with systemic risk to show that there is an optimal CCyB policy and that interest rate policy leads to no welfare gains. Brunnermeier and Sannikov (2014) focus on financial frictions in the monetary policy transmission mechanism, but these are the only sources of inefficiencies in the model, meaning that the traditional trade-off with inflation targeting is removed by assumption. Further, Brunnermeier and Sannikov (2014) document a "volatility paradox" where low financial volatility leads to agents taking on more debt and making themselves more vulnerable to shocks. Suh (2017) reproduces this finding in a simple model à la Bernanke et al. (1999).

Clerc et al. (2015) perform a welfare analysis of capital regulation similar to Laséen et al. (2017) and mine in spirit. They develop a model with financial intermediaries that allocate funds raised from households and bankers to mortgage and corporate lending activities, and introduce a minimum capital requirement. The need for macroprudential regulation arises through banks, households, and entrepreneurs being able to default and not through a financial constraint risk channel. However, the model is solved using a first-order approximation, which does not capture potential non-linearities as the transition from regular times to periods of stress cannot be identified (Mendoza, 2016).

Stress tests have been regularly performed since the crisis to assess the quality of assets at financial institutions as well as their ability to survive severe downturns. Recently, particularly at the ECB and the Federal Reserve System, policymakers have started to develop macroprudential stress tests where the scenario incorporates systemic risk and financial spillovers.[3] Constâncio (2017) characterises macroprudential stress tests as dynamic, interacting with the real economy, having interconnected financial institutions, and assessing system-wide liquidity to the point where they address systemic risk and system-wide financial instability. Anderson et al. (2018) further extenuate the roadmap for macroprudential stress tests, the importance of having macroprudential stress tests, and the remaining challenges for policymakers. Thus, this policy instrument has increasingly a macroprudential effect and it should be compared to other macroprudential tools. Georgescu, Gross, Kapp, and Kok (2017) determine empirically the importance of stress tests on European bank fundamentals. They show that publication of results enhances price discrimination through the impact on credit default swaps and equity prices being stronger for the weaker performing banks. To remedy this higher scrutiny by the market, financial intermediaries have to change their asset portfolio to less risky assets.

This type of macroprudential stress test has not yet been modelled in a macroeconomic model, which is what my thesis attempts. Modelling stress tests in a theoretical framework allows me to asses the effects of government policy and compare different macroprudential policy tools in the same lab economy. To perform such a welfare analysis, I use a model with financial frictions, which conveys a need for macroprudential policy.

3 The model

In this section, I introduce the discrete-time approximation of my model based on HK2014 and DW2014, extended with a housing sector.[4] Here, the focus is on understanding the non-linear behaviour introduced by the financial sector and how the model can endogenously generate a financial crisis. I first describe the model, then I show how to calibrate it, and finally I analyse how the economy reacts to small shocks.

3.1 Model description

The economy has four sectors: households, financial intermediation, goods production, and capital production. Household and production sectors are a variation of the standard stochastic growth model whereas the financial sector is non-standard.

[3] See Dees, Henry, and Martin (2017), who develop such a stress test scenario for the 2018 bank stress test executed jointly by the European Banking Authority and the ECB.

[4] HK2014 introduce the model with housing in a continuous-time environment whereas DW2014 introduce the setup in a discrete-time environment, but omitting the housing sector. Since housing is often thought to have an important role in the financial cycle, moving closely with leverage, it seems imperative to include (Iacoviello, 2015).

Agents are infinitely lived and time is discrete and indexed by $t \in \{0, 1, ...\}$. The main characteristics of the model are as follows.

Households. Households consume goods, rent housing, and own the competitive capital producers. They are not able to invest directly in capital nor housing, but instead they invest into financial intermediaries. Households invest at least a fraction λ of their wealth in bonds. The remaining wealth is invested in either risky equity or more bonds.

Financial intermediation. Financial intermediaries are funded by households who invest in bonds and equity issued by the intermediaries. Financial intermediaries use their funding to invest in capital and housing. Furthermore, they own the goods producers, to whom they provide capital for production, and they rent out the housing stock to households.

Production of consumption good. Goods production follows a standard AK-technology process. Producers pay households a fraction l of income and rebate the remainder to their owners, the financial intermediaries.

Production of capital. Capital producers are turning income into capital, which they sell to financial intermediaries. They only produce as much as is demanded and rebate their profits to their owners, the households.

Housing. Housing is demanded by households who rent each unit from financial intermediaries at a price r_t^H, the rental rate on housing. Housing is owned by the intermediaries who invest based on how much is demanded by the households. Banks face no costs in creating housing; they turn output one-for-one into housing stock.

Next, I develop the model.

3.1.1 Household sector

A representative household maximises expected utility:

$$U_t = E_0 \sum_{t=0}^{\infty} \beta^t \ln(C_t^{1-\theta} H_t^{\theta}), \tag{3.1}$$

where β is the discount factor, C_t consumption in period t, and H_t is the housing stock rented in period t. θ indicates the expenditure share of housing and reflects the relative market value of the housing and the goods sector. Households maximise their objective function subject to an intertemporal budget constraint, given by:

$$W_t = lY_t - C_t - r_t^H H_t + \tilde{R}_t V_{t-1} + (1 + r_{t-1})B_{t-1} + D_t^K, \tag{3.2}$$

where W_t is financial wealth and lY_t is the labour income earned by households. Households hold their wealth either in risky equity V_t or in risk-free bonds B_t emitted by the financial sector, thus $W_t = V_t + B_t$. Additionally, households own the capital producers, which rebate their profits back as D_t^K. Households also pay for consumption C_t and housing rent $r_t^H H_t$. For the allocation of wealth over bonds and equity, I follow HK2014 and DW2014: a minimum fraction of household wealth λ is channelled into risk-free bonds for a gross return $1 + r_{t-1}$, where r_{t-1} is the real risk-free rate. The consumption-savings choice leads to a standard Euler equation:[5]

$$\beta(1 + r_t)E_t \frac{C_t}{C_{t+1}} = 1. \tag{3.3}$$

The consumption-housing choice leads to a second Euler equation:[6]

$$\frac{C_t}{H_t} = \frac{1-\theta}{\theta} r_t^H. \tag{3.4}$$

The other fraction of wealth $1 - \lambda$ is invested either in equity, which earns a return of $\tilde{R}_t$ or in more bonds. The portfolio choice of investing depends on the reputation ε_t acquired by financial intermediaries. Reputation can be seen as trust in intermediaries or as their historical track record and acts as a threshold for the willingness of households to invest in risky equity. If reputation is sufficiently high ($\varepsilon_t > (1-\lambda)W_t$), the fraction $1-\lambda$ is invested in equity, otherwise reputation acts as upper bound on equity investment.[7] Figure 1 visualises the allocation of household wealth.

Financial intermediaries		Households	
Assets: $qK + pH$	**Bonds:** $B = B_1 + B_2$ **Equity:** V	**Allocation:** $\lambda W = B_1$ $(1-\lambda)W = B_2 + V$	**Wealth:** W

Figure 1: Funding allocation of the financial intermediaries

Note: Household investment $(B_1 + B_2 + V)$ and financial intermediary funding $(B + V)$ must be equal. Time-subscripts are dropped for simplicity.

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[5]See Appendix A.1 for a detailed derivation of the consumption-savings Euler equation.

[6]See Appendix A.2 for a detailed derivation of the consumption-housing Euler equation.

[7]Since the household asset allocation between equity and bonds is price insensitive, I assume that arbitrage is limited and equity and bonds are not close substitutes. Hence, there is no arbitrage equation linking equity and bond returns. Asset prices equilibrate demand and supply of funds in the financial sector.

3.1.2 Production sector

Production follows a standard AK-production technology. Firms employ a level of capital K_t, which given a specific technology (TFP) process $A_t = A_{t-1} + (1-q_t)\sigma_t^A \bar{A}$ generates output:

$$Y_t = A_t K_t, \tag{3.5}$$

where $\bar{A}$ is steady state technology, σ_t^A is a TFP shock,[8] and q_t is the price of capital. Modelling productivity dependent on the capital price creates a direct macro-financial interaction between asset prices and the real sector. Decreasing asset prices make it more difficult for firms to obtain intertemporal financing for productivity-enhancing technology. A fixed share of output lY_t is paid as labour income to households, while the remainder is paid as dividends $D_t = (1-l)Y_t - \delta K_t$ to the financial intermediaries which own the production firms. The law of motion for physical capital is given by:

$$K_t = (1 - \delta - \sigma_t^K)K_{t-1} + i_{t-1}K_{t-1}, \tag{3.6}$$

where δ is the deterministic depreciation rate and i_t the investment rate in new capital. Furthermore, there is a second exogenous shock σ_t^K, which reduces capital efficiency. Capital goods producers turn output one-for-one into capital and sell new capital at a price of q_t to the intermediaries. They face adjustment costs of $\Psi(K_t, i_t) = i_t K_t + \frac{\kappa}{2}(i_t - \delta)^2 K_t$. Thus, capital goods producers choose to maximise net profits $q_t i_t K_t - \Psi(K_t, i_t)$ and set optimal investment to:[9]

$$i_t = \delta + \frac{q_t - 1}{\kappa}. \tag{3.7}$$

Since capital producers sell only to the intermediaries, the investment rate is driven by the intermediaries valuation of capital. There is no difference between new and old capital, the value of the capital stock is thus $q_t K_t$. Capital producers are owned by households and rebate their profits back: $D_t^K = q_t i_t K_t - i_t K_t - \frac{\kappa}{2}(i_t - \delta)^2 K_t = (q_t - 1)\left(\delta + \frac{q_t - 1}{2\kappa}\right)K_t$.

[8]Shocks in a stochastic model are normally distributed with a mean 0 and an exogenous standard deviation, which is in general either set to 1% or calibrated to match a data process (See Christiano et al., 2005). When simulating the model, I choose a 1% standard deviation for the shocks.

[9]See Appendix A.3 for a detailed derivation.

3.1.3 Financial sector

Financial intermediaries play the crucial role that leads to systemic risk in the model. I introduce two financial frictions within the financial sector that lead to systemic risk. First, ownership and control of the intermediary is separated; households are shareholders through equity financing, but a manager makes investment decisions. Second, the share of equity financing determined by the reputation ε_t of the intermediaries faces a binding constraint during bad times.

Intermediaries raise funds from households in the form of risky equity V_t and risk-free bonds B_t. The funds are used to purchase the two assets, capital K_t and housing H_t, giving a total value of the intermediaries assets of $q_t K_t + p_t H_t$. Figure 1 depicts the balance sheet of the representative intermediary and how household wealth is allocated to equity and bonds. Household total wealth is given by W_t, where λW_t is invested in bonds and $(1-\lambda)W_t$ is allocated between equity and bonds. This allocation depends on reputation.

The reputation process of the intermediary is given by the history of realised returns on intermediary equity $\tilde{R}_t$:

$$\varepsilon_t = \varepsilon_{t-1}(1 + m\tilde{R}_t - \eta), \tag{3.8}$$

where η takes into account the exit rate of financial intermediaries[10] and m represents the degree of risk aversion of intermediaries. This reflects the widely held belief that the performance of the investment strategy directly affects the reputation and trust of an intermediary. A better investment record increases reputation and households invest more in intermediaries. Return on equity is given by:

$$\tilde{R}_t = \alpha^{FI}_{t-1} R_t + (1 - \alpha^{FI}_{t-1})(1 + \tau^{CCyB}_{t-1}) r_{t-1}, \tag{3.9}$$

and return on total assets:[11]

$$R_t = \frac{q_t K_t (1 - \tau^{ST}_{t-1}) + D_t + p_t H_t + r^H_t H_t}{q_{t-1} K_{t-1} + p_{t-1} H_{t-1}}, \tag{3.10}$$

where α^{FI}_t is the leverage (assets over equity) of the intermediary and $\alpha^{FI}_t = (q_t K_t + p_t H_t)/V_t$. Return on assets R_t, which shows how the funding is used, is amplified by leverage. Two macroprudential policy tools, τ^{CCyB}_t and τ^{ST}_t, are available to the macroprudential regulator and are described below.

[10]For the model to be stationary in steady state, a positive intermediary exit rate is required. Otherwise, reputation has a positive drift and the equity constraint would never bind (HK2014).

[11]Return on assets aggregates the return on capital investment $R^K_t = \dfrac{q_t K_t (1 - \tau^{ST}_{t-1}) + D_t}{q_{t-1} K_{t-1}}$ and return on housing investment $R^H_t = \dfrac{p_t H_t + r^H_t H_t}{p_{t-1} H_{t-1}}$, where banks also earn rent from housing.

Following the literature on asset pricing (Li & Ng, 2001), optimal leverage is determined by the intermediary following a growth optimal strategy for reputation, given as a mean-variance portfolio strategy:[12]

$$\max_{\alpha_t^{FI}} E_t \tilde{R}_{t+1} - \frac{m}{2} \mathrm{Var}_t \tilde{R}_{t+1}. \tag{3.11}$$

The mean-variance portfolio maximisation leads to an optimality condition for leverage:[13]

$$\alpha_t^{FI} = \frac{E_t(R_{t+1} - (1+\tau_t^{CCyB})r_t)}{m\mathrm{Var}_t(R_{t+1})}, \tag{3.12}$$

where leverage increases in the expected risk premium and decreases with higher uncertainty of investment returns.

Total reputation plays a major role in the allocation of household investment. As discussed above, total equity funding of the financial sector is given by the occasionally binding equity constraint:

$$V_t = \min(\varepsilon_t, (1-\lambda)W_t). \tag{3.13}$$

Thus, in good times (when reputation is high) households invest the fraction $1-\lambda$ of their wealth in equity, whereas in bad times (when reputation is low) they only invest in equity up to the level of reputation. This occasionally binding constraint reflects the idea of households restricting equity financing when reputation falls below a certain level, which happened during the financial crisis (Acharya, Gujral, Kulkarni, & Shin, 2011). Thus, reputation affects risk and risk pricing in the capital market and determine the composition of funding and leverage. A low reputation leads to restricted equity funding from households and higher leverage. This higher leverage has to be compensated by higher risk premia in the capital market.

When the equity constraint binds, a negative shock reduces total assets $q_tK_t + p_tH_t$ through Equation 3.10, which feeds back to reducing reputation ε_t and thus also equity available. This comes from the levered intermediary sector, where return on equity amplifies return on assets and reputation is a multiple of return on equity due to the presence of risk aversion in Equation 3.8. Thus, when total assets decrease, both return on assets and return on equity decline, thereby reducing reputation

[12] See HK2014, who start with the intermediaries optimisation problem in continuous-time:

$$\max_{\alpha^{FI}} E \int e^{-\eta t} \ln \varepsilon_t dt,$$

which is equivalent to a mean-variance portfolio strategy where the financial intermediary wants to maximise returns but with minimal uncertainty (DW2014).

[13] See Appendix A.4 for a detailed derivation of the optimal allocation rule.

which causes less equity to be available and leverage to spike up. Higher leverage in turn implies that the risk premium demanded on the market increases by Equation 3.12.

However, occasionally binding constraints introduce complications when solving the model, requiring global solution methods. Therefore, following DW2014, I introduce an alternative non-linear, continuously binding constraint:[14]

$$V_t = \frac{(1-\lambda)W_t}{1+\alpha_\varepsilon\left(\dfrac{W_t}{\varepsilon_{t-1}-\varepsilon_{MIN}}\right)^3}, \tag{3.14}$$

where ε_{MIN} and α_ε are constants. This equation captures the essential features of the equity constraint[15] and is differentiable. Equity increases in household wealth and decreases in reputation. Furthermore, the model with this continuously binding constraint can be solved using Dynare's third-order perturbation procedures.

3.1.4 Macroprudential policy

The government has access to two different macroprudential policy tools. τ_t^{CCyB} is equivalent to a countercyclical capital buffer requirement and acts as a tax on bonds, as in Laséen et al. (2017). It encourages intermediaries to raise equity instead of debt. τ_t^{ST} is equivalent to a macroprudential stress test and acts as a tax on asset investment, in particular, it is a tax on capital investment and not on housing investment. It discourages risky investment by the intermediary as it raises the risk-weights attached to the risky asset while leaving the risk-weights of the risk-free asset unchanged. Thus, the stress test tool encourages investment in higher quality assets à la Constâncio (2017). Government revenue from macroprudential policy is used to fund administrative expenses and infrastructure. In particular, it is not rebated to consumers.[16]

Macroprudential policy is necessary since households do not internalise the systemic effect of their portfolio allocation as they are price insensitive when investing in equity. Further, the investment decisions by the intermediaries do not take into account household preferences for risk. These two distortions imply that asset prices are distorted and risk is misspriced, which macroprudential policy tries to remedy.

[14]Continuously binding constraints were first introduced by Kiyotaki and Moore (1997) as a collateral constraint, whereas here it is a constraint on the funding and is asymmetric between good states and bad states. An alternative interpretation of the equation would be a penalty function as in Kim, Kollmann, and Kim (2010).

[15]DW2014 perform a comprehensive study of the continuously binding constraint. They show that the non-linear properties are still captured (Figure 5 in their paper). The asymmetry and amplification of their model can be seen in Figure 9 and Table 7 of their paper.

[16]Implementing macroprudential policy rebates as income to consumers through the budget constraint leads to a more unstable model. Since consumers would have higher W_t, welfare levels should be extenuated, increasing the magnitude of the results.

Following the literature on monetary policy (Laséen et al., 2017), misspricing of risk can be defined as a disruption in the Euler equation:

$$\omega_t = \beta E_t \frac{C_t}{C_{t+1}}(R_{t+1} - r_t), \tag{3.15}$$

where a rise of expected return on capital R_{t+1} above the risk-free interest rate r_t indicates higher risk. Misspricing of risk is countercyclical as it is higher in times of stress (high risk premium) and lower in good times (low risk premium). In the absence of financial frictions, $\omega_t = 0$.

3.1.5 Equilibrium conditions

In equilibrium, the chosen actions and resulting prices clear all markets. The market clearing condition in the goods market is:

$$Y_t = C_t + \Psi(K_t, i_t). \tag{3.16}$$

Wealth in the household sector must equal the financial assets of intermediaries:

$$W_t = V_t + B_t = q_t K_t + p_t H_t. \tag{3.17}$$

The capital market clearing identifies leverage:

$$\alpha_t^{FI} V_t = q_t K_t + p_t H_t. \tag{3.18}$$

The last equation makes explicit that capital market prices are related to leverage. Combining Equations 3.17 and 3.18 relates household wealth to intermediary leverage:

$$\alpha_t^{FI} V_t = W_t.$$

Plugging in Equation 3.14 and solving for α_t^{FI} implies a non-linear allocation rule for leverage:

$$\alpha_t^{FI} = \frac{1}{1-\lambda} + \alpha_\varepsilon \left(\frac{q_{t-1}K_{t-1} + p_{t-1}H_{t-1}}{\varepsilon_{t-1} - \varepsilon_{MIN}} \right)^3. \tag{3.19}$$

It follows that when reputation declines and total wealth increases, intermediary leverage shoots up.

Plugging Equation 3.5 and $\Psi(K_t, i_t)$ into Equation 3.16 yields $C_t = K_t(A_t - i_t - \frac{\kappa}{2}(i_t - \delta)^2)$ which, together with the Euler Equation 3.4, narrows down the expression for the rental rate on housing to:

$$r_t^H = (A_t - i_t - \frac{\kappa}{2}(i_t - \delta)^2)\frac{\theta}{1-\theta}\frac{K_t}{H_t}. \tag{3.20}$$

Finally, one assumption has to be imposed on the model to make it solvable. In line with HK2014, housing is in fixed supply and cannot be increased, which represents the idea that land is limited.

Assumption 1 (**Housing stock**). *The housing stock is in fixed supply and normalised to $H = 1$.*

This concludes the model description. Definition 1 defines a competitive equilibrium that solves the model.

Definition 1 (**Competitive equilibrium**). *A competitive equilibrium is a path of real allocations $\{\alpha_t^{FI}, i_t, B_{t+1}, V_t, K_t, H_t\}$ and prices $\{q_t, p_t\}$ satisfying Equations 3.2, 3.3, 3.4, 3.5, 3.6, 3.7, 3.8, 3.10, 3.12, 3.16, 3.17, 3.18, 3.19, 3.20 and Assumption 1.*[17]

3.2 Calibration

In this subsection, I calibrate the model to match empirical moments. Table 1 lists the choice of parameter values used. I follow the literature as closely as possible (see DW2014 and Laséen et al., 2017 for their specifications). The main goal of the calibration is not to fully replicate all empirical moments, but to capture the endogenous risk behaviour and the transmission to the real economy for reasonable parameters. Eight parameters are conventional, while λ, α_{EPS}, and ε_{MIN} are specific to the model. For the households, the discount rate β is set to 0.99. The wage share of income l is 0.6. On the producer side, the capital depreciation rate δ is assumed to be 0.10. I use an aggregate productivity parameter $\bar{A}$ of 0.35, which gives an output-to-capital ratio of 1/3. Investment adjustment costs κ are high at 80, balancing the volatility of asset prices and the price sensitivity to investments. For the financial intermediary, the sensitivity of reputation m is set at 2.5.[18] The exit rate for bankers η is 2.5% and the debt share λ is 0.5, giving an average leverage ratio of 204%, which is on the lower side of empirical approximations. The choice for the expenditure share on housing, $\theta = 0.0741$ gives a steady state value for the share of housing $\dfrac{pH}{qK + pH} = 34\%$.[19] The leverage constant $\alpha_{EPS} = 0.025$ and the

[17]For reference, Appendix B produces a list of all equations used in the Dynare model block.

[18]With $m = 2.5$, the sharpe ratio is between 2.0 and 0.1, which is corresponds to typical calibrations in asset pricing (DW2014).

[19]This choice is on the conservative side of recent estimates of the housing-to-wealth ratio (Wind, Lersch, & Dewilde, 2017). A higher ratio implies leads to a higher house price volatility as more value is stored in housing.

minimum reputation $\varepsilon_{MIN} = 0.2$ are chosen so that the model solves.

Table 1: Calibration of the model (annualised)

Parameter	Value	Description
Household:		
β	0.99	Discount factor
l	0.60	Wage share
Producer:		
δ	0.10	Depreciation rate
$\bar{A}$	0.35	Productivity constant
κ	80	Adjustment costs
Financial intermediary:		
m	2.5	Reputation sensitivity/ risk aversion
η	0.025	Banker exit rate
λ	0.5	Debt share
α_{EPS}	0.025	Leverage constant
ε_{MIN}	0.2	Minimum reputation
Housing:		
θ	0.0741	Share of housing

The model is approximated around a deterministic steady state using third-order perturbation methods in Dynare.[20,21] From the dynamics of reputation, the deterministic steady state is undetermined, meaning that I can approximate the model around any value of reputation. Following DW2014, I choose $\bar{\varepsilon} = 0.50$ so that reputation is located at the center of the stochastic distribution obtained by third-order simulations of the model. This steady state value of reputation also compares to the critical value in a regime with the occasionally binding constraint.[22]

Figure 2 presents the simulation-based solution for the baseline model. The two upper panels show leverage α^{FI} and consumption C as a function of reputation. Reputation determines leverage; a low level of reputation leads to an increase in intermediary leverage. While the non-linear impact on leverage created by the equity constraint is not as extenuated as in HK2014, it is present and possesses similar model characteristics as extensively argued by DW2014. As a result of the equity constraint, also consumption falls with decreasing reputation.

In the second and third rows, equity V is slightly increasing in reputation, while

[20]Dynare is a software package that solves and simulates DSGE models based on perturbation methods. Due to the equity constraint introducing non-linear dynamics, a third-order approximation is necessary to take into account how future volatility affects decisions. The method is based on Juillard and Kamenik (2004) who develop the k-order perturbation approximation in Dynare.

[21]The third-order approximation can introduce explosive behaviour beyond a certain number of simulations. For this reason, I limit the simulation to 300 periods. An alternative to remove explosive behaviour is "pruning" as developed by Andreasen, Fernández-Villaverde, and Rubio-Ramírez (2018), however, this method also removes the economic interpretation of variables as it distorts the simulations. Den Haan and De Wind (2012) also provide an improved algorithm to reduce explosive behaviour, albeit at a higher programming complexity.

[22]See DW2014 for a comparison of the level of reputation when the constraint is continuously binding against when it is occasionally binding in their model specification. In Figure 6 in their paper, the constraint is binding below a value for reputation of 0.4.

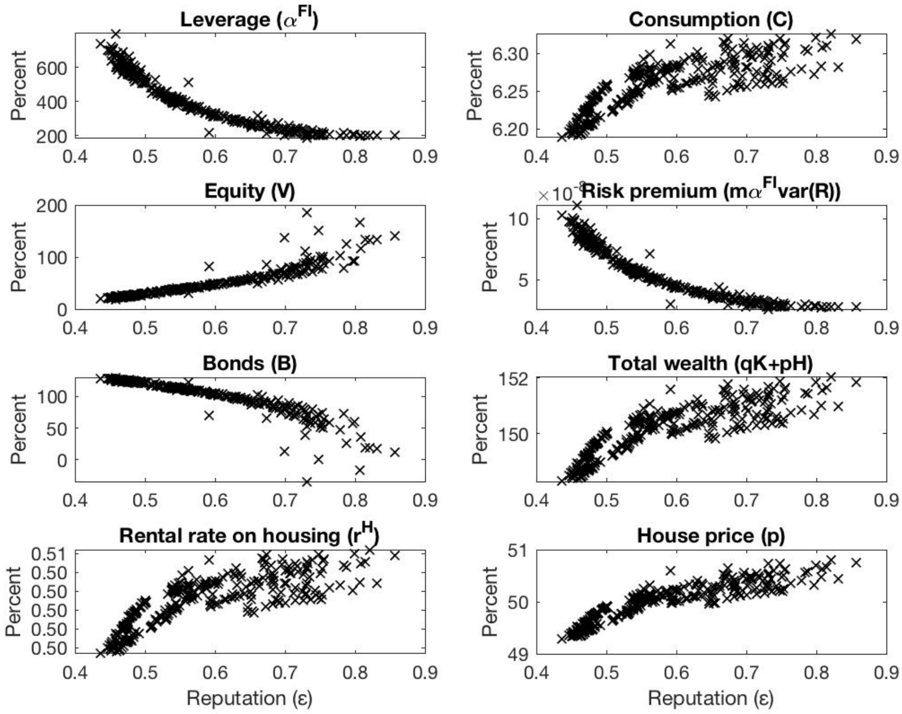

Figure 2: Simulation-based solution of the model

Note: Solution of the third-order approximation. Simulation-length is 300 periods. Variables are expressed in terms of reputation.

the opposite holds true for bonds B. Furthermore, total assets $qK + pH$ are decreasing with a fall in reputation. Thus, bad times (when reputation is low) are characterised with low levels of wealth and low equity, which is counteracted by an increase in bonds that leads to overleverage. Hence, the intermediaries' balance sheet expands cyclically; total assets expand during good times and decrease during bad times, which is often seen as driving financial crises (Adrian & Shin, 2014). As in the model of Laséen et al. (2017), changes in debt are correlated with changes in total assets while changes in equity are not correlated with changes in total assets. In line with Adrian and Shin (2014), this means that intermediaries expand their balance sheet with debt rather than equity, except for in crisis periods where assets have to be sold off rapidly.

The fall in wealth is mainly driven by decreases in the house price p, and relatively little by adjustments in the capital price q. This fall in asset prices is due to an increased risk aversion when reputation is low and can be seen in the risk premium $m\alpha^{FI}\text{Var}(R)$ (Panel 4 in Figure 2), which indicates that the return on assets has to shoot up when reputation falls. However, the third-order approximation of the risk premium $E(R-r)$ only captures the monotonically decreasing slope (not depicted) as the approximation method uses the constant elasticity of risk aversion around the local steady state and the constant variance of return on assets. DW2014 determine this missing risk channel to have a propagation effect that extenuates the results.

Following HK2014, I define a state of recession as periods where the equity constraint binds. However, the use of a continuously binding equity constraint makes this definition more arbitrary. Therefore, a recession is also defined as a period of financial stress with the 33% lowest observations of reputation.[23] Table 2 reports how the model is able to replicate moments of key variables in the data. The data is downloaded from the ECB (2018a) statistical data warehouse and described in Appendix C. Table 2 depicts moments for the baseline simulation as well as for the model where housing is omitted to show that adding housing brings benefits but also disadvantages. The first two columns show the volatility during recessions and normal times, respectively. The last column shows the difference in the mean during recessions and normal times.

Table 2: Summary statistics (in %)

	Std dev recession	**Std dev normal**	**Mean recession-mean normal**
Baseline simulation			
Leverage	60.82	86.51	285.90
Equity growth rate	5.27	13.95	-1.54
Risk premium	0.00	0.00	0.01
Real GDP growth rate	0.10	0.11	-0.01
Consumption	0.02	0.02	-0.05
Investment	0.01	0.01	-0.02
House price	0.17	0.25	-0.59
Simulation with no housing ($\theta = 0$)			
Leverage	15.17	4.20	10.72
Equity growth rate	6.83	62.11	-9.00
Risk premium	0.01	0.01	0.02
Real GDP growth rate	1.09	0.86	-0.91
Investment	0.09	0.09	-0.10
Data			
Leverage		74.41	
Equity growth rate	24.79	19.07	-13.33
Real GDP growth rate	1.97	0.99	-4.37
Investment	4.47	3.54	-0.11
House price	4.44	3.05	-0.06

Note: Standard deviations are based on the sample mean. The two states, "recession" and "normal" are defined as periods of financial stress (33% lowest observations of reputation) and periods without financial stress, respectively. The third column represents the difference in the mean value of the variables between recession and normal states. Data moments are constructed using CEPR (2018) recessions and ECB (2018a) data. Appendix C provides a description of the empirical data series used.

The asymmetry between the volatility of leverage in both states should be considered a success of the model. Additionally, leverage is higher in a recession than in

[23] Alternatively, defining a threshold for the risk premium leads to similar results.

a normal period. This reflects the equity constraint in action. The baseline model is better at generating the magnitude of volatility than the reduced model without housing. Further, the model is able to generate an equity growth rate that is lower in recessions than in normal times, however it cannot replicate the equity volatility in the data, this is in particular due to the more volatile increase of equity during normal times in the model. Again, the baseline model is better at matching the magnitude of the data.

Gilchrist and Mojon (2018) show that variation in risk premia is a good forecasting device as it is closely related to financial intermediary health measures, partially composing credit spreads. My model matches this observation through the increased risk premium during recessions. In terms of macroeconomic variables, the model is able to capture the difference in GDP, consumption, and investment between recession and normal times, however not the magnitudes of changes seen in the data. Here, the model without housing is slightly more accurate than the baseline model. House price data is based on commercial property price statistics, which shows falling house prices during recessions, which the model is able to replicate.

Thus, in line with the discussion in DW2014 and Laséen et al. (2017) on their model, Table 2 shows the ability of my model to replicate some movements in the data. The baseline model is better at generating the non-linear financial behaviour, whereas the model without housing is better at generating the magnitude of macro moments. Both the baseline model and the no-housing model are successful at generating systemic risk, characterised by the non-linear spike in leverage when reputation falls.

3.3 Model analysis

In this subsection, I explore how the model behaves when small shocks hit the economy under the baseline calibration. The impulse response functions (IRFs) change with the state of the economy. I differentiate between a state with average reputation and a state with low reputation (a recessionary state)[24] and I calculate conditional impulse response functions.[25]

[24] Average reputation is where reputation is close to its deterministic steady state of 0.5, whereas low reputation is where reputation is in the range of where the occasionally binding constraint would hold around 0.4.

[25] Conditional IRFs can be calculated using the following algorithm (Fernández-Villaverde et al., 2011): 1. Simulate the model starting from the deterministic steady state (choosing the starting point for reputation) with a burn-in rate of 20 periods to get to the stochastic steady state. 2. From the stochastic steady state, hit the model with a 1% shock to either capital or technology. 3. Report the resulting impulse responses as percentage deviations from the stochastic steady state.

3.3.1 Impact of demand shocks

Figure 3 shows the effect of a negative capital efficiency σ^K shock on macroeconomic and financial variables. This shock can also be seen as a demand shock since it reduces the availability of capital. In the first panel, GDP falls by around 1% in both states; initially more when reputation is average but after 10 periods it decreases more when reputation is low. The effect on GDP is very persistent. This effect comes from falling reputation and increased leverage in the economy (Panels 2 and 3). Here, low reputation has an adverse effect on financial variables which comes from a higher exposure to bonds in the low reputation state. The bottom row shows that falling house prices are partially responsible for changes in the return on assets and thus the return on equity, which negatively feeds back to reputation. This process is much more extenuated for the low reputation economy.

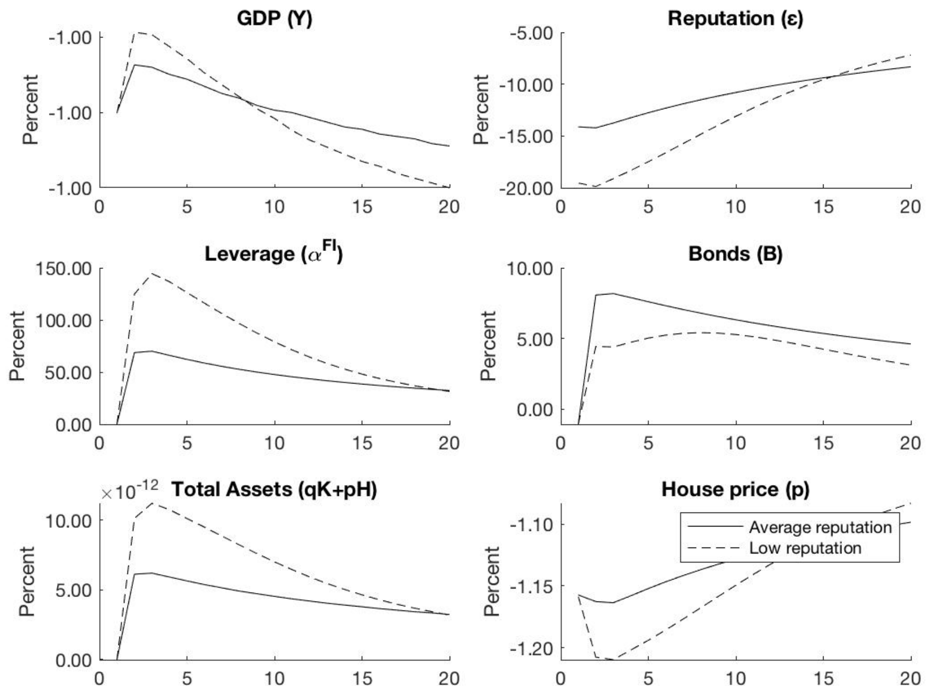

Figure 3: Negative capital efficiency shock

Note: Conditional IRF to a 1% negative shock. The state with average reputation (solid lines) is defined as $\bar{\varepsilon} = 0.5$ and the state with low reputation (dashed lines) as $\bar{\varepsilon} = 0.4$.

3.3.2 Impact of supply shocks

Figure 4 shows the effect of a negative technology σ^A shock on macroeconomic and financial variables. This shock can also be seen as a supply shock as it reduces the production capabilities of the goods producer. The technology shock shows a large discrepancy between the economy with low and average reputation. GDP only falls for the low reputation economy because reputation and leverage only react under these conditions. The equity constraint is only binding when reputation is low and the the economy is unaffected by the shock when the equity constraint does not hold. However, the magnitude of the effects is low; the supply shock is relatively unimportant in generating large falls in GDP or large rises in leverage. For instance, the change in total assets in Panel 5 shows no change in either state.

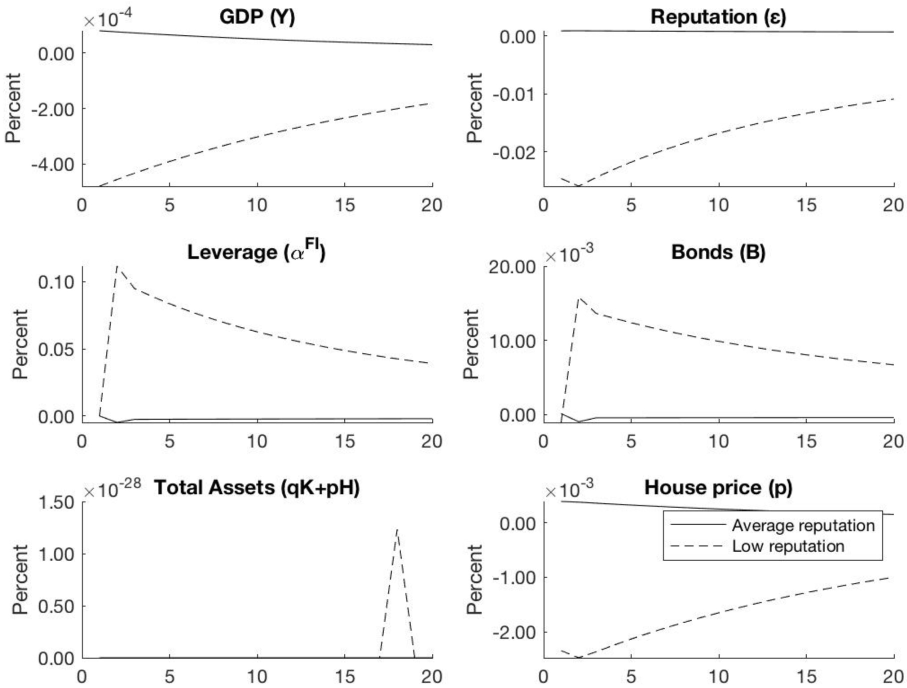

Figure 4: Negative technology shock

Note: Conditional IRF to a 1% negative shock. The state with average reputation (solid lines) is defined as $\bar{\varepsilon} = 0.5$ and the state with low reputation (dashed lines) as $\bar{\varepsilon} = 0.4$.

Empirically, the financial cycle extends for a longer time and is more extenuated than the business cycle (Borio, 2014). This effect is captured by the long persistence of the effects of both shocks in the model. The IRFs for both shocks show that there is a big difference in how small shocks effect the economy depending on the state. When reputation is low, small shocks have bigger effects than when reputation is average. This behaviour reflects the successful modelling of the equity constraint.

With this section, it becomes clear that the model is able to generate large real economy changes and the transition from a state with average reputation to a state with low reputation can be triggered endogenously.

4 Welfare analysis

In this section, I analyse the welfare gains from the macroprudential policy tools and I calculate the optimal level of regulatory intervention. First, I analytically find the optimal macroprudential rate that removes the misspricing of risk in the economy. However, since a financial authority cannot observe misspricing of risk, I also devise a policy rule that is targeting excessive leverage and I numerically search over a grid of possible parameters in order to find the best approximation of the optimal rate.

As the objective function to maximise, I take the household utility function which is based on Faia and Monacelli (2007) and Gertler and Karadi (2011), expressed recursively as:[26]

$$U_t = \ln(C_t^{1-\theta} H_t^{\theta}) + \beta E_t U_{t+1}. \tag{4.1}$$

I take the third-order approximation of U_t in order to find the unconditional expectation of lifetime utility $U = E[U_t]$, which is independent of time.

4.1 Optimal macroprudential policy

The optimal macroprudential policy removes the financial frictions in the model. With Equation 3.15 defining the misspricing of risk, optimal macroprudential policy sets the misspricing to zero, $\omega_t = 0$. Thus, it is instructive to derive the optimal tax rates τ_t^{CCyB} and τ_t^{ST} that reestablish a world with fair pricing of risk.

Solving Equation 3.12 for τ_t^{CCyB} gives:

$$\tau_t^{CCyB} = \frac{E_t R_{t+1} - r_t - \alpha_t^{FI} m \mathrm{Var}_t R_{t+1}}{r_t},$$

which together with setting $\omega_t = 0$ in Equation 3.15 yields:

$$\tau_t^{CCyB} = \frac{E_t r_{t+1} - r_t - \alpha_t^{FI} m \mathrm{Var}_t R_{t+1}}{r_t}. \tag{4.2}$$

Solving Equation 3.10 for τ_t^{ST} gives:

$$\tau_t^{ST} = 1 + E_t \frac{D_{t+1} + p_{t+1} H_{t+1} + r_{t+1}^H H_{t+1} - R_{t+1} W_t}{q_{t+1} K_{t+1}},$$

which together with setting $\omega_t = 0$ in Equation 3.15 yields:

$$\tau_t^{ST} = 1 + E_t \frac{D_{t+1} + p_{t+1} H_{t+1} + r_{t+1}^H H_{t+1} - r_{t+1} W_t}{q_{t+1} K_{t+1}}. \tag{4.3}$$

[26] Since the model's real economy variables are scaled values between $[0, 1]$, using a log-utility function leads to negative utilities. As I am comparing different utilities, this is not a problem.

Implementing both iterations of optimal macroprudential policy features countercylical characteristics that reflect the idea of making leverage in bad times more expensive. In line with Laséen et al. (2017), τ_t^{CCyB} in Equation 4.2 subsidises debt financing when the risk premium shoots up during crises. An increasing risk premium comes with an increase in leverage, where higher leverage implies a fall in asset prices which implies that a higher rate of return is required. But Equation 4.2 is also decreasing in leverage.[27] τ_t^{ST} in Equation 4.3 makes holding capital more expensive when there is a disruption in the capital price q_t and less expensive when there is a disruption in the house price p_t. During recession times, this subsidises the asset whose price is falling more. Furthermore, when leverage increases and wealth decreases, the tax averts crises by incentivising safer housing investment over capital investment. The gain from macroprudential policy comes from breaking the feedback loop that links equity, asset prices, and asset returns.[28]

4.2 Approximation of best macroprudential policy

A financial authority is, however, not able to directly observe misspricing of risk in the economy. Instead, they are able to observe some financial variables that indicate a coming crisis period, for example leverage or asset prices. Choosing the appropriate macroprudential policy based on leverage allows the authority to indirectly curb systemic risk and increase welfare. I define the two macroprudential rates as follows:

$$\tau_t^{CCyB} = \phi_1^{CCyB}(\alpha_t^{FI} - \bar{\alpha}^{FI}) + \phi_2^{CCyB}, \tag{4.4}$$
$$\tau_t^{ST} = \phi_1^{ST}(\alpha_t^{FI} - \bar{\alpha}^{FI}) + \phi_2^{ST}, \tag{4.5}$$

where ϕ_1^{CCyB}, ϕ_2^{CCyB}, ϕ_1^{ST}, and ϕ_2^{ST} are parameters determining the magnitude of counterleverage policy and static policy, and $\alpha_t^{FI} - \bar{\alpha}^{FI}$ is the deviation of leverage from its deterministic steady state. The parameters with subscript 1 (ϕ_1^{CCyB} and ϕ_1^{ST}) increase the tax rate when leverage is above its steady state level and the parameters with subscript 2 (ϕ_2^{CCyB} and ϕ_2^{ST}) determine a static tax level that is applied independently of leverage. The parameters can take different values, which leads to different utilities. Thus, the challenge for the financial authority is to find the parameters that best approximate the optimal rule and maximise welfare.

I rank alternative policies in terms of steady state consumption equivalent Δ,

[27] In the numerical approximation of the optimal policy rule in the next subsection, I assume the first effect to be dominating, in line with the current understanding of how CCyB policy operates (Borio, 2014).

[28] An interesting exercise would be to calculate the welfare gains associated with optimal macroprudential policy, however, due to computational challenges (1. The difficulty of modelling a variance in Dynare; 2. The explosive behaviour of optimal policy), I omit such a calculation.

which gives the fraction of consumption gain that equates welfare in the deterministic steady state $\bar{U}(\Delta\bar{C}, \bar{H})$ to the welfare level resulting from the macroprudential policy U^*. Thus, Δ measures the household's consumption gain required for households to be indifferent between $\bar{U}$ (economy with misspricing of risk) and U^* (economy with macroprudential policy reducing risk). A higher Δ implies a higher consumption equivalent gain for the households and indicates that a policy is more desirable from a welfare perspective. I impose $\bar{U} = \dfrac{\ln((\Delta\bar{C})^{1-\theta}\bar{H}^{\theta})}{1-\beta} = U^*$ and solve for Δ:

$$\Delta = \exp\{U^*(1-\beta)/(1-\theta) - \ln(\bar{C}) - \theta/(1-\theta)\ln(\bar{H})\}. \tag{4.6}$$

I search for the optimal macroprudential policy over the grid of parameters $\{\phi_1^{CCyB}, \phi_2^{CCyB}, \phi_1^{ST}, \phi_2^{ST}\} \in [0, 10] \times 10^{-4}$ that optimises utility in the economy characterised by the model in Section 3. To compute welfare, I simulate the economy for 200 periods (50 years). I repeat each simulation 100 times using a different seed in Dynare and discard simulation failures. If a simulation is explosive, I record it as a failure and move on to draw another seed. This method allows me to compare welfare across only successful simulations and check failure rates. High failure rates indicate an unstable specification and a high variance in the results. Finally, I compute the median value of lifetime utility U of the simulations.

The results are presented as follows. For each policy, one figure (Figures 5 and 6) depicts the results graphically. Furthermore, Table 3 reports numerically the results for selected macroprudential tax rates, showing how welfare and other macroeconomic and financial variables react when the policies are introduced. In Appendix D, I add more graphical results for the extended model and I report robustness checks to see how the model behaves under slightly different policies. Variables are expressed as percentage deviations from their stochastic steady state.

4.2.1 Countercyclical capital buffer

First, I report the results for the CCyB policy rule. A higher ϕ_1^{CCyB} imposes a higher countercyclical tax on the debt of intermediaries, increasing the cost of debt-financing when leverage is high. A higher ϕ_2^{CCyB} imposes a lump-sum tax that is independent on the state of the economy and affects risk by increasing the cost of funding throughout the financial cycle.

Figure 5 plots the results for the CCyB policy rule in the model without housing ($H = 0$). Appendix D shows the results for the model including housing ($H = 1$). The first row shows that welfare is first slightly increasing in ϕ_1^{CCyB}, reaching a maximum of below 4% and afterwards decreasing rapidly to -100% (not depicted). The welfare maximising rate takes into account the tradeoff between reducing risk and increasing costs. Table 3 explains the model dynamics (the first row corresponds to the welfare maximising rate in the upper panel of Figure 5, when only ϕ_1^{CCyB} is chosen). First, welfare is increasing with the countercyclical tax rate on debt since bond holdings are more expensive during bad times and a rapid build-up of leverage is prevented. Intermediaries instead issue more equity and are able to increase their capital investments and thereby increase wealth. Since more capital is acquired, the return on capital falls and the risk premium, which was an important component of the misspricing of risk, falls. As such, misspricing of risk is reduced.

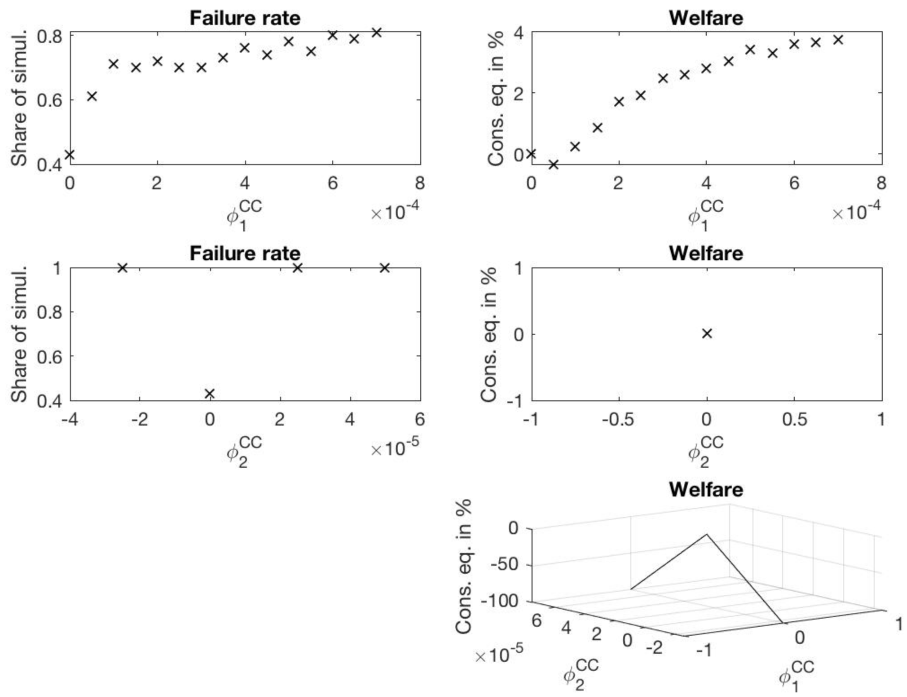

Figure 5: No-housing model: Macroprudential policy gains of CCyB rule

Note: Top row shows the failure rate and welfare when the rule only targets leverage (ϕ_1^{CCyB}). Middle row shows the failure rate and welfare when the rule targets a static tax (ϕ_2^{CCyB}). Bottom row shows the failure rate and welfare when the rule targets both leverage (ϕ_1^{CCyB}) and a static tax (ϕ_2^{CCyB}). Simulation length is 200 periods and each simulation is repeated 100 times using a different seed. Failures are recorded and discarded.

In the middle panels of Figure 5, only the static tax ϕ_2^{CCyB} is used. We see that only a rate of zero is feasible. Higher rates lead to high failure rates of the simulation due to the unstable nature of the model. In particular, the higher static rates lead to more expensive debt throughout the financial cycle which decreases not only bond holdings, but also overall wealth held by intermediaries, thus no welfare gain is expected.

The bottom row shows the results for when both ϕ_1^{CCyB} and ϕ_2^{CCyB} are included in the policy rate. Adding a positive ϕ_2^{CCyB} immediately reduces the welfare gains (leading to negative welfare gains) as it decreases bond holdings during the entire financial cycle. There are no immediate benefits to adding the static rate and the graph highlights (or rather does not show) the explosive behaviour introduced by the static rate.

Thus, the tax on debt financing makes welfare increase as households shift their holdings from debt to equity, but levels up the economy. Prices adjust so that capital investment becomes feasible again and risk premia are reduced. In the model with housing ($H = 1$; Forth row in Table 3 and Appendix D), I also find a welfare maximising macroprudential rate. However, the model dynamics when a housing sector is included are different. Here, welfare is increasing due to a higher level of wealth, but this is not enough to reduce return on assets, which to the contrary increases and makes reputation decrease. This has the effect that the economy has to leverage up even more to sustain the level of wealth, which amplifies the misspricing of risk. The magnitude of welfare gains is lower than in the model where housing is excluded.

Table 3: Welfare maximising policy rules (in %)

	Welfare	Reputation	Leverage	Wealth	Return on assets
No-housing model:					
$[\phi_1^{CCyB}, \phi_2^{CCyB}]$					
$[7, 0]$	3.7410	-4.0755	3.1294	2.8944	-1.5257
$[\phi_1^{ST}, \phi_2^{ST}]$					
$[5, 0]$	3.0813	-3.1230	1.2918	2.3579	0.2183
$[\phi_1^{CCyB}, \phi_1^{ST}]$					
$[4, 3]$	3.7816				
Model with housing:					
$[\phi_1^{CCyB}, \phi_2^{CCyB}]$					
$[22.5, 0]$	1.3664	-16.6420	34.9133	0.7247	1.8378
$[\phi_1^{ST}, \phi_2^{ST}]$					
$[35, 0]$	1.3688	-16.8212	33.4617	0.7236	0.0447
$[\phi_1^{CCyB}, \phi_1^{ST}]$					
$[10, 30]$	1.3779				

Note: Welfare is expressed in terms of consumption-equivalent. Variables are expressed as percentage deviation from stochastic steady state values. Parameters $\{\phi_1^{CC}, \phi_2^{CC}, \phi_1^{ST}, \phi_2^{ST}\}$ are expressed in basis points (10^{-4}). I maximise over the linear grid: $\{\phi_1^{CCyB}, \phi_2^{CCyB}, \phi_1^{ST}, \phi_2^{ST}\} \in [0, 10] \times 10^{-4}$. The housing model uses baseline calibration, whereas the no-housing model sets $H = 0$ and $\theta = 0$.

4.2.2 Stress tests

Next, I report the results for the stress testing policy rule. A higher ϕ_1^{ST} imposes a countercylical tax on the risk-weighted assets of intermediaries, increasing the cost of riskier assets (capital) when leverage is high. A higher ϕ_2^{ST} imposes a lump-sum tax that is independent on the state of the economy and affects risk by increasing the cost of holding risky assets throughout the financial cycle.

Similar to the previous subsection, Figure 6 (and Appendix D) plots the results for the stress test policy rule, while Table 3 describes the model dynamics for selected policy rates. The first row in Figure 6 shows that with the stress testing rule that adjusts the risk-weights by only targeting leverage ϕ_1^{ST}, welfare is increasing in the tax rate and drops to -100% after it reaches a maximum (not depicted), similar to the result when debt is taxed. Thus, a maximum welfare level (Second row in Table 3) exists where prices adjust and additional investment leads to higher total wealth levels that are however financed relatively more with bonds, thereby increasing leverage. Higher wealth levels lead to increasing return on assets, a higher risk premium, and therefore higher misspricing of risk.

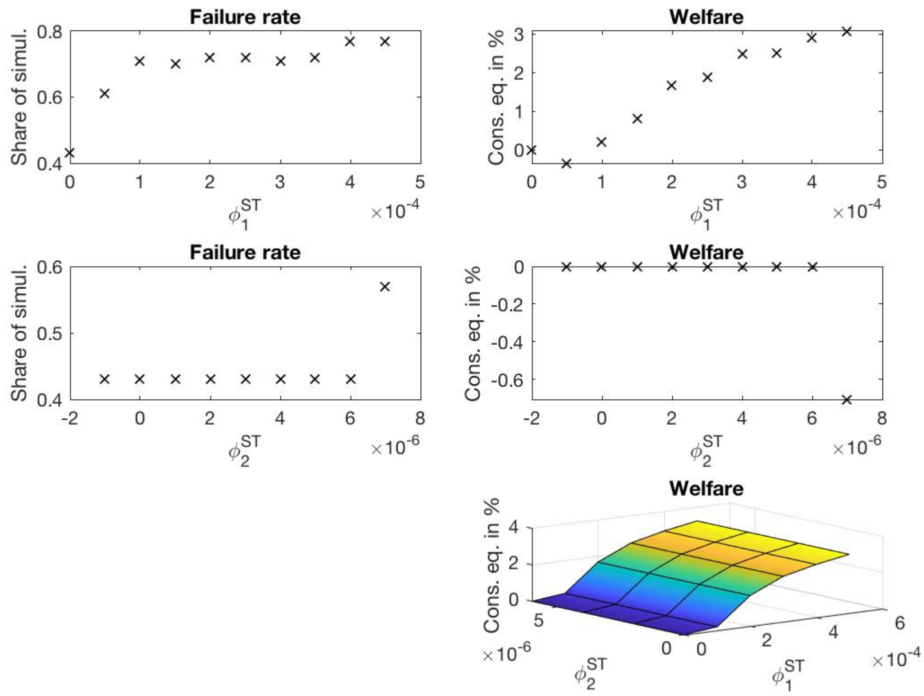

Figure 6: No-housing model: Macroprudential policy gains of stress testing rule

Note: Top row shows the failure rate and welfare when the rule only targets leverage (ϕ_1^{ST}). Middle row shows the failure rate and welfare when the rule targets a static tax (ϕ_2^{ST}). Bottom row shows the failure rate and welfare when the rule targets both leverage (τ_1^{ST}) and a static tax (ϕ_2^{ST}). Simulation length is 200 periods and each simulation is repeated 100 times using a different seed. Failures are recorded and discarded.

The second row in Figure 6 plots welfare and the failure rate for the static stress testing rule ϕ_2^{ST}. Welfare is maximised around a tax rate of zero, suggesting again that having a static tax throughout the financial cycle is not adequate. When the static tax increases, investment in the economy is disincentivised and total wealth is reduced. This leads to lower overall welfare for consumers.

The third row in Figure 6 combines the two parameters targeting both leverage ϕ_1^{ST} and a static tax ϕ_2^{ST}. The results are unchanged from the case where only leverage is targeted (top row) as the small static tax has little effect on overall welfare. However, similar to the result when only the static rate is chosen (middle panels), increasing the static parameter exacerbates the drop in welfare due to reduced wealth.

Thus, the tax on risk-weighted assets increases welfare by slightly levelling up the economy, but not as much as in the CCyB policy case (in Table 3, 3.08% $<$ 3.74%). The misspricing of risk is slightly increasing as return on assets increases with the economy and with leverage (leverage increases wealth which increases asset prices and, subsequently, return on assets and the misspricing of risk).

As described above, Table 3 shows the consumption-equivalent welfare gains from selected macroprudential policies. Comparing the best policy rates in the CCyB regime ($\phi_1^{CCyB} = 7bp$) and the stress test regime ($\phi_1^{ST} = 5bp$) shows that welfare gains are about 0.7 percentage points higher when debt instead of risk-weighted assets is taxed. This also goes hand-in-hand with a reduction of the return on assets and thereby a reduction in the misspricing of risk, which cannot be observed for the stress test regime.

When introducing housing to the model (fourth and firth row in Table 3), the advantages of CCyB policy disappear. Welfare is marginally higher when targeting risk-weighted assets (1.3688% $>$ 1.3664%) and the misspricing of risk deteriorates more in the CCyB regime. Thus, the inclusion of housing and the specific targeting of one asset class via the stress testing tax clearly changes the discussion and makes stress tests more attractive.

Enacting both macroprudential policies simultaneously (third and sixth row in Table 3) gives a slightly larger welfare gain, meaning that there is a benefit to taxing debt and assets at the same time. However, this simulation also gives very large percentage increases in reputation (not recorded) suggesting problems with the stability of the simulation.

Appendix D shows robustness tests. In particular, more model parameters are reported and different policy examples show lower welfare gains.

4.3 Discussion

The purpose of the welfare analysis is to find a macroprudential policy tax rate that maximises welfare and approximates the optimal policy rule. The results in the previous subsection demonstrate that the countercyclical capital requirement policy rule can increase welfare through an increase in wealth and a decrease in the misspricing of risk. This finding is in line with Laséen et al. (2017), who find that optimal CCyB policy can raise welfare by 1.5%. When housing is included in the model, it becomes clear that part of the welfare increase is attributable to a further levelling up of the economy's wealth through higher leverage and part is due to a decrease in misspricing of risk. This theme is also present in the stress testing regime where welfare is increased through levelling up of the economy's wealth, albeit with a funding more geared towards equity and thereby not increasing leverage as much.

Thus, welfare gains come through two channels:

1. A decrease in misspricing of risk (decrease in asset prices to decrease in return on assets to decrease in risk premium);

2. An increase in total wealth (decrease in asset prices to increase in leverage to increase in assets).

In Table 4, I depict which channel is dominating given the different macroprudential policy regimes and the inclusion of housing in the model. Only in the first case (CCyB; no-housing) is the first channel dominating, shown as a reduction in misspricing of risk in Table 3. In the other three cases, the second channel is dominating, which leads to an increase in wealth, but also an increase in misspricing of risk in Table 3. Thus, the second channel increasing total wealth by more than the first channel decreases misspricing of risk. This explains the counter-intuitive result where macroprudential policy leads to higher misspricing of risk. This phenomenon can be considered an example of Brunnermeier and Sannikov (2014)'s "volatility paradox", where agents tend to be more leveraged when financial volatility is low.

Table 4: Channels for welfare gains

	No-housing model	**Housing model**
CCyB regime	Channel 1 > Channel 2	Channel 1 < Channel 2
Stress test regime	Channel 1 < Channel 2	Channel 1 < Channel 2

Note: Depicts the two channels that increase welfare and which channel is dominating given the macroprudential policy regime and the inclusion of housing in the model. Channel 1 decreases misspricing of risk. Channel 2 increases total wealth.

By definition, I maximise welfare to find the best macroprudential policy in my analysis. As the results indicate, this maximisation does not necessarily reduce the misspricing of risk nor is it minimising it. Since welfare depends primarily on consumption, which is a fraction of GDP, the level of total wealth in the economy is crucial. A policy increasing wealth is welfare improving, but not necessarily reducing systemic risk. Since systemic risk manifests itself by reducing wealth during occasional recessions, excessive risk decreases welfare. An economy with a small, reasonable amount of risk can still thrive, however.

4.3.1 Policy implications

The takeaway for a financial authority deciding on macroprudential policy tools is threefold. First, the model omitting housing suggests that welfare can increase more through a CCyB policy than through a stress test (3.741% > 3.081%), while the model with housing shows more moderate and opposite results as stress tests increase welfare slightly more than CCyBs (1.369% > 1.366%). The regulator would first need to establish how relevant the housing sector is in the economy and whether it would make sense to solely look at the results without housing.

Second, a regime that combines stress tests and CCyB policies is more appropriate as it looks at both the funding side and the asset side of intermediaries. The results show that this regime features the largest welfare gains, but with a reduced size of tax parameters (4bp<7bp and 3bp<5bp, respectively). Concluding that both policies should be enacted simultaneously is also in line with current political developments, where CCyB requirements are established in the Basel III framework and stress tests are regularly conducted by financial authorities.

Third, while targeting overleverage with macroprudential policy leads to a correction in asset prices, the "volatility paradox" suggests that systemic risk need not necessarily decrease. The question macroprudential regulators should ask then is not "how can policy minimise systemic risk?", but rather "how can policy lead to the optimal trade-off between leverage that increases wealth and leverage that increases systemic risk?"

4.3.2 Limitations and future research

While I demonstrate that my results hold under the specifications of my model, research on macroprudential policy still has far to go. I want to touch on two themes here. First, my modelling choices on macroprudential policy are simplistic and should be scrutinised. Second, DSGE models can only describe the economy that is modelled and different models could lead to different results.

My modelling choice for CCyB policy is based on Laséen et al. (2017) with the argument that a tax on debt financing makes issuing debt more expensive when leverage is high. Similarly, the choice for stress tests is intentionally simple and based on the idea that a tax on risk-weighted assets incentivises intermediaries to hold higher-quality assets. To guarantee the validity of these choices, more empirical research using bank-level microdata is needed to show that these relationships hold. Additionally, Constâncio (2017) only started advocating for macroprudential stress tests to be included in the 2018 stress test for which no empirical data is yet available. Further expanding the foundations for modelling these macroprudential policies to see how they affect the behaviour of financial intermediaries would be useful robustness checks. Additionally, while I let the financial authority target leverage when setting macroprudential policy, the argument motivating the targeting of asset prices or a more sophisticated measure of financial instability instead might be made.[29]

[29] In fact, Lozej, Onorante, and Rannenberg (2017) argue that a macroprudential regulator should be following a rule targeting house prices rather than credit indicators.

Furthermore, Williams (2017)'s critique of DSGE modelling highlights the importance of using other models that feature different methods or focus on other peculiarities as robustness checks when advocating for policy action. Comparing stress tests and CCyB policies in a diverse set of macro models featuring not only systemic risk would be a useful exercise. In particular, my model developed a closed economy without monetary policy. Since macroprudential policy discussions often feature the tradeoff with monetary policy regimes, including nominal wage rigidities would lead to the need for monetary policy action and provide further insight into how macroprudential policy reacts when a central bank sets the interest rate. Additionally, employing open economy models where assets flows are determined exogenously would be useful to evaluate macroprudential policies in small open economies such as Sweden. Similarly, endogenous systemic risk can be modelled in different ways. Clerc et al. (2015) analyse bank reserve requirements in a model where default is the driving force of risk. Introducing stress tests to their model could prevent a large number of defaults and show the effects of macroprudential policy from a different perspective.

5 Conclusions

Motivated by the need for macroprudential policy that guarantees financial stability in a world where financial sector imperfections are continuously creating systemic risk, I do two things in this thesis. First, I replicate HK2014's model, which is successful in generating systemic risk, letting the economy move endogenously towards a state of recession. I extend the model with a housing sector to mirror the importance of housing for the banking sector in the eurozone.

Second, to counteract systemic risk, I introduce two macroprudential policy tools that act as a tax on debt (CCyBs) and a tax on risk-weighted assets (stess tests). I derive the optimal macroprudential policy that removes the financial frictions completely, which shows that policy should be countercyclical. Since the financial authority cannot exogenously remove the frictions, I define an approximation of the macroprudential policy rate that targets leverage and I search for the welfare maximising rate over a grid of parameters.

My findings indicate that an economy less reliant on the housing sector is better off in a CCyB regime, but this result seems less clear for an economy where housing is important: here, the stress test regime maximises welfare. Combining stress test and CCyB regimes renders the highest welfare gains, suggesting this to be the best path for the macroprudential regulator. Both countercylical tax regimes improve welfare through two channels: by decreasing the misspricing of risk and by increasing the total wealth of households. The latter channel highlights the presence of Brunnermeier and Sannikov (2014)'s "volatility paradox", as macroprudential policy incites higher leverage.

My study develops the first analysis of macroprudential stress tests in a DSGE model. In particular, with the coming of macroprudential stress tests à la Constâncio (2017), this area of research will be more and more important in the future. The comparison with CCyB policy contributes towards the research by Laséen et al. (2017) and Clerc et al. (2014), who focus on the advantage of CCyBs over monetary policy and minimum capital requirements when agents default, respectively. Furthermore, by including housing in my model, I provide the first assessment of macroprudential policy in a model with housing. Considering that a majority of macroprudential regulators are concerned with housing developments, this addition seems imperative. As such, this research also provides the building blocks for more extensive analysis of macroprudential policy within DSGE models, which is desperately needed to ensure that we are educated about policies that are expected to prevent the next financial crisis.

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Appendices

A Model derivations

In the following subsections, A.1, A.2, A.3, and A.4, I derive Equations 3.3, 3.4, 3.7, and 3.12, respectively.

A.1 Derivation of the consumption-savings Euler equation

The household problem is given by the household utility function 3.1 and the budget constraint 3.2, which can be combined to form the Lagrangian:

$$\begin{aligned}\mathcal{L} = E_0 \sum_{t=0}^{\infty} [\beta^t \ln(C_t^{1-\theta} H_t^{\theta}) \\ + \lambda_t (lY_t - C_t - r_t^H H_t + \tilde{R}_t V_{t-1} + (1 + r_{t-1}) B_{t-1} + D_t^K - W_t)],\end{aligned} \tag{A.1}$$

where λ_t is the Lagrange multiplier. Taking the first order conditions (FOC) yields:

$$\frac{\partial \mathcal{L}}{\partial C_t} = \beta^t \frac{1}{C_t}(1-\theta) - \lambda_t = 0, \tag{A.2}$$

$$\frac{\partial \mathcal{L}}{\partial C_{t+1}} = \beta^{t+1} \frac{1}{C_{t+1}}(1-\theta) - \lambda_{t+1} = 0, \tag{A.3}$$

$$\frac{\partial \mathcal{L}}{\partial B_t} = \lambda_{t+1}(1 + r_t) - \lambda_t = 0. \tag{A.4}$$

Dividing A.3 by A.2 and substituting in A.4 gives:

$$\beta \frac{C_t}{C_{t+1}} = \frac{\lambda_{t+1}}{\lambda_t} = \frac{1}{1 + r_t}$$

$$\Leftrightarrow \beta(1 + r_t) \frac{C_t}{C_{t+1}} = 1. \tag{3.3}$$

■

A.2 Derivation of the consumption-housing Euler equation

The household problem is given by the household utility function 3.1 and the budget constraint 3.2, which can be combined to form the Lagrangian A.1:

$$\begin{aligned}\mathcal{L} = E_0 \sum_{t=0}^{\infty} [\beta^t \ln(C_t^{1-\theta} H_t^{\theta}) \\ + \lambda_t (lY_t - C_t - r_t^H H_t + \tilde{R}_t V_{t-1} + (1 + r_{t-1}) B_{t-1} + D_t^K - W_t)],\end{aligned} \tag{A.1}$$

where λ_t is the Lagrange multiplier. Taking the FOC yields:

$$\frac{\partial \mathcal{L}}{\partial C_t} = \beta^t \frac{1}{C_t}(1-\theta) - \lambda_t = 0, \tag{A.2}$$

$$\frac{\partial \mathcal{L}}{\partial H_t} = \beta^t \frac{1}{H_t}\theta - \lambda_t r_t^H = 0. \tag{A.5}$$

Dividing A.2 with A.5 gives:

$$\begin{aligned} \frac{H_t}{C_t}\frac{1-\theta}{\theta} &= \frac{1}{r_t^H} \\ \Leftrightarrow \frac{C_t}{H_t} &= \frac{1-\theta}{\theta} r_t^H. \end{aligned} \tag{3.4}$$

■

A.3 Derivation of the optimal investment rate

Capital goods producers maximise net profits given by selling $i_t K_t$ capital at a price q_t to intermediaries at a cost of $\Psi(K_t, i_t)$:

$$\max_{i_t} q_t i_t K_t - \Psi(K_t, i_t), \tag{A.6}$$

with $\Psi(K_t, i_t) = i_t K_t + \frac{\kappa}{2}(i_t - \delta)^2 K_t$. Taking the FOC, using the fact that $K_t > 0$, and solving for the investment rate i_t yields:

$$\begin{aligned} \frac{\partial}{\partial i_t} &= q_t K_t - K_t - \kappa(i_t - \delta)K_t = 0 \\ &\Leftrightarrow K_t(q_t - 1 - \kappa(i_t - \delta)) = 0 \\ &\Leftrightarrow i_t = \delta + \frac{q_t - 1}{\kappa}. \end{aligned} \tag{3.7}$$

■

A.4 Derivation of the optimal allocation rule

Financial intermediaries maximise a mean-variance portfolio strategy given by Equation 3.11:

$$\max_{\alpha_t^{FI}} E_t \tilde{R}_{t+1} - \frac{m}{2}\text{Var}_t \tilde{R}_{t+1}. \tag{3.11}$$

Since return on equity $\tilde{R}_t$ is given by Equation 3.9: $\tilde{R}_t = \alpha_{t-1}^{FI} R_t + (1 - \alpha_{t-1}^{FI})(1 + \tau_{t-1}^{CCyB}) r_{t-1}$ and the interest rate is risk-free: $\text{Var}_t r_{t-1} = 0$, it must be that the variance of return on equity is: $\text{Var}_t \tilde{R}_{t+1} = (\alpha_{t-1}^{FI})^2 \text{Var}_t R_t$.

Thus, 3.11 can be rewritten as:

$$\max_{\alpha_t^{FI}} E_t[\alpha_{t-1}^{FI} R_t + (1-\alpha_{t-1}^{FI})(1+\tau_{t-1}^{CCyB})r_{t-1}] - \frac{m}{2}(\alpha_{t-1}^{FI})^2 \mathrm{Var}_t R_t. \tag{A.7}$$

Taking the FOC and solving for leverage α_t^{FI} yields:

$$\begin{aligned}
\frac{\partial}{\partial \alpha_t^{FI}} &= E_t R_t - (1+\tau_{t-1}^{CCyB})r_{t-1} - m\alpha_{t-1}^{FI}\mathrm{Var}_t R_t = 0 \\
\Leftrightarrow \alpha_{t-1}^{FI} &= \frac{E_t R_t - (1+\tau_{t-1}^{CCyB})r_{t-1}}{m\mathrm{Var}_t R_t} \\
\Leftrightarrow \alpha_t^{FI} &= \frac{E_t R_{t+1} - (1+\tau_t^{CCyB})r_t}{m\mathrm{Var}_t R_{t+1}}.
\end{aligned} \tag{3.12}$$

■

B Fully specified model

The following equations are necessary and sufficient to solve and simulate the model in Dynare. They follow from Definition 1:

$$W_t = lY_t - C_t - r_t^H H_t + \tilde{R}_t V_{t-1} + (1+r_{t-1})B_{t-1} + D_t^K, \tag{3.2}$$

$$\beta(1+r_t)E_t\frac{C_t}{C_{t+1}} = 1, \tag{3.3}$$

$$\frac{C_t}{H_t} = \frac{1-\theta}{\theta} r_t^H, \tag{3.4}$$

$$A_t = A_{t-1} + (1-q_t)\sigma_t^A \bar{A},$$

$$Y_t = A_t K_t, \tag{3.5}$$

$$K_t = (1-\delta-\sigma_t^K)K_{t-1} + i_{t-1}K_{t-1}, \tag{3.6}$$

$$i_t = \delta + \frac{q_t - 1}{\kappa}, \tag{3.7}$$

$$\varepsilon_t = \varepsilon_{t-1}(m\tilde{R}_t - \eta), \tag{3.8}$$

$$R_t = \frac{q_t K_t(1-\tau_{t-1}^{ST}) + D_t + p_t H_t + r_t^H H_t}{q_{t-1}K_{t-1} + p_{t-1}H_{t-1}}, \tag{3.10}$$

$$\alpha_t^{FI} = \frac{E_t(R_{t+1} - (1+\tau_t^{CCyB})r_t)}{m\mathrm{Var}_t(R_{t+1})}, \tag{3.12}$$

$$Y_t = C_t + \Psi(K_t, i_t), \tag{3.16}$$

$$W_t = q_t K_t + p_t H_t = V_t + B_t, \tag{3.17}$$

$$\alpha_t^{FI} V_t = q_t K_t + p_t H_t, \tag{3.18}$$

$$\alpha_t^{FI} = \frac{1}{1-\lambda} + \alpha_\varepsilon \left(\frac{q_{t-1}K_{t-1} + p_{t-1}H_{t-1}}{\varepsilon_{t-1} - \varepsilon_{MIN}} \right)^3, \tag{3.19}$$

$$r_t^H = (A_t - i_t - \frac{\kappa}{2}(i_t - \delta)^2)\frac{\theta}{1-\theta}\frac{K_t}{H_t}. \tag{3.20}$$

C Data sources

Table C.1 describes the variables used to calibrate the stochastic moments in Table 2 and reports the data sources.

Table C.1: Data sources

Variable	**Years**	**Frequency**	**Source**	**Retrieved from**
Leverage	2014Q4:2017Q3	Quarterly	ECB Bank assets ECB Bank equity	Link Link
Equity growth rate	1999Q1:2017Q3	Quarterly	ECB Shares issued total economy	Link
Real GDP growth rate	1995Q1:2017Q3	Quarterly	ECB GDP	Link
Investment	1995Q1:2017Q3	Quarterly	ECB Capital formation	Link
House price	2000Q1:2017Q3	Quarterly	ECB Commercial property price indicator	Link

D Welfare analysis: Robustness checks

Figures D.1 and D.2 report the welfare maximisation in the model with housing ($H = 1$) that were omitted in section 4. Table D.1 reports more robustness checks to the welfare analysis. Furthermore, I also report how equity and capital behave in the macroprudential policy regimes, further elaborating on Table 3.

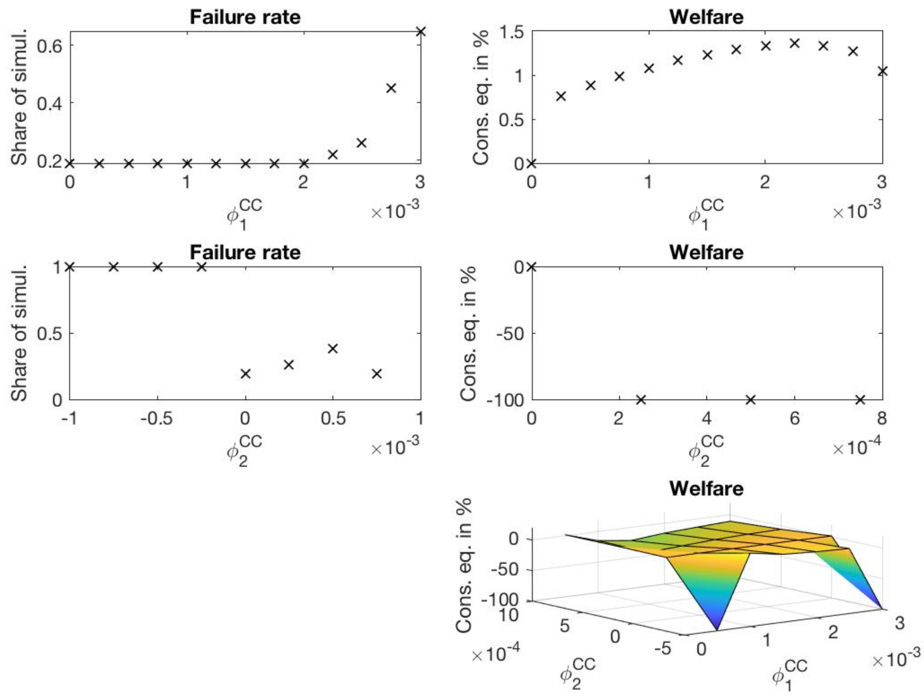

Figure D.1: Housing model: Macroprudential policy gains of CCyB rule

Note: Top row shows the failure rate and welfare when the rule only targets leverage (ϕ_1^{CCyB}). Middle row shows the failure rate and welfare when the rule targets a static tax (ϕ_2^{CCyB}). Bottom row shows the failure rate and welfare when the rule targets both leverage (ϕ_1^{CCyB}) and a static tax (ϕ_2^{CCyB}). Simulation length is 200 periods and each simulation is repeated 100 times using a different seed. Failures are recorded and discarded.

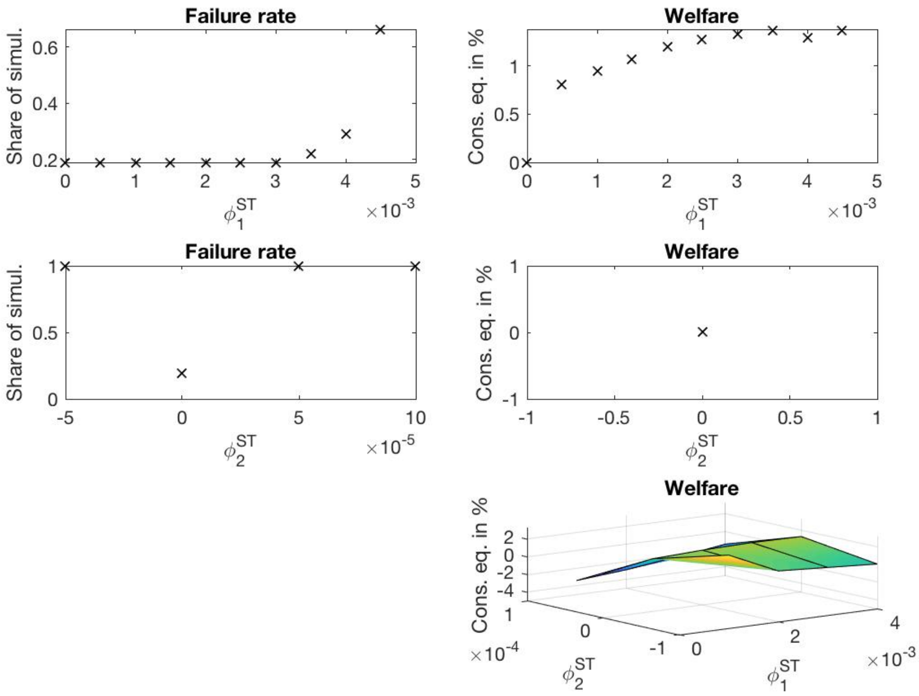

Figure D.2: Housing model: Macroprudential policy gains of stress test rule

Note: Top row shows the failure rate and welfare when the rule only targets leverage (ϕ_1^{ST}). Middle row shows the failure rate and welfare when the rule targets a static tax (ϕ_2^{ST}). Bottom row shows the failure rate and welfare when the rule targets both leverage (ϕ_1^{ST}) and a static tax (ϕ_2^{ST}). Simulation length is 200 periods and each simulation is repeated 100 times using a different seed. Failures are recorded and discarded.

Table D.1: Welfare maximising policy rules (in %)

	Welfare	**Reputation**	**Leverage**	**Wealth**	**Equity**	**Capital**	**Return on assets**
No macroprudential policy:							
$[0, 0]$	0	0	0	0	0	0	0
No-housing model:							
$[\phi_1^{CCyB}, \phi_2^{CCyB}]$							
$[7, 0]$	3.7410	-4.0755	3.1294	2.8944	0.0260	1.5312	-1.5257
$[6, 0.25]$	-1.3530						
$[\phi_1^{ST}, \phi_2^{ST}]$							
$[5, 0]$	3.0813	-3.1230	1.2918	2.3579	-0.1794	1.3042	0.2183
$[5, 0.25]$	3.2323						
$[\phi_1^{CCyB}, \phi_1^{ST}]$							
$[4, 3]$	3.7816						
Model with housing:							
$[\phi_1^{CCyB}, \phi_2^{CCyB}]$							
$[22.5, 0]$	1.3664	-16.6420	34.9133	0.7247	-39.1477	0.4850	1.8378
$[30, 5]$	-6.1000						
$[\phi_1^{ST}, \phi_2^{ST}]$							
$[35, 0]$	1.3688	-16.8212	33.4617	0.7236	-45.3964	0.4661	0.0447
$[40, 1]$	-1.4575						
$[\phi_1^{CCyB}, \phi_1^{ST}]$							
$[10, 30]$	1.3779						

Note: Welfare is calculated as deviation from steady-state welfare and expressed in terms of consumption-equivalent. Other variables are expressed as percentage deviation from stochastic steady-state values. Parameters $\{\phi_1^{CC}, \phi_2^{CC}, \phi_1^{ST}, \phi_2^{ST}\}$ are expressed in basis points (10^{-4}). I maximise over the linear grid: $\{\phi_1^{CCyB}, \phi_2^{CCyB}, \phi_1^{ST}, \phi_2^{ST}\} \in [0, 10] \times 10^{-4}$. For the no-housing model $H = 0$ and $\theta = 0$.