Essays on household loan-to-value macroprudential policy

William Gatt

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Abstract

This thesis is a collection of three papers on the use of the loan-to-value (LTV) ratio as a borrower-based macroprudential policy tool. The first chapter discusses the practical and theoretical development of the LTV ratio as a policy tool over time, as well as reviews the empirical evidence on its general effectiveness in dampening credit growth and its recent specific implementation in two advanced economies, New Zealand and Ireland. The second chapter studies the implications of LTV policy that is implemented asymmetrically over the medium term: a strong tightening response during a boom but a weak unwinding in the bust and recovery phase of the cycle. This is motivated by policymakers' recent statements as well as some empirical evidence. Using numerical simulations I show that this policy is inferior to symmetric policy implementation as it leads to a deeper bust and a more volatile economic environment. In the third chapter, I study the long run distributive effects of the introduction of a macroprudential policy regime which lowers the LTV ratio permanently. I compare the long run effects between economies with two levels of wealth inequality, capturing a range that is representative of several countries in Europe. I show that the policy has a very small long run effect on total wealth inequality, and this is true for the two polar economies. Homeownership falls, with similar dynamics in both economies. While housing wealth inequality increases, the effect is stronger in the economy with lower initial wealth inequality. This is because in the latter economy a greater share of households become borrowing-constrained. Therefore, the same policy can have differential impacts across countries.

Supervisors: Dr. Alex Possajennikov
Dr. Margarita Rubio

Declaration

I declare that this thesis contains original work authored solely by myself during my registration in the Economics PhD programme at the University of Nottingham. Any contribution that is not my own is duly referenced.

Any views expressed in this thesis are my own and are not necessarily those of the Central Bank of Malta.

William Gatt
25 September 2020

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Contents

Preface

This thesis is composed of three papers that explore the use of the loan-to-value (LTV) ratio as a macroprudential policy tool from different research perspectives. In the first paper I set the general scene for the use of macroprudential policies to address externalities associated with excessive household leverage. I then document the transition of the LTV ratio from a catch-all process for financial shocks in theoretical models with financial frictions to its practical development as a policy tool within a macroprudential policy framework. I argue that chronologically the practical implementation of LTV policy largely preceded theoretical research on this topic, but the theoretical and empirical literature has caught on following the financial crisis of 2008. I then review cross-country evidence on its effectiveness in taming financial cycles and study the recent experience of two advanced economies – New Zealand and Ireland – with this tool. The targeted exemptions to specific borrower types in these countries may have prevented unintented consequences such as lower homeownership among young adults.

In the second paper I use a DSGE model with housing and a potentially slack collateral constraint to explore the implications of a macroprudential policy regime that operates an asymmetric Taylor-type LTV rule. This rule tightens borrowing terms during a boom much more severely than it unwinds them during a bust, and is motivated by policymakers' recent statements as well as empirical findings. I show that while this rule dampens the boom better than its symmetric counterpart, it introduces more volatility in the economy by exacerbating the correction that follows. This makes business cycles more volatile compared to symmetric policy, even when borrowing constraints are slack, and this volatility rises with asymmetry. Furthermore, I find that the asymmetric policy rule causes the borrowing constraint to become slack not just during a credit boom, but also during a credit bust. This is due to higher inflation volatility that feeds back into the collateral constraint. The higher the policy asymmetry, the more frequently the economy visits this regime.

In the third paper I explore the long run unintended consequences of a macroprudential regime which introduces a lower LTV ratio cap permanently. Motivated by varying degrees of wealth inequality in Europe, I study whether the introduction of the same policy across two economies with differing levels of wealth inequality has different effects on home ownership and housing wealth inequality. I use a continuous-time heterogeneous agent model with uninsurable income risk and an endogenous borrowing limit in the form of a collateral constraint, and find that initial conditions matter. The lower is wealth inequality *ex-ante*, the higher is the fall in house prices and the greater is the rise in the share of constrained homeowners and housing wealth inequality *ex-post*. The effects are also non-linear in the LTV ratio, with progressively stronger effects at lower LTV ratios, especially when inequality is comparatively low. A blanket policy applied to several countries can therefore have differential effects.

Chapter 1

The loan-to-value ratio as a macroprudential policy tool*

Abstract

The aim of this paper is to analyse the development of the loan-to-value (LTV) ratio as a policy tool within a macroprudential policy framework by surveying both the theoretical and empirical literature. I argue that the practical implementation of the LTV ratio preceded theoretical studies, but since the financial crisis studies have caught up, including those on which indicators seem to work best in flagging a potential future crisis. Empirical studies show that in practice LTV ratio limits tend to be effective tools in buffering credit and house price growth, although attributing casual effects is not always easy. The benefits seem to outweigh some potential side-effects, such as the output costs of tightening credit. I then survey the recent success with LTV policy in New Zealand and Ireland, particularly by targeting the riskier borrowers.

Keywords: *loan-to-value, household credit, house prices, financial crises*

JEL codes: E65, G01, G28, R38

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"Rapid credit growth, by itself, may pose little threat to the stability of the financial system. The same could be said for rapid increases in asset prices or an investment boom. Rather, the historical narratives suggest that it is the combination of events, in particular the simultaneous occurrence of rapid credit growth, rapid increases in asset prices and, in some cases, high levels of investment – rather than any one of these alone – that increases the likelihood of problems."

– Borio and Lowe (2002, p.11)

1.1 Introduction

Credit booms are episodes during which credit to the private sector rises quickly relative to a measure of economic scale, such as GDP, and are associated with rising asset prices and economic expansions (Mendoza and Terrones, 2008). However, one out of every three credit booms has historically ended in a banking crisis, and such 'crisis-booms' tended to be bigger and more prolonged than other booms (Dell'Ariccia et al., 2014). It is credit booms that specifically generate an increase in household debt that are associated with a boom-bust cycle (Mian et al., 2017), and in advanced economies these are mainly consumption-led cycles (IMF, 2017). Moreover, booms that start at a higher credit-to-GDP ratio are more likely to end in a crisis, all else equal (Dell'Ariccia et al., 2014). On the other hand, booms that have not ended in crisis have led to financial deepening and are associated with an increase in real income per capita (Dell'Ariccia et al., 2014). Credit booms therefore have the potential to increase economic development if managed well. Macroprudential policies targeting household borrowing try to do exactly that; facilitate the flow of credit to the right borrower while avoiding excesses. In this paper I discuss the progress made towards addressing these excesses through loan-to-value (henceforth LTV) ratio limits by surveying both the theoretical and empirical literature on the conduct of macroprudential policy, as well as by looking at specific implementations of LTV caps for borrowers.

But what are these excesses? In brief, household borrowing externalities that arise from collateral constraints. Collateral constraints are the result of limited enforcement capacity of lenders to get borrowers to honour debt repayment. In a decentralized equilibrium households do not internalize the effects of leverage and its effect on aggregate asset prices, which can drive consumption demand through changes in net worth (Lorenzoni, 2008; Bianchi, 2011; Bianchi and Mendoza, 2010; Korinek and Simsek, 2016). This occurs both when leverage is rising and when, in the wake of a negative aggregate shock, households deleverage and put downward pressure on asset prices by selling them, potentially through fire sales.[1] In this decentralized equilibrium, the level of debt that

[1] The aggregate shock need not originate from within the financial system; in principle any shock that causes a

is optimal for a household is socially suboptimal. This externality matters for aggregate demand as borrowers which are credit constrained have a higher marginal propensity to consume than savers. A drop in asset prices and a rise in deleveraging implies that borrowers have to reduce spending, which drags down aggregate spending, further depressing asset prices. This is the financial accelerator effect, first proposed in the seminal work of Kiyotaki and Moore (1997) and Bernanke et al. (1999), then popularized by Iacoviello (2005) through the application to housing. This application is important since middle income households tend to hold most of their wealth in housing (Piketty, 2014, p.260); wealth of the bottom 90% of households in the US comprises mostly housing, and in the euro area housing also comprises the main household asset (HFCS, 2020). A macroprudential policy framework therefore has to address the link between real estate as the primary asset relevant to the financial accelerator through credit.

One potential tool that can be used to limit household leverage in practice is a maximum LTV ratio, which affects the collateral constraint. Crowe et al. (2013) document a positive cross-country relationship between the maximum LTV ratio and house price growth in the run up to the financial crisis of 2008, and a negative relationship between this house price growth and the subsequent cumulative decline in GDP that followed. Although not necessarily causal, it illustrates an important link between the LTV ratio, house prices and credit that has implications for business cycles. The contribution of this paper is to analyse how the thinking about macroprudential policy – specifically the LTV ratio as a policy tool – evolved over time, and whether it is an effective tool.

The LTV ratio is identified as one of the best macroprudential tools used to deal with booms that are driven by strong activity in the real estate market (Crowe et al., 2014) because it can be aimed directly at the source of the problem and not stifle all credit flows. When the LTV constraint binds, a prospective borrower needs to accumulate more internal funds to finance the purchase, while homeowners using a home equity line of credit have access to less finance. To this end, such macroprudential policy not only reduces leverage but also encourages household saving. Yet, macroprudential policy frameworks are scarcely based on a single instrument like the LTV ratio. Empirical studies have recently distinguished tools by the targeted actor, namely borrowers or lenders (Galati and Moessner, 2018). Tools aimed at the former are mainly LTV, loan-to-income (LTI) and debt service-to-income ratios, while tools targeted towards financial institutions typically include the capital buffer ratio, leverage ratio, risk weights, concentration limits and so on. While LTV and LTI restrictions are associated with household credit demand, capital measures affect the supply side of credit, since they place limits on banks' balance sheets.[2] Bank capital measures are

reallocation of resources can lead to an episode of deleveraging and falling asset prices. Throughout this paper I restrict my attention to bank-based credit.

[2] However, this classification may be somewhat confusing as an LTV ratio limit is a limit faced by both households *and* banks. An LTV cap that is truly binding must set a minimum downpayment that is higher than what banks in general ask for.

more wide-ranging and can affect not only the supply of credit to household but also to firms.[3]

My findings can be summarized in three main points. The first is that the general macroprudential objectives are now clearer than they were a decade ago, both in theory and in practice. Second, empirical evidence indicates that the LTV ratio can be an effective policy tool in dampening credit growth. While this conclusion has been typically plagued with endogeneity concerns, more recent studies that establish a causal link confirm the finding that LTV policy works, although macroprudential policies are rarely dependant on a single tool to achieve their objectives. The third draws on the successful experience of New Zealand and Ireland in implementing LTV policies. Although LTV ratios were lowered, the use of 'speed limits' and other targeted exemptions likely prevented overly tight policy which may have otherwise give rise to unintended consequences, such as lower home ownership among young adults.

The rest of this paper is structured as follows. In the rest of this section I discuss the collateral constraint as the key economic object that is a function of the LTV ratio, along with the general objectives, targets and instruments of macroprudential policy. In section 1.2 I summarize the development of macroprudential policy from mainly being policy-driven to its theoretical modelling in DSGE models, and describe how such tools are typically implemented in these models. I also discuss what observables the literature recommends as useful indicators for the likelihood of a financial crisis. In section 1.3 I survey the empirical studies on the effectiveness of LTV policy and in section 1.4 I document the recent experience of New Zealand and Ireland with LTV policy and its apparent success.

1.1.1 The collateral constraint and the LTV ratio

The starting point of the analysis is to think about the LTV ratio m in two ways. It can be a leverage ratio chosen by a household, or a maximum ratio that is imposed by a regulator such that borrowing is limited to a fraction of the value of some collateral. These definitions can be written in a slightly different, although potentially equivalent, algebraic expressions to represent this subtle distinction. Let B denote borrowing, H a stock of assets held, such as housing, and q the price of that asset. Then, ignoring the time dimension for simplicity, the first and the second interpretations can be written respectively as:

$$\mathsf{m}^* := \frac{B}{qH} \tag{1.1}$$

$$B \leq \mathsf{m}\,(qH)\,. \tag{1.2}$$

[3] For example, sectoral risk weights on bank assets or outright sectoral concentration ratio limits may affect the share of loans extended to the construction sector.

Written in this manner, the main difference is the object of interest in each expression. In equation (1.1) the focus is on the LTV ratio that results from a choice of B and possibly also H, and indeed (1.1) generally defines the LTV ratio.[4] On the other hand, inequality (1.2) puts the focus on the choice B as a function of the maximum LTV ratio, taken as given, and the same potential choice H. This is the collateral constraint that a borrower faces. Of course, these boil down to the same thing when the leverage choice of the household hits the limit that the policy allows. When this happens, the policy becomes binding and (1.2) becomes an equality. When (1.2) binds, borrowers cannot smoothen consumption optimally. Consequently, movements in q induce large changes in borrowing and spending through the financial accelerator effect. As I discuss below, not only can an LTV limit be introduced and kept at a fixed value over time, but it is typically raised or lowered countercyclically with some measure of systemic risk. Several countries have adopted LTV-based macorprudential policies, by passing directives and empowering institutions such as central banks and financial authorities to take and implement such policies.

1.1.2 Macroprudential policy: objectives, targets and instruments

Galati and Moessner (2018) describe the conduct of macroprudential policy within the framework discussed in Schoenmaker and Wierts (2011), focusing on the objectives, targets and instruments. The objective broadly defined is the financial stability of the system as whole, noting that systemic risk evolves endogenously and has both structural and time-varying elements. The former relates to the network of financial institutions through which a shock can propagate, while the latter features the cyclical component composed of booms and corrections. The ultimate objective is to avoid the output costs of financial crises (Borio, 2003). Macroprudential policy is therefore defined as a policy that aims to pre-emptively limit the build up of systemic risk (Bank of England, 2009), and limiting vulnerabilities brought on by excessive credit growth is therefore a prime objective of macroprudential policy (ECB, 2016).[5]

Meeting this objective means addressing the externalities that arise from collateralized borrowing. Unlike the interest rate as the conventional monetary policy tool, there is no clear default instrument that is specifically dedicated to macroprudential policy. This is perhaps because the objective can be ambiguously achieved through different channels. Although there may be some merit to using the interest rate for financial stability objectives since it *"gets in all the cracks"* (Stein, 2013), the interest rate is generally a blunt instrument for this purpose, as large movements would be required to achieve financial stability, at the cost of other targets (Trichet, 2005; Bernanke, 2010, 2017). Moreover, the use of a single instrument for multiple objectives violates

[4] The discussion here is general and allows the possibility that the stock of assets H is given for an individual, say as an initial condition.

[5] Constraining some activity is likely to put some drag on the economy, no matter how targeted the policy is. Therefore, there is potentially a long-run trade-off between the resilience of the financial sector and the growth of output (Barwell, 2018).

the Tinbergen principle of one tool for one goal (Galati and Moessner, 2013). Although there are several macroprudential tools that can be used in this regard, in this paper I focus on the LTV ratio as a borrower-based tool used to limit household leverage. Figure 1.1 shows the number of LTV policies that were implemented across 160 countries since 2000. Although use of this tool has always been on a rising trend, it accelerated following the financial crisis of 2008.

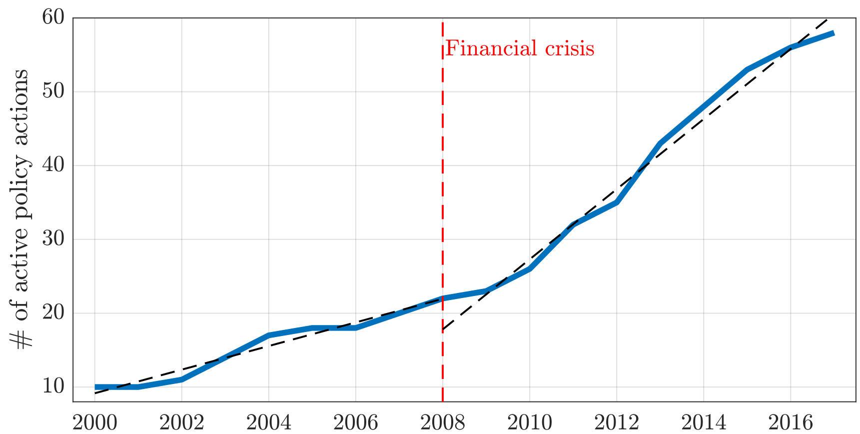

Figure 1.1: Use of the LTV ratio as a tool over time

Notes: The solid blue line shows the number of policy actions in each year, including introduction, tightening or loosening, across 160 countries for real estate transactions, sourced from the 2018 update of Cerutti et al. (2017). The red dashed vertical line denotes the financial crisis of 2008, while the dashed black lines denote pre- and post-financial crisis trends.

1.2 Policy before theory and the eventual catch-up

The implementation of macroprudential policies seems to pre-date any rigorous theoretical framework. The term 'macroprudential' started to be used in the 1970s at the Bank for International Settlements (BIS) *"to denote a systemic or system-wide orientation of regulatory and supervisory frameworks and the link to the macroeconomy"* (Borio, 2009, p.32). Another account attributes this term to David Holland from the Bank of England in 1979 (Turner, 2018). Regardless of who coined the term, it became synonymous with the BIS in the early 2000s. This term gained so much traction since then that in 2009 it prompted Claudio Borio, at the time Head of Research and Policy Analysis at the BIS, to declare that *"we are all macroprudentialists now"*, despite the fact that a decade prior the term was barely used in policy discussions (Borio, 2009, p.32).[6] Despite

[6] See Kenç (2016) and Brunnermeier and Schnabel (2016) for an early account of the macroprudential policy histories of several countries, and Kelber and Monnet (2014) for the early European experience. Monnet (2014) discusses a number of 'quantitative controls' in France from after the second world war up to the late 1970s.

this progress, in 2012 Charlie Bean, then Deputy Governor for Monetary Policy, compared the Bank of England's macroprudential development stage to the 'Stone Age' relative to its experience wih monetary policy, and called for academia to assist in this regard (Bean, 2012). In the working paper version of Angelini et al. (2014), issued in 2011, the authors describe the modelling of macroprudential policy objectives and instruments as *"uncharted territory"* (Angelini et al., 2011, p.7).

1.2.1 The macroprudential loss function

As Barwell (2018) argues, a discussion on the objectives and targets implies that the policymaker minimizes a defined loss function. Without this, it is not clear how macroprudential policymakers can take objective decisions.[7] Furthermore, it is not clear how policymakers can be held accountable for their actions if the objectives and targets are at best only vaguely defined. For instance, monetary policymakers are said to minimize a quadratic loss function that is rising in the deviation of inflation and the output gap or unemployment from some defined targets (Woodford, 2003; Walsh, 2017). On the other hand, there is no clear objective function that corresponds to macroprudential policy. This could in part be due to a lack of agreement on the main, 'irreducible' set of financial frictions that a model for macroprudential policy should include, and therefore, address (Barwell, 2018). In turn, this uncertainty reflects the significantly more complicated channels that are switched off when a number of simplifying assumptions have to be made to keep a model tractable and an approximate solution to it reliable.[8]

Nevertheless, this has not stopped some economists from proposing a candidate loss function for their model policymaker. For instance, Angelini et al. (2014) propose a loss function with the (asymptotic) variances of the credit-to-GDP ratio ($\sigma^2_{B/Y}$), output (σ^2_Y) and the policy tool (in their

[7] See Haldane (2017) and the references therein for a discussion.

[8] The predominant approach to solving such models in the literature is based on linear approximations of the model's policy functions around the stochastic steady state. Besides restricting the analysis to the neighbourhood of the steady state, such solutions miss potentially important non-linearities such as occasionally binding constraints. Mendicino (2012) and Lambertini et al. (2013b) introduce smoothness in the policy function by using a barrier method through the introduction of a penalty function that is continuous and differentiable into the utility function of borrowers. This allows them to study the nature of a slack borrowing constraint indirectly by introducing a cost term that rises fast when the debt limit is exceeded, discouraging borrowers from taking on more debt. Guerrieri and Iacoviello (2015) and Holden (2016) propose algorithms that can capture some of these non-linearities in other ways; see Grodecka (2020), Guerrieri and Iacoviello (2017), Holden et al. (2020), Rubio and Yao (2019) and Chapter 2 for such applications. Some exceptions are Boissay et al. (2016), Brunnermeier and Sannikov (2014) and He and Krishnamurthy (2019), who solve for the global non-linear dynamics of the models they use for their analysis of financial crises. However, such solution techniques can be used mainly because these models are small in the sense of having few state variables. Applying the same techniques to solve medium-scale models with many more state variables typically used in policy institutions is practically not feasible due to the curse of dimensionality. In such cases, perturbation-based approaches therefore remain dominant as they trade off the curse of dimensionality with local approximations.

paper the capital to assets ratio ν, σ_ν^2) as the arguments:

$$\mathcal{L} = \sigma_{B/Y}^2 + \kappa_{Y,mp}\sigma_Y^2 + \kappa_\nu \sigma_{\Delta\nu}^2 \tag{1.3}$$

where $\kappa_{Y,mp}$ and κ_ν are the relative weights on the volatlity of output and the capital to assets ratio. Although they admit that this loss function is ad-hoc rather than microfounded, their motivation is seemingly based on practice:[9]

> *"Modeling the objectives of macroprudential policies is not easy because systemic risk can come in various forms and environments and most macroeconomic models (including ours) have no specific proxy for it. Therefore, the choice and specification of the authority's loss function becomes a central issue and needs discussion. Ours could be described as a "revealed-preferences" approach: since the objectives of macroprudential policy are clear in theory (minimize systemic risk, enhance the resilience of the financial system) but are hard to measure in practice, we focus on the goals macroprudential authorities are actually aiming for."* (p. 1085)

The authors argue that the focus for systemic risk is the abnormal or excessive growth in credit, and therefore focus on the credit-to-GDP ratio as one key argument in the loss function. Indeed they then specify a policy rule for the time-varying capital requirement ratio that moves countercylically with the credit-to-GDP ratio, tightening banks' activity by requiring a higher capital to assets ratio as credit-to-GDP rises.[10] On the other hand, De Pauli and Paustian (2017) derive a microfounded loss function for the macroprudential authority that is quadratic in deviations of output ($\widehat{y}^g$) and credit spreads ($\widehat{f}$) from their steady-state values:

$$\mathcal{L} = \mathbb{E}_t \left\{ \sum_{i=0}^{\infty} \beta^i \left[\chi_y^{mp} \left(\widehat{y}_{t+1}^g\right)^2 + \left(\widehat{f}_{t+1}\right)^2 \right] \right\}. \tag{1.4}$$

Credit spreads result from the distortion induced from banks' moral hazard arising from costly enforcement. Rubio and Yao (2019) derive a welfare-based loss function as a second-order approximation of the social welfare function:

$$\mathcal{L} \simeq -\frac{1}{2} \left[\text{Var}(\widehat{y}) + \lambda_\pi \text{Var}(\widehat{\pi}) + \lambda_c \text{Var}(\widehat{c}) + \lambda_h \text{Var}(\widehat{h}) \right] \tag{1.5}$$

which is a function of the volatility in the output gap, the deviation of inflation from its steady state value, and the gap between borrowers' and savers' consumption ($\widehat{c}$) and housing ($\widehat{h}$), with relative policy weights $\lambda_\pi, \lambda_c, \lambda_h$. The last two terms highlight the welfare losses associated with

[9] See also the discussion in Paez-Farrell (2014) and Wieland and Wolters (2013) on the use of ad hoc loss functions in analysis of policy.

[10] See Gelain and Ilbas (2017) for a similar macroprudential loss function.

the financial friction in the model, arising from the collateral constraint. Ferrero et al. (2018) derive a similar loss function which also includes the variance of bank capital requirements as an argument. The inclusion of these additional arguments highlights the fact that, as discussed above, loss functions are conditional on the model the policymaker has in mind, which in turn must capture an irreducible set of financial frictions.

More recently, Carney (2020) characterises the loss function of Bank of England's Financial Policy Committee (FPC) as having the 'GDP at risk' ($G@R$) – the potential fall in GDP brought about by financial instability – and the central GDP forecast (y), given by potential output growth, up to horizon $i = 0...T$, as arguments:

$$\mathcal{L} \equiv \mathbb{E}_t \left\{ \sum_{i=0}^{T} \beta^i \left[f(G@R_{t+i}) - \phi y_{t+i} \right] \right\}. \tag{1.6}$$

These two arguments reflect the primary and secondary objectives of the FPC's mandate, respectively. The concept of the GDP at risk emphasizes the lower tail of the distribution of GDP growth (lower 5$^{\text{th}}$ percentile 'tail risks'), and is discussed in Adrian et al. (2019).[11] The function $f(G@R_{t+i})$ captures the social cost of financial instability and is convex and increasing in $G@R$ ($f'(G@R) > 0$ and $f''(G@R) \geq 0$). Because of this, the loss function is asymmetric, as an increase in the GDP-at-risk induces a bigger change in loss than a reduction. The parameter $\phi > 0$ captures the trade-off between gains from increasing financial stability and potentially slower output growth. When GDP-at-risk is high, the macroprudential authority likely sets ϕ to a low number, assigning more weight to the primary objective of reducing the potential losses in output from a crisis.

Loss functions (1.3), (1.4), (1.5) and (1.6) are similar to the extent that they all include an output stabilization objective. However, the presence of other, different arguments highlights the potential ambiguity of macroprudential policy objectives. These ambiguities are the result of the varied forms of financial frictions that policymakers may want to address.[12] Indeed, some authors prefer not to specify an ad-hoc loss function at all but instead calibrate the parameters of an macroprudential LTV response function such that the policy maximises social welfare based on the utility of households.[13] For example, Lambertini et al. (2013b) and Rubio and Carrasco-Gallego (2014) look at the welfare gains experienced by saver and borrower households separately on the basis of optimized LTV policy rules. I discuss these rules next.

[11] This concept is akin to the Value-at-Risk (VaR) measure in finance.

[12] Furthermore, loss function (1.6) highlights an additional complication since the GDP-at-risk metric is not observable and in practice needs to be estimated somehow.

[13] In Chapter 2 I use a macroprudential loss function similar to (1.3), but without output volatility as an argument, to calibrate the optimal response parameter in an LTV policy rule.

1.2.2 Policy tools in macro-financial models

Not long ago, the maximum LTV ratio m was not considered a policy tool in some models but rather played the role of a reduced-form 'credit shock'. For instance, in Gerali et al. (2010) the LTV ratio for impatient households (and entrepreneurs) follows a persistent AR(1) stochastic process around the steady-state value $\overline{\mathsf{m}}$:

$$\mathsf{m}_t = \rho \mathsf{m}_{t-1} + (1-\rho)\overline{\mathsf{m}} + \varepsilon_t \tag{1.7}$$

where $\varepsilon \sim N(0, \sigma^2)$ are i.i.d shocks. In their model, shocks to the LTV ratio represent a subset of the shocks that affect the *"supply side of credit [...] that capture an exogenous decrease in loans availability"* (p. 117). A similar interpretation is given to the LTV ratio in the credit constraint faced by entrepreneurs in Liu et al. (2013). In their model, an LTV ratio shock is labelled as a *"... "collateral shock" that reflects the tightness of the credit market related to financial regulations or financial innovations"* (p.1156). Both these models introduce the friction via the collateral constraint as in Kiyotaki and Moore (1997). However, Quadrini (2011) argues that shocks to collateral or more generally shocks to enforcement constraints appear in different forms across the literature but all have similar effects on the economy.[14] The stochastic process is estimated in both these models using system estimation based on a Bayesian Metropolis Hastings Monte Carlo Markov Chain approach. In both studies, the estimated quarterly AR(1) parameter ρ for each stochastic process is very high, ranging from 0.894 for firms in Gerali et al. (2010) to 0.98 for entreprenuers in Liu et al. (2013). These results highlight the highly persistent nature of changes to the LTV ratio or leverage and the implied slow return to the steady state value following such a credit shock.

In both of these studies the credit shocks contribute to a significant share of the fluctuations of key macroeconomic variables. Gerali et al. (2010) find that shocks to euro area firms' borrowing limits were behind the expansion in investment a few years before the financial crisis of 2008. Similarly, Liu et al. (2013) show that the collateral shock accounts for about 10-15% of the fluctuations in investment, output and labour hours. Since these studies use data that just include the crisis of 2008, they do not feature any discussion on macroprudential policy and only ascribe shocks to the LTV ratio as reflecting changes to regulation as one possible structural interpretation.[15] The take-away from this discussion is the fact that, in advanced economies in particular, the LTV ratio as a policy tool is a very recent concept.[16]

[14] Some studies use the costly state verification framework in business cycle models (Bernanke and Gertler, 1989; Bernanke et al., 1999) and study shocks to the cross-sectional variation of the efficiency of entrepreneurial capital, such as Christiano et al. (2014). This makes investments riskier and affects entrepreneurs' net worth and borrowing conditions, and therefore acts in a way that is similar to the collateral constraint (Quadrini, 2011).

[15] In Gerali et al. (2010) banks are also subject to capital requirements but these are exogenous and fixed over the business cycle.

[16] Although published in 2010 and 2013 respectively, periods in which the debate on such policies had already taken off, the first versions of these papers were written in 2008 and 2009 respectively.

One of the first studies to consider the role of active LTV ratio policy is Angelini et al. (2011).[17] The authors use the model of Gerali et al. (2010) to study the role of active macroprudential policy rules based on either the capital to assets ratio or the LTV ratio, in conjuction with monetary policy. They specify a policy rule that moves the LTV ratio against an indicator of economic activity:

$$\mathsf{m}_t = \rho \mathsf{m}_{t-1} + (1-\rho)\overline{\mathsf{m}} + (1-\rho)\gamma X_t \tag{1.8}$$

where γ is the reaction parameter that maps movements in X to changes to the LTV ratio.[18] Since a higher LTV ratio raises the borrowing limit, a countercyclical policy stance requires $\gamma < 0$. Note that the LTV ratio is deterministic when described by a policy rule, and therefore is fundamentally different from a stochastic process as in (1.7). As a result, the interpretation of the persistence parameter ρ is such that it now reflects policymakers' aversion to large movements in m_t between any two periods, a feature borrowed from the celebrated 'Taylor rule' that captures the behaviour of monetary policy and determines interest rate movements. In their benchmark settings the authors use real house price growth as the macroeconomic indicator. They justify this on the basis that house prices are behind the collateral effects in the first place and it is the variable that policymakers seem to have in mind, and optimise the parameters of this rule which minimise the loss function (1.3) discussed above. They show that in the case of a housing demand shock that raises house prices and credit, a macroprudential policy rule such as (1.8) leads to lower loss brought about from higher stabilization of the credit-to-ouput ratio.[19]

Mendicino (2012) is also amongst the first to study countercyclical LTV ratio rules. She specifies a policy rule akin to (1.8) but sets credit growth instead of house price growth as the indicator variable. She finds that a time-varying LTV ratio is welfare improving compared to one that is fixed, since the rule reduces the volatility of the credit-to-output ratio and of other macroeconomic variables. The effect on social welfare is rising and monotonic in the response parameter γ.[20] Another early study with active LTV ratio policy is Lambertini et al. (2013b). The authors add news shocks to the model of Iacoviello and Neri (2010) and use it to study the implications of using countercyclical policy to tame housing boom-bust cycles. They also specify a 'Taylor-type' policy

[17] Christensen and Meh (2011) also propose an active countercylical LTV rule. I explore and build on a similar rule in Chapter 2.

[18] Throughout this section, whenever possible, I convert authors' different notation into the same notation across the different rules.

[19] Other types of macroprudential tools used to reach the same objectives have been explored in the literature. To name a few, Angelini et al. (2014), Kannan et al. (2012) and Rubio and Carrasco-Gallego (2016b) consider a bank capital requirement ratio that affects lending rates such that it dampens credit growth, while Korinek and Simsek (2016) show that an insurance subsidy for borrowers can mitigate the drop in aggregate demand following a shock, since borrowers have a high MPC. Bianchi and Mendoza (2010) and Funke and Paetz (2018) study the use of macroprudential taxes. A more detailed discussion of all of these is however outside the scope of this work.

[20] The author reports an optimal LTV rule with a very high γ but with an smooting parameter $\rho = 0$. This rule therefore is likely to lead to very volatile LTV ratios over time, which in practice is unlikely to be the case.

rule that moves the LTV ratio against an indicator of economic activity as in (1.8).[21] The authors consider changes in credit (Δb_t), house prices (Δq_t) and GDP (ΔGDP_t) as the policy-relevant indicators, $X_t = \{\Delta b_t, \Delta q_t, \Delta GDP_t\}$ and look for the values of γ and ρ that in each case maximise social welfare. They show that a time-varying LTV ratio improves social welfare compared to a fixed LTV ratio, making the case for active countercylical LTV ratio policy. Moreover, the policy rule that is based on credit growth delivers the best stabilization in their model in terms of the credit-to-GDP ratio and GDP.[22]

Of course, a feedback rule like (1.8) is an approximation of the behaviour of policy makers, as revisions to the LTV ratio are in practice likely to be discrete and at irregular intervals rather than smooth and continuous. Funke and Paetz (2018) argue that in practice, early warning indicators are likely to be noisy and may not always necessarily flag a bad boom. Consequently, policymakers may be hesistant to revise LTV ratios immediately. Their motivation is the use of LTV ratios in Hong Kong to control booms in property markets that may lead to bubbles and their eventual bursting. To capture this behaviour, they propose a non-linear threshold rule that only lowers the LTV ratio when a relevant indicator of financial stability breaches a threshold:

$$\mathsf{m}_t = \overline{\mathsf{m}} + \gamma \left((X_t - \overline{X}) - \widetilde{X} \right)^+ \tag{1.9}$$

where $\gamma < 0$, $\widetilde{X}$ is the threshold and the term within the large brackets is positive when the threshold is breached.[23,24] When they set the threshold to a 5% quarterly house price inflation, they find that this rule is more effective in reducing house price inflation compared to a linear Taylor-type LTV rule as (1.8).[25]

The LTV as a policy tool has also been studied in the context of the euro area, where in the model monetary policy is implemented supranationally but macroprudential policy is the prerogative of each nation state. Rubio and Carrasco-Gallego (2016a) show that a country within the euro area stands to gain when other countries except itself implement a countercyclical macroprudential LTV policy in the wake of shocks. Yet, the country and the area as a whole benefit more when all countries coordinate on the implementation of such policies. Burlon et al. (2018) consider how countercyclical LTV policy operated at the country level would fare during a housing boom in the

[21] The authors highlight that in practice macroprudential authories are likely to implement LTV policies in conjuction with other tools, such as LTI restrictions.

[22] The authors show that embedded within this conclusion is the heterogeneous impact of these policies on different household types. In their model, borrowers favour the use of the LTV rule and a monetary policy rule that reacts to inflation and output growth, whereas savers prefer a constant LTV policy but monetary policy that also reacts to credit growth.

[23] The actual specification in their paper is slightly more complicated as it adjusts the threshold such that, once breached, the LTV is not raised further in every subsequent period in which X_t remains above the initial threshold.

[24] In Chapter 2 I explore the implications of such policymaking asymmetry in the use of the LTV ratio.

[25] However, they also show that a similar threshold rule applied to a property transfer tax on the value of housing instead is in fact more effective than the threshold LTV rule.

context of the ECB's non-standard monetary measures through its Asset Purchase Programme. They show that using a rule like (1.8), where the indicator X_t is the credit-to-GDP ratio, would play an important stabilization role if a country experiences a housing bubble, and would prevent the need for the ECB to scale back on the non-standard monetary intervention that is needed in other countries in the euro area.

Several authors have also explored the potential merit for cooperation between monetary and macroprudential policy, where the latter can use different tools. Angelini et al. (2014) show that the best outcome in terms of stabilization obtains when the monetary and macroprudential authorities cooperate by choosing the parameters in the separate interest rate and LTV ratio rules such that they minimise the sum of the losses of both the central bank and the macroprudential authority. Similar results are found by Rubio and Carrasco-Gallego (2014), while Kannan et al. (2012) and Quint and Rabanal (2014) show that this obtains mainly when the economy is hit by financial or housing demand and risk shocks, respectively. Moreover, De Pauli and Paustian (2017) show that even when the two authorities do not cooperate, similar welfare gains can be achieved if the macroprudential authority 'leads' by taking into account the effect of its policy on that of the monetary authority. As the authors argue, this is encouraging since a macroprudential policy stance is likely revised less frequently than a monetary policy stance, and is likely to take into account the environment in which it is operating and how it will affect future monetary policy decisions. In fact, stress tests typically look at the effect of a rise in the interest rate on the ability of households to honour higher payments in the case of variable-rate mortgages; see Karasulu (2008) and Giordana and Ziegelmeyer (2020) for such exercises in Korea and Luxembourg respectively. In sum, macroprudential policy tools – such as the LTV ratio – have inherited in macro-financial models the feedback structure of the Taylor rule used in monetary policy, with credit being the most popular reference indicator.

1.2.3 Implementation in practice: which indicator?

Having defined the objectives, goals and instruments of macroprudential policy, as well as approximate macroprudential rules, I now turn to the issue of which indicators of systemic risk are useful for the implementation of such rules in practice. The literature proposing countercyclical LTV rules surveyed in the previous section agrees on a small set of key observables that can indicate credit and real estate market overheating, namely credit and house price growth, and movements in the credit-to-GDP ratio. The latter is said to capture abnormal growth in credit; credit growth that is likely above fundamental growth, the latter proxied by GDP growth (Angelini et al., 2014). Indeed, the Basel III countercylical capital buffer is operated using a measure of the credit gap based on a one-sided Hodrick-Prescott (HP) filtered credit-to-GDP ratio, henceforth the 'Basel gap' (Basel

Committee, 2010).[26] This fact in itself already seemingly settles the debate on how to measure gaps, advocating a method that is easy to use and, importantly, communicate. However, the literature and some policy institutions have explored different indicators.

Schularick and Taylor (2012) show that a simpler metric – credit growth – is in itself a very good predictor of the likelihood of a financial crisis. Using a logit model on the probability of a financial crisis for a panel of 12 advanced economies, they find that up to five annual lags of credit growth are jointly significant in explaining an increased probability of a financial crisis. Their benchmark model delivers an Area Under the Receiver Operating Characteristic (AUROC) of 0.717, which confirms the model's predictive success in terms of frequently signalling a true positive of a higher probability of a financial crisis.[27] They show that these features are also present in out-of-sample forecasting exercises, which is what policymakers care about when monitoring systemic risk. Schularick and Taylor (2012) also show that in the postwar period credit and broad monetary aggregates became delinked, and that it is credit, not money, that is a useful indicator of systemic risk. Indeed they state (p. 1051): "*. . . if financial stability is a goal, then our results suggest that a better* [policy] *pillar might make use of credit aggregates instead, and their superior power in predicting incipient crises.*". These results support the narrative that high economy-wide leverage is the single most important predictor of financial crisis across many countries (Borio and Lowe, 2002; Jordà et al., 2016).

However, macroprudential authorities typically do not restrict their attention to a single indicator, but adopt an array of indicators which could signal rising risk-taking, market exuberance and unsustainable behaviour. Indeed, the ECB adopts a cyclical risk scoreboard that consists of 6 such indicators featuring 2 to 3-year changes in the credit-to GDP ratio, the house price to income ratio, total real credit, equity prices, the debt servicing ratio and the current account balance (Constâncio et al., 2019, p.51). The emphasis on 2 to 3-year changes illustrates the fact that high frequency changes carry a low signal to noise ratio, and are therefore not informative early warning indicators. Moreover, the ECB also maintains another scoreboard related specifically to the residential real estate sector, which includes an array of indicators for house prices (4), household credit (3) and household balance sheets (3). In this context, policymakers are more likely to act if a 'dashboard' of indicators 'lights up' at once than if just one or two indicators signal strong activity in a given sector, including the housing market.

Nevertheless, these indicators remain statistical measures. Consequently, they are largely void of any structural interpretation and, in addition, can be vulnerable to shortcomings of their own. For instance, the Basel gap is said to have a highly persistent trend which adjusts very slowly, biasing the gap downwards after a credit boom (Lang and Welz, 2017). This is because high credit

[26] This gap was first proposed by Borio and Lowe (2002). The recommended smoothing parameter λ is set to 400,000 for quarterly data. See Drehmann and Tsatsaronis (2014) and Wezel (2019) for a discussion.

[27] An AUROC of 0.5 implies that a model is no better than a simple coin toss in predicting true positives, while a value of 1 obtains when a model never predicts a false positive.

growth becomes embedded within the estimated credit-to-GDP trend over time, and a subsequent correction results in a very large and negative gap. In a related point, the use of the HP filter for any economic analysis, using both one sided and two-sided versions, has been questioned since it has a number of shortcomings, including inducing spurious dynamics unrelated to the underlying economic data generating process (Hamilton, 2018; Schüler, 2020). However, Drehmann and Yetman (2018) show that historically this did not condition the signalling power of an early warning indicator like the Basel gap, at least not with respect to other statistical gap measures. Using data for up to 42 countries starting from 1980, they show that the Basel gap has signalling ability that is on par with that of gaps based on 5-year growth in the credit-to-GDP ratio and real credit per capita, with very similar AUROC scores at different forecast horizons spanning up to 3-years in advance.[28] However, when they split the sample into two (1980–1999) and (2000–2017), they find that the performance of the gap based on the 5-year growth in real credit per capita deteriorates over time, but the gaps based on the 5-year growth in credit-to-GDP and the Basel gap still perform well, with AUROCs above 0.7 at most forecasting horizons. Therefore, it remains to be seen whether the downward bias from the credit gap that arises from the HP filter – following the large negative gap that persists due to the financial crisis of 2008 – will affect the future signalling power of the Basel gap in the run up to the next crisis.

Motivated by this issue, Lang and Welz (2018) propose an interesting semi-structural gap measure that does not suffer from the downward bias embedded HP-filtered series yet has superior early warning signalling power. The approach is based on optimal credit demand from young and middle-aged low-income households derived in the model of Eggertsson et al. (2019), an overlapping generations model with young, middle-aged and old households.[29] They embed a simplified version of the equilibrium demand equation into an unobserved components state-space model that decomposes real household credit c_t into the trend c_t^* and cycle $\widehat{c}_t$ components.[30] Since the trend is modelled as a simplified version of the equilibrium credit demand relation, the authors label it a

[28] See also Aldasoro et al. (2018), who conduct a similar horse race among different indicators, including an HP filter-based property price gap, and find that the indicators with the highest AUROC scores are the credit-to-GDP gap and the debt service ratio. They also show that combining information from property prices further increases the share of crises that these two indicators correctly predict.

[29] In the model young and middle aged low-income households, which are credit constrained, borrow from high income middle-aged households who are saving for retirement.

[30] The authors show that, with a few simplifications, the equilibrium demand for real household credit is a function of population growth, income inequality, institutional quality, the share of the young age population, potential output, trend output growth, the output gap, the disposable income share in GDP and the equilibrium real interest rate. An increase in all of the variables, except for population growth and the real interest rate, generates an increase in credit. The version used in the estimation is based on real potential GDP, the equilibrium real interest rate, the share of young and middle-aged households and institutional quality. See Lang and Welz (2018) for further details.

semi-structural credit gap. The 3-equation system that they estimate is given by:

$$c_t = c_t^* + \widehat{c}_t \tag{1.10}$$

$$c_t^* = \alpha_0 + y_t^* + \gamma_t + \alpha_1 r_t^* + \alpha_2 \text{dem}_t + \epsilon_t^{c^*} \tag{1.11}$$

$$\widehat{c}_t = \beta_1 \widehat{c}_{t-1} + \beta_2 \widehat{c}_{t-2} + \epsilon_t^{\widehat{c}} \tag{1.12}$$

where y_t^* is an estimate of real potential output in logs, γ_t is a non-linear transformation of an indicator of institutional quality, r_t^* is an estimate of the equilibrium real interest rate and dem_t is the share of young and middle aged households in logs. The cyclical component is modelled as an AR(2) process and the reduced-form coefficients α, β and variances of the disturbances ϵ_t are estimated using Maximum Likelihood via the Kalman Filter.

They key advantage of this approach over statistical-based measures is that the trend is driven by fundamental factors that can be given an economic interpretation, and therefore changes in the gap $\widehat{c}_t$ can be decomposed into these underlying factors. The authors estimate the credit gaps in a number of EU countries and find financial cycles that last between 15–25 years, results in line with other estimates (Drehmann et al., 2012; Schüler et al., 2015). They also show that on average their semi-structural credit gap turns positive and increases about four years prior to a systemic financial crises, peaking close to the start of the crisis and then closing four years after. Crucially, they show that this signalling power is also present in real time estimation, and policymakers using this technique in 2004 would have predicted a positive and rising credit gap in several EU countries, ahead of the crisis of 2008. Such an indicator is therefore promising; it is based on credit, which the literature finds to be the single most informative variable, but it has a structural foundation, and therefore allows changes in the gaps to be decomposed to specific macroeconomic changes.

In conclusion, although a few decades ago macroprudential policy practice was largely ahead of theory, the latter has made considerable progress in embedding such policy in mainstream macroeconomic models and explored their usefulness. Although there are different ways of modelling policymakers' perceived objectives, the common thread is a focus on the trade-off between economic stabilization and overly-aggressive policy actions. The main indicators used in these macroeconomic models are shown to have good signalling qualities in practice.

1.3 Empirics: cross-country evidence

Does LTV ratio policy dampen credit growth and reduce the likelihood of a costly boom and bust cycle in practice? In this section I survey the abundant econometric analysis of the effectiveness of macroprudential LTV policy on credit, house prices and delinquecy rates in the literature. A general issue in regression-based approaches is endogeneity bias, since some policies can be implemented in anticipation of a rise in credit or house prices. As a result, estimated intervention effects can be weak or not statistically significant (Vandenbussche et al., 2015; Kuttner and Shim, 2016). With this caveat in mind, I turn to the key references on this topic. The studies by Wong et al. (2011), Lim et al. (2011) and Igan and Kang (2011) are amongst the earliest assessments. Wong et al. (2011) reflect on the experience of LTV ratio policy in Hong Kong and run a panel regression over 13 countries for the period 1991–2010 to test for the link between mortgage deliquency rates and the presence of LTV policy. They find that in countries with an active LTV policy, fluctuations in house prices and GDP are associated with lower changes in delinquency rates than in economies without such a policy. The differences in the estimated coefficients are statistically significant at the 10% level, but in general the results are not necessarily causal.[31] Lim et al. (2011) extend the analysis to a range of macroprudential tools used across 49 countries for the period 2000-2010. Using a panel regression they find suggestive evidence that the instruments used by countries in their sample are effective in dampening credit growth. In particular, LTV ratio restrictions are associated with a fall the procyclicality of credit with GDP of up to 80%.

Igan and Kang (2011) use household-level data for the period 2001–2009 for Korea and divide their sample into households that are similar except for whether they are treated or not treated with LTV or LTI restrictions, allowing them to infer casual effects. They find that households which were subject to LTV restrictions had lower house price expectations and reduced their demand for housing in the year following the annoucement of the measure.[32] Importantly, they show that this reduction in demand comes mainly from households who already have a residence, labelled 'speculators', and not first-time buyers. Therefore, this policy was able to tame house price growth in Korea but did not have significant detrimental effects on home ownership rates. Kuttner and Shim (2016) consider a range of non-interest rate tools, including the LTV ratio, as potential stabilizers of household credit and house prices. They find that the LTV ratio on its own is associated with lower credit growth, but when other tools are included in the estimation the coefficient is not statistically significant. On the other hand, debt service-to-income limits tend to be more important for dampening credit growth, even when other tools are controlled for. However, the authors report that LTV and debt service-to-income limits tend to be used together as policy tools, and part of the loss of significance for the LTV ratio coefficient could be due to this. The authors also report a loss of significance when data for Korea is excluded, hinting that it is the effectiveness of LTV policy in this country that may be driving any statistical significance. On the other hand, there is a weakly statistically significant relationship between LTV and house prices, but not between debt

[31] Out of 13 countries in the sample, which include Asian and European countries and the US, 4 countries have an active LTV policy in that sample period and all of these are Asian. Besides selection effects, reverse causality also cannot be ruled out. A more stable economic environment is expected, all else equal, to have lower delinquency rates than an economy which is subject to strong booms and deep recessions.

[32] LTI restrictions on the other hand are found to raise expected house price growth by households which are affected by the restriction. The authors hypothesise that the policy might give households which nevertheless still qualify for a mortgage an improved assessment of their affluence, and therefore these are willing to pay high prices for a given property.

service-to-income limits and house prices.

Cerutti et al. (2017) use the Global Macroprudential Policy Instruments survey database compiled by the IMF and document that, in 2000, 9% of countries from a sample of 119 had at least one borrower-based policy in place. This rose to 34% by 2013. The authors find that the implementation of borrower-based tools (including LTV caps) has a negative and statistically significant effect on household credit in advanced economies. Although the success or lack thereof of these policies is not conditional on which institution implements these policies, the authors document that 70% of all policy tools across the 119 countries are implemented by the central banks of these countries. Vandenbussche et al. (2015) study the use of an array of macroprudential policy tools in Central, Eastern and South Eastern European countries from the early 2000s to 2011. Several of these countries experienced strong house price growth over this period and policymakers implemented several macroprudential tools to control such excessive growth. They document that borrower-based tools such as LTV and LTI ratio limits were used only sparsely, while capital measures such as capital adequacy ratios and risk weights on housing loans, and liquidity measures such as reserve requirements where much more popular instruments. Possibly as a result of this, they find that capital and liquidity instruments were associated with slower house price and credit growth, while the borrower-based measures where not.

Morgan et al. (2019) focus on the effects of LTV policies but use bank-level credit, rather than aggregate credit measures, in an attempt to limit endogeneity and reverse casuality concerns. They find a statistically significant and negative link between the existence of an LTV policy and bank mortgage credit creation, but the effect is mainly attributed to developments in Asian economies as the coefficient on bank credit in advanced economies is not significant.[33] This is because very few advanced economies had used the policy up until 2013. In their prefered linear specfication, the authors report an LTV dummy coefficient of -5.9%, which is the average over all countries in the sample. Nevertheless, the authors do not establish a causal link. When they allow for interactions of the LTV cap with bank characteristics, they find a lower LTV slope coefficient for larger banks or banks with a higher share of non-performing loans, a result also driven by banks that are not in advanced economies.[34] The authors suggest that bigger banks may already practice similar LTV thresholds before the policy is implemented, and are therefore largely unaffected by it. Akinci and Olmstead-Rumsey (2018) combine data from multiple sources to study the use and resulting effects of macroprudential policy tools across a wide range of countries. They confirm the notion that macroprudential policy frameworks were set up in various countries after the global financial crisis, especially in advanced economies, mainly targeting the housing market. LTV caps were present in

[33] See also Claessens et al. (2013) for analysis of the effects of macroprudential policy tools on bank-level measures of risk, and Zhang and Zoli (2016) for an analysis of housing related policies and their effects on bank credit, house prices and capital inflows in Asia.

[34] A loan is classified as non-performing when a borrower fails to make the regular payments, typically over more than 90 days.

more than half of the 57 countries in their sample over the period 2000–2013, ranking this as the most popular tool. However, it is also likely used in conjuction with debt service-to-income limits, which add another potentially binding constraint on households.[35] They find that macroprudential policy implementation is associated with lower household credit growth, driven mainly by policies targeted specifically at households.

In an important contribution, Alam et al. (2019) build on previous research by amalgamating several macroprudential policy databases into one, called iMaPP. Using qualitative dummies that indicate policy tightening or loosening, they confirm as causal the findings of Cerutti et al. (2017) and Kuttner and Shim (2016) that demand-side tools such as LTV and debt service-to-income tightening has a strong effect on credit but weak effects on house prices. They argue that the common identifying restriction that is based on a timing assumption (that policy does not affect macroeconomic variables within the same quarter) is a strong assumption which leads to attenuation bias if invalid. Moreover, they add a quantitative measure based on the average LTV in a country at a point in time to iMaPP. Using this measure together with an inverse propensity-score weighted estimator as in Richter et al. (2019), they find stronger effects of policy, confirming the attenuation bias hypothesis. They estimate that a typical LTV tightening – a drop of up to 10 percentage points – lowers credit growth by 0.65 percentage points for every 1 LTV percentage point reduction. The fixed effects estimate is lower at 0.43 and is not statistically significant. They also find evidence for non-linearities; the elasticity on credit growth is lower when the LTV is dropped by between 10 and 25 percentage points.[36] In addition, they find a statistically significant side-effect of macroprudential policy in the form of lower consumption growth, although there is no strong evidence of non-linearities in this regard.

Finally, it is important to consider the consequences of using macroprudential policies on economic growth. To this end, Richter et al. (2019) study the side-effects of LTV policies on output and inflation. They address exogeneity concerns using a narrative identification approach, and show that LTV policies tend to be unrelated to the state of the real cycle. Additionally, they depart from a simple LTV indicator dummy approach that is commonly used in the literature and build an intensity-adjusted variable that is able to distinguish between small and large policy actions. Using local projections they find the effects of LTV policies in general to be weak on inflation and output in advanced economies.[37] In emerging economies the policy leads to a statistically significant fall in output in the first two years, likely due to some misallocation of credit induced by the policy. This is in line with Kim and Mehrotra (2018), who find that a range of macroprudential policies in Asian economies tend to reduce output and inflation. Richter et al. (2019) also show the same policy is effective in reducing mortgage credit and has a dampening effect on house prices that

[35] See Grodecka (2020) for an analysis of the implications of multiple constraints on macroeconomic outcomes.

[36] Although the fixed effect estimate also yields the same qualitative result, the estimate is also lower in absolute terms and not statistically significant.

[37] The results are also not statistically significant for output from a 1-quarter to a 16-quarter horizon.

is significant two years following the implementation and which becomes stronger by the fourth year. They express these as causal effects by using inverse propensity-score weights to assign more importance to LTV policies that are less predictable.

Summing up, the general finding is cautiously optimistic that the LTV ratio seems to be an effective tool in curbing excessive credit growth in some countries but not in others. These differences can be due to several reasons, including difficulty in measuring the intensity of the LTV restriction, not accounting for non-linearities, country specificities and policymakers not focusing on the LTV ratio as a primary tool in the first place. Moreover, few studies can claim causality flowing from LTV tightening to a slowdown in credit growth. On the other hand, and as discussed above, non-statistically significant results could be due to endogeneity bias, since some policies might have been implemented ahead of the peak rise in the dependent variable, leading to lower estimated intervention effects. Non-statistically significant results could also be due to short samples, since many non-Asian countries only introduced LTV limits relatively recently. Little variation in LTV policy actions make it hard to estimate coefficients with precision. This could explain why LTV policies appear to be significant primarily in Asian countries, which have a much longer experience with this tool. Therefore, there is up to now suggestive evidence that LTV ratio limits can be effective in curbing a credit boom, but the policy is likely to be successful if it is used together with other instruments, such as debt service-to-income limits.

1.4 Country case studies

While cross-country panel studies can shed light on the general effectiveness of a policy, they miss interesting qualitative factors that lie behind the implementation and communication of such a policy. To capture some of these factors, I focus on the recent experience of New Zealand and Ireland.[38] Both of these countries introduced LTV ratio limits as part of their recent macroprudential policy framework, during a period of high house price growth. New Zealand has a small open economy with both monetary and macroprudential policy tools at its disposal. Given that it was the first country to adopt formal inflation targeting in 1990 (McDermott et al., 2018), and is known for its transparent policy communication, it is interesting to assess how it implemented its macroprudential policy framework too. I then study the case of Ireland, a small open economy in the euro area that does not have independent monetary policy. Ireland, previously referred to as the 'Celtic tiger', experienced a severe house price and credit boom-bust cycle along the great financial crisis.

[38] Even though countries like Korea and Hong Kong have long been using LTV ratio policies, they are well surveyed in the literature. See Craig and Hua (2011) and Wong et al. (2011) for a discussion on the experience of Hong Kong, and Akinci and Olmstead-Rumsey (2018) and Igan and Kang (2011) for a survey of the case of Korea.

1.4.1 New Zealand

The Reserve Bank of New Zealand (RBNZ) introduced its macroprudential policy framework in 2013, when the property market in New Zealand was running hot but inflation was low (see Figure 1.2).[39] This meant that even if it wanted to, the RBNZ could not use monetary policy to tame the credit and property price boom. The process began in March 2013, when the RBNZ ran a public consultation, replying to submissions on the consultation paper a few months later in May. It then signed a memorandum of understanding (MoU) with the Minister of Finance which formalized the objective, instruments and decision-making body. The objective is *"to increase the resilience of the domestic financial system and counter instability in the domestic financial system arising from credit, asset price or liquidity shocks"* (Reserve Bank of New Zealand, 2013a, p.2). The framework featured four policy instruments, namely the countercyclical capital buffer, a minimum core funding ratio, sectoral capital requirements and LTV restrictions. In August 2013, the RBNZ formally announced to the public its intention to introduce the LTV restrictions in October 2013.

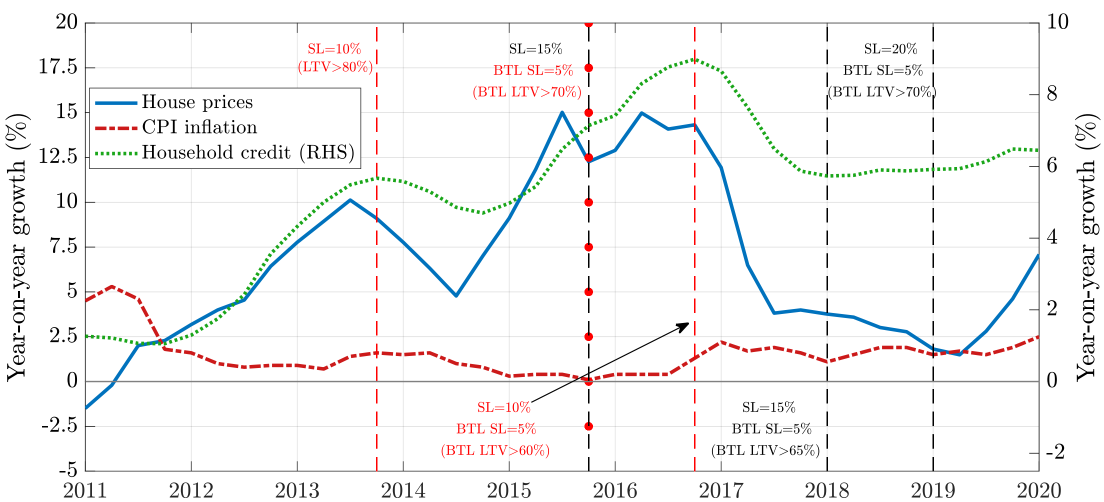

Figure 1.2: House prices, household credit and LTV policy actions in New Zealand

Notes: SL – Speed Limit, BTL – Buy To Let. The label on the x-axis denotes the first quarter of the year. Text and lines in red denote policy tightening, while black text and lines denote policy loosening. The red dots along the black line towards the end of 2015 denote the tightening with respect to buy-to-let loans in Auckland. Data sources: Statistics New Zealand (house prices and inflation) and Reserve Bank of New Zealand (household credit).

Instead of imposing a maximum LTV limit across the board, the RBNZ adopted a so-called 'speed limit' approach, in which banks can issue a small fixed share of new loans at an LTV greater than a given maximum (Hargreaves, 2016). Therefore, although this policy set the maximum LTV

[39] The RBNZ aims to keep inflation at between 1%-3%, with a mid-point target of 2% in the medium term.

ratio for house loans at 80%, it allowed banks the possibility to write up to 10% of new loans at a higher LTV ratio.[40] This allows banks to extend mortgages at a higher LTV to borrowers who can comfortably service repayments, such as first time buyers (Rogers, 2014). Furthermore, it exempted from the LTV restrictions houses built after the initial implementation, such that the policy did not discourage housing supply (Armstrong et al., 2019).[41] The RBNZ states that it does not stick to any formal policy rules to re-assess the thresholds. Instead, it opts for 'guided discretion' by looking at several indicators and publishing these considerations in its Financial Stability Reports (Rogers, 2014, p.7). In its effort to guide the public, it pledges to provide a minimum notice period of 2 weeks for any changes to the LTV conditions. However, it has historically announced intended policy stances several months in advance.[42]

The RBNZ has revised the LTV restrictions several times since 2013, most of the time altering the speed limit of a particular loan type or lowering the LTV for buy-to-let loans, but it has never raised the benchmark LTV above 80%; see Table 1.1.[43] The first action it took was in October 2015, when it relaxed the speed limit to 15% for mortgages across all cities except for Auckland, which was rather uniquely experiencing strong house price and credit growth. At this point, house prices in Auckland reached about 9 times average income, and were growing at about 25% annually (Hargreaves, 2016). Furthermore, the RBNZ introduced lower limits for buy-to-let loans at 70% for properties in Auckland and reduced the speed limit for this loan class to 5%.[44] In this period investors were seeking high returns from housing given the low interest rate environment that prevailed, and property in Auckland was considered a lucrative investment. This two-tier system of LTV ratio restrictions highlights the flexibility of the LTV ratio in comparison with the interest rate, which cannot in general be applied regionally. Nevertheless, this marked a departure from initial plans to not target *"particular borrower segments, such as investors, or regions such as Auckand"* (Rogers, 2014, p.6), on concerns that such targeting raises the potential for circumvention or does not address an integral part of high LTV loans, such as those by first time buyers.

With house prices and credit growth showing no signs of slowing down, the bank tightened the speed limit for all residential mortgage loans again to 10% in October 2016, and reduced the

[40] Banks have to abide by relevant conditions of registration which prevent them from circumventing the policy by, for example, issuing a second mortgage to the same borrower, or having a second bank providing a top-up for borrowers who are at the limit.

[41] It also exempted loans that form part of Housing New Zealand's Mortgage Insurance Scheme and similar programs, since these are regarded as posing little risk to financial stability as any bank losses are guaranteed by Housing New Zealand (Reserve Bank of New Zealand, 2013a).

[42] This has the potential to weaken the effectiveness of policy by allowing enough time for front-loading of house purchases before tighter measures are in effect. However, this did not seem to have taken place in New Zealand (Bank of England, 2014)

[43] A full history is given at `https://www.rbnz.govt.nz/regulation-and-supervision/banks/macro-prudential-policy/loan-to-valuation-ratio-restrictions`.

[44] See Lu (2019, p.7) for a detailed description of LTV restrictions around this time.

Table 1.1: Recent LTV ratio history in New Zealand

Announcement	**Effective**	**Policy measure**
August 2013	October 2013	LTV of 80% with a 10% SL
May 2015	October 2015	LTV of 80% with a SL increased to 15% outside Auckland Buy-to-let loans LTV at 70% with a 5% SL in Auckland
July 2016	October 2016	LTV of 80% with a SL reduced to 10% Buy-to-let loans LTV reduced to 60%, unchanged SL
November 2017	January 2018	LTV of 80% with a SL increased to 15% Buy-to-let loans LTV increased to 65%, unchanged SL
November 2018	January 2019	LTV of 80% with a SL increased to 20% Buy-to-let loans LTV increased to 70%, unchanged SL
April 2020	May 2020	All limits relaxed

Notes: The policy tightening that was announced in July 2016 was initially targeted for September 2016 but was then deferred to October on the request of banks. Source: Reserve Bank of New Zealand

maximum LTV ratio for buy-to-let loans further to 60% at the same speed limit of 5%.[45] This second round of tightening seems to have been successful at taming activity in the housing market, as average house price growth fell to less than 5% and credit growth also slowed down to about 6% within a year. Indeed, in November 2017 the RBNZ announced that it would relax policy effective from January 2018, increasing the speed limit again to 15% and allowing an LTV of up to 65% for buy-to-let loans. Following further signals that the housing market had settled to more sustainable levels, the bank further eased policy again a year later, raising the speed limit to 20% and allowing a buy-to-let LTV ratio of up to 70%. More recently, the RBNZ relaxed all LTV ratio restrictions on account of the expected economic downturn caused by the COVID-19 shock, even though house price growth had started to edge up again.[46] The policy stance will be assessed again in the beginning of the second quarter of 2021.

The RBNZ has described its experience so far with this borrower based macroprudential policy as a *"qualified success"* (Spencer, 2018, p.4). It estimates that its LTV ratio policy has significantly improved the resilience of the banking system in New Zealand, reducing the share of high LTV ratio

[45] The speed limit on the buy-to-let category was kept at 5% until 2020.

[46] Due to the severity of the situation, the RNBZ announced its intention to relax all measures on 21 April 2020 and allowed only 7 days for feedback from stakeholders. Indeed, it implemented the relaxation effective from 1 May 2020. See https://www.rbnz.govt.nz/news/2020/04/reserve-bank-removes-lvr-restrictions-for-12-months.

mortgages, especially in the base of buy-to-let loans, and therefore reducing the 'stressed' default rate (Bloor and Lu, 2019). Price et al. (2014) uses a VAR to estimate that the introduction of the LTV restrictions in October 2013 led to a reduction in house price and credit growth of 3.3% and 0.9% respectively by March 2014. Using an estimated DSGE model of the New Zealand economy, Funke et al. (2018) estimate that the introduction of the LTV policy in 2013 led to a 3.8% drop in house price growth, close to the estimate from the VAR model. Yao and Lu (2020) estimate that the LTV policy has been associated with an average reduction in loan growth of 2 percentage points in the 6 months that follow, and this reduction comes mainly from banks that are small or have less stable funding. Armstrong et al. (2019) identify the causal effect of this LTV policy using the fact that, as discussed above, newly-built houses were exempt from the restrictions. Using such houses as controls, they find that the introduction of the policy in 2013 led to a reduction in house price growth of 2.4% in the first six months, after which it weakens to about 1.5% at twelve months. The relaxation of policy in October 2015 in all regions except Auckland led to a recovery in house prices of 2.6%, while the tightening of restrictions in Auckland did not have any statistically significant effect on prices. On the other hand, the further LTV tightening of October 2016 reduced house prices by 3.1% in Auckland, and by 2.2% elsewhere.

1.4.2 Ireland

In Ireland the Central Bank of Ireland is the national macroprudential authority, and is the designated national authority in charge of macroprudential policy implementation as per the Capital Requriements Regulation and Capital Requirements Directive (CRR/CRD IV) (Central Bank of Ireland, 2014).[47,48] The Central Bank of Ireland has independence in the use of macroprudential tools but cooperates with the ECB for any broad macroprudential measures that need to be carried out and also has MoUs with other institutions, such as the Department of Finance.[49] The objectives of its macroprudential framework are "*to mitigate the risk of a disruption to the provision of financial services, caused by an impairement of all or parts of the financial system with serious negative consequences for the real economy*" (Central Bank of Ireland, 2014, p.2).[50] A more concrete understanding is defined through intermediate objectives, which includes preventing excessive credit growth and leverage amongst others. Borrower-based instruments are the tools allocated

[47] CRR/CRD IV was trasnposed via Regulation (EU) no. 575/2013 on prudential requirements for credit institutions and investment firms (CRR), and Directive 2013/36/EU on access to the activity of credit institutions and the prudential supervision of credit institutions and investment firms. These transpose the Basel III agreement into EU law.

[48] See Rubio (2017) for a discussion of the issues related to macroprudential policy implementation in the euro area as a monetary union.

[49] The European Systemic Risk Board, which has oversight at the EU level, can issue recommendations to EU Member States. The Single Supervisory Mechanism gives the ECB macroprudential supervisory tasks for credit institutions in Member States, and therefore the ECB can request stricter requirements than imposed the national level or can introduce a requirement into a country if need be.

[50] See also ESRB (2014a) and ESRB (2014b).

to address this intermediate objective.[51] The discussion that follows on the introduction of the framework draws from Cassidy and Hallissey (2016) and focuses on the borrower-based measures and the thinking behind it.

The Central Bank of Ireland introduced maximum LTV and LTI ratios as their borrower-based instruments in February 2015 following a two-month consultation process with several stakeholders. At the time house price growth was strong, reaching levels witnessed in the run up to the financial crisis, particularly in Dublin (Figure 1.3). The aim of these mortgage market measures is *"to mitigate the risks of credit-house price spirals emerging"* (Central Bank of Ireland, 2017, p.4). However, the objective of these policies is not to influence house prices directly. Rather, the framework is largely pre-emptive, introducing mechanisms that prevent credit from rising in response to the rise in house prices in the first place. The policy set an LTV ratio limit of 90% on loans for first-time buyers (FTBs) on the first €220,000, with a further 80% limit for the residual property value. This threshold gives rise to an effective 'sliding LTV' limit; it starts at 90% but starts to fall slowly as the value of the property of interest excess the threshold (Figure 1.4). This avoids a sudden and relatively large fall in borrowing capacity as the property value exceeds the threshold. Meanwhile, second and subsequent buyers (SSBs) faced a maximum LTV ratio of 80% on the full amount. A speed limit of 15% for both loans to FTBs and SSBs applies. On the other hand, buy-to-let borrowers were subject to a 70% LTV ratio limit, with a 10% speed limit allowance. The Central Bank of Ireland also introduced complementary maximum LTI ratios of 3.5 of borrowers' combined gross annual income for non-investment house purchases, with a speed limit of 20%. Some borrowers, such as those with negative equity, were exempted from some of these measures; see Cassidy and Hallissey (2016) for further details. This tightening is henceforth referred to as Round 1.

There are two main rationales for this policy configuration; reducing pro-cyclicality and enhancing resilience. Prior to the financial crisis, the share of mortgages with a low LTV (less than 80%) fell from 70% in the late 1990s to 50% in 2006, while those with an LTV greater than 95% rose to about 20%. Moreover, over the same period the share of loans at an LTI above 3.5 rose from around 5% to more than 60%. These patterns were consistent with a housing boom that reached unsustainable levels and which in fact started to experience a correction by the end of 2007, before the full onset of the international financial crisis (Whelan, 2014). By introducing LTV and LTI ratio caps, the policy sets to have limits in place which kick-in automatically and restrict the build-up of leverage. This reduces the pro-cyclicality of housing booms. The policy also introduces a preventive arm; a high LTV loan implies that the borrower has little equity in the house, making it easier for the borrower to fall into negative equity in a downturn. Similarly, a high LTV loan implies a

[51] Other objectives include the prevention of maturity mismatch and market illiquidity, limit direct and indirect exposure concentration, and to reduce the potential for systematically important banks to adopt destabilising strategies and the mitigate the impact of such actions. Bank balance sheet tools, such as minimum capital requirements, are the tools used to meet these objective. See Central Bank of Ireland (2014, p.5) for more information.

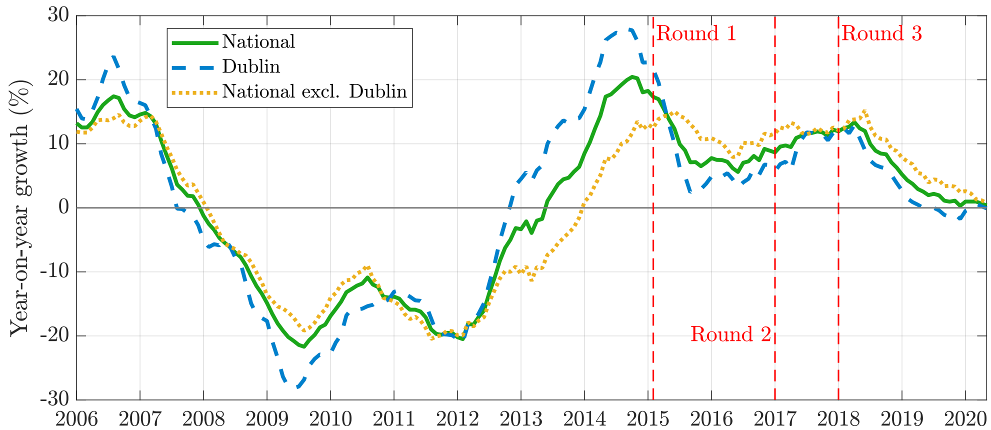

Figure 1.3: House prices and macroprudential policy measures in Ireland

Notes: 'Round 1' relates to the introduction of the policy in February 2015, while 'Round 2' and 'Round 3' correspond to the further tightening rounds in January 2017 and January 2018, respectively (see Table 1.2 for information on each round). Data is sourced from Central Statistics Office, Ireland.

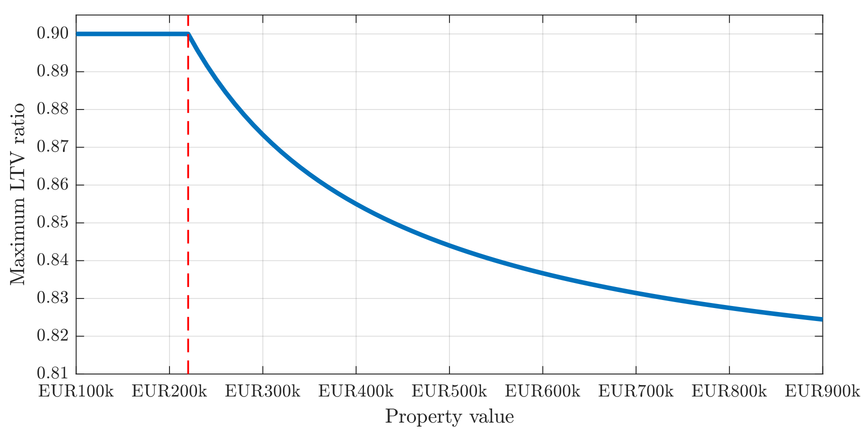

Figure 1.4: Sliding LTV limit for FTBs in Ireland

Notes: Figures on the x-axis are in thousands of euro. The dashed red line denotes the threshold of €220,000.

potentially high loss given default for banks.[52]

LTV and LTI limits complement each other since, as discussed in section 1.1.1, the collateral

[52] Similar logic applies for the LTI limit; keeping up with repayments becomes much harder in bad times when financing such payments is already stretched in good times. Indeed, Hallissey et al. (2014) find a positive association between high LTV and LTI loans at origination and subsequent defaults, and high LTV loans and banks' losses from defaults.

constraint defines an individual's borrowing limit as primarily a function of the LTV ratio and house prices (refer to equation (1.2)). A rise in house prices leads to a rise in the absolute borrowing limit if the LTV ratio is unchanged. However, as income is less procyclical than house prices, the LTI constraint is more likely to remain binding during a boom.[53] On the other hand, an LTV limit reduces a borrower's incentive to default by having skin in the game. The speed limits that form part of this policy are there for reasons similar to the RBNZ, however the FTBs have a higher LTV cap and the 'sliding LTV' is a unique feature that caters specifically for FTBs. The threshold behind the sliding LTV was motived by the fact that in the first half of 2014 median house price of a FTB was about €182,000, and transactions at just under the 60th percentile were for houses costing less than €200,000. The threshold therefore was not restrictive at the time of implementation.[54]

A number of peculiar issues stand out with this policy. First, why are buy-to-let (BTL) transactions exempted from the LTI limit? Second, why not allow FTBs a flat 90% limit? Third, why are borrowers with ex-ante negative equity exempted from the restrictions? On the first, the Central Bank of Ireland argues that the affordability of a loan to rental investors is not a function of income but of future rental income streams, which is hard to quantify and therefore regulate on. On the second, the policy recognises that a flat LTV limit would not dampen the pro-cyclicality of credit. Even though FTBs in Ireland have a lower probability of default (Kelly et al., 2018), when prices are rising, a flat 90% LTV ratio implies an increase in the amount of credit drawn by households up to the point at which they are up against the income constraint.[55] Regarding the third peculiarity, the Central Bank of Ireland noted that at the time of the policy formulation around 40% of outstanding credit was at negative equity for the borrower, which was a rather unique situation. Banks were offering solutions for borrowers who wanted to sell their house to relocate. A borrower would sell the house and add the shortfall from the original mortgage to the new mortgage debt that is incurred. This allows individuals to move to a different city in the country, possibly because of job movements. In this case, the Central Bank of Ireland did not want to hamper allocative efficiency and saw it fit to delegate risk considerations associated with these transactions to the banks themselves, especially since there were relatively few such households who opted for these solutions.[56]

Considerations about side-effects of the policies are also discussed in Cassidy and Hallissey (2016). Policymakers in Ireland considered the potential for the rules to lead to circumvention at-

[53] See Grodecka (2020) for an analysis of LTV and DSTI constraints in the case of Sweden, where the latter operates in a similar way to LTI limits.

[54] The house price at the 84th percentile was under €300,000. At that value, a maximum LTV of 86% would apply under the sliding LTV policy.

[55] Even then, the presence of speed limits means some of these transactions manage to slip through both constraints and raise household leverage, unless the speed limits are tightened.

[56] In contrast with the policy in New Zealand, borrowers benefiting from mortgage insurance are not exempted from the restrictions in Ireland. The justficiation for this is that insurance does not explicity reduce pro-cyclicality but simply shifts potential losses from banks to insurers.

tempts which would derail the financial stability pursuit. These include shifting activity to unregulated sectors, borrowers using unsecured credit as a means to finance the requirement downpayment, over-reporting of the value of the house and front-loading of house purchases upon announcment of the policy.[57] Cassidy and Hallissey (2016) argue that there may be some anecdotal evidence suggesting that some front-loading did take place, indeed encouraged by mortgage brokers.[58] Although aware of this possibility, the Central Bank of Ireland had to strike a balance between sufficient time for public consultation and prompt introduction of the restrictions, which nevertheless may still be enough for some front-loading. The potential effects of the restrictions on house prices and the rental market were also considered, as they were a matter of concern to a number of stakeholders, who feared that the policy might put upward pressure on rents as individuals potentially delayed or postponed their house purchase. However, these concerns relate to short-run market outcomes that would be addressed in the medium term as supply catches up, and therefore did not affect the policy.

The Central Bank of Ireland reviews the appropriateness of and decides on any changes to the restrictions once a year, publishing these findings in a report.[59] The full history of these reviews is documented in Table 1.2. The first review was carried out in November 2016, during which it made some adjustments to the original policy, effective as from January 2017 (Round 2). Mortgage approvals had slowed down sharply following the introduction of the policy, as did the average value of a mortgage, however they resumed an accelerating rate again a year later (Figure 1.5). Similary, the growth rate of property prices had started to rise again. To reflect past developments in house prices, the Central Bank of Ireland abolished the sliding LTV mechanism and allowed all borrowing to FTBs to be capped at 90% of the total value of the property. Property prices in Dublin had grown strongly around the introduction of the regulations, and the €220,000 threshold that was based on median house prices in Dublin at the time quickly fell short of the median of €280,000 by the first half of 2016 (Central Bank of Ireland, 2016). Anticipating other such revisions in the future, the Central Bank of Ireland opted to remove the threshold altogether, pointing to the existence of the LTI limit as a mechanism that prevents high leverage induced from a 90% LTV on a high-value property.[60] At the same time, it reduced the speed limit for loans in this category to

[57] Recently, an article in the Irish Times illustrates a potential attempt at circumventing BTL restrictions. It discusses whether a person who has never purchased a house could benefit from the favourable FTB terms if that person intends to use the home as a BTL investment rather than as a primary residential dwelling ('Can a first-time buyer get relief on a buy-to-let home?', 3-Aug-2020); see https://www.irishtimes.com/business/personal-finance/can-a-first-time-buyer-get-relief-on-a-buy-to-let-home-1.4318583.

[58] See https://www.irishtimes.com/business/personal-finance/early-approval-can-beat-new-mortgage-rules-1.1970686.

[59] See, for instance, Central Bank of Ireland (2018).

[60] This admittedly contrasts with the original scope of the sliding LTV discussed above, which was deemed necessary to dampen credit pro-cyclicality. Nonetheless, this episode highlights the fact that policymakers face a learning curve at the early stage of the framework and constant trade-offs thereafter. A possible solution that does not completely do away with the sliding LTV would be to introduce, within the regulations, an automatic adjustment to the threshold on a yearly basis, based on the same median price used to calibrate the rule in 2014. This would

5% to reflect the fact that few exceptions were justified with the removal of the sliding LTV, while it raised the speed limit to 20% for SSBs.

Table 1.2: Recent LTV ratio history in Ireland

Announcement	**Effective**	**Policy measure**
October 2014	February 2015	LTV of 90% for FTB, sliding at €220,000 with a 15% SL LTV of 80% for SSB, with 15% SL LTV of 70% for BTL, with 10% SL LTI of 3.5, with 20% SL for all categories
November 2016	January 2017	LTV of 90% for FTB at all values, with a reduced 5% SL LTV of 80% for SSB, with an increased 20 SL% LTV of 70% for BTL, with 10% SL (unchanged) LTV of 3.5, with 20% SL for all categories (unchanged)
November 2017	January 2018	All LTV limits as above (unchanged) LTI of 3.5, with a 20% SL for FTB (unchanged) LTI of 3.5, with a reduced 10% SL for SSB
November 2018	January 2019	No changes
December 2019	January 2020	No changes

Notes: Announcement dates were sought from the Central Bank or Ireland's website. Source: Central Bank of Ireland.

A year later, it tightened policy by revising the LTI ratio speed limit down to 10% for SSBs (Round 3). However, it kept the speed limit for FTB unchanged since most borrowers in this category tend to be young and therefore are more likely to experience strong income growth until the loan matures.[61] The Central Bank of Ireland maintained these limits in 2019 and 2020 up to the time of writing as it deemed the restrictions to be appropriate; house price growth and mortgage approvals were subdued since the third round of tightening.

How did this macroprudential framework work? Acharya et al. (2020) find that the introduction of the policy in 2015 led to a re-allocation of residential mortgage credit from low-income to high-income borrowers and from hot urban markets to cooler ones. The resulting drop in house price growth observed in Figure 1.3 is therefore the result of market activity slowing down in hot markets, and an increase in market activity in other regions. Indeed, house price growth in Dublin decelerated strongly after 'Round 1' while in other regions the dampening is much more modest. The authors

retain the declining LTV mechanism but keep it relevant to the current market environment.

[61] See Central Bank of Ireland (2017).

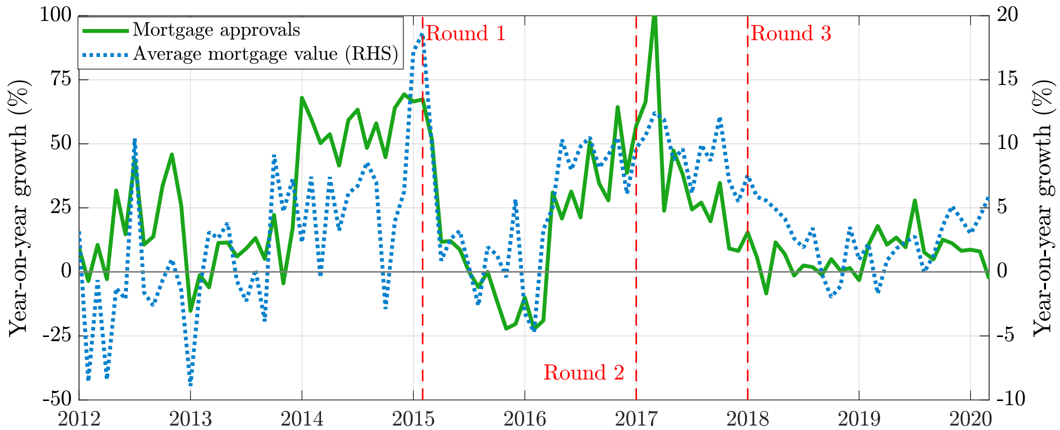

Figure 1.5: Mortgage approvals and macroprudential policy measures in Ireland
Notes: 'Round 1' relates to the introduction of the policy in February 2015, while 'Round 2' and 'Round 3' correspond to the further tightening rounds in January 2017 and January 2018, respectively (see Table 1.2 for information on each round). Data is sourced from Banking & Payments Federation Ireland.

argue that this is consistent with the policy's objective of reducing credit-house price spirals, but that it also managed to reduce heterogeneiety in the market. This faciliates the conduct of policy as it avoids the need for calibrating tools for different regions, as the RBNZ had to do for Auckland. Moreover, Acharya et al. (2020) go beyond partial equilibrium analysis and use the methodology of Mian et al. (2019) to show that the policy weakened the general equilibrium effects related to the credit-house price spiral in Ireland, confirming its effectiveness.

The experiences of New Zealand and Ireland show that while LTV ratio policies can be effective, they require a lot of initial work as well as constant analysis to assess the appropriateness of the restrictions, as well as monitor possible circumvention efforts. They also illustrate the fact that policymakers also face a learning curve, and may need to fine-tune policies as they gain more experience with them. Partly because of this, public credibility in the institution, reinforced through transparent communication, likely improves policy outcomes.

1.5 Conclusion

Credit booms can get out of hand and end in a crisis. Macroprudential policy can try to prevent this by, *inter alia*, correcting for or minimizing the borrowing externalities associated with real estate. In this paper I argue that while the deployment of macroprudential policies such as maximum LTV ratios preceded theory, there has been progress on this in academia. Policy-driven research, led by the BIS, on which indicators are relevant for operating macroprudential tools has also advanced. LTV policy seems to be effective in managing credit-house price spirals, at least in a number of countries.

Studying the effectiveness of this policy is likely to be aided in the future as more advanced economies implement such policies. In the meantime, the recent experience of some countries has shown that it is possible to implement mortgage borrowing restrictions without choking the market. Targeted policies, such as different LTV limits for first-time buyers and buy-to-let investors, can address exuberant buying behaviour while limiting the effect on home ownership rates. There will likely be other unintended consequences of these policies, namely slower consumption and GDP growth, as well as re-distributive effects such as shifting credit from low to high income borrowers and from one region to another, as documented in Ireland. Policymakers face a learning curve. Fine-tuning these policies to reduce unintended consequences, as well as learning from the experience of other countries, leads to a second-best outcome.

Chapter 2

Housing boom-bust cycles and asymmetric macroprudential policy*

Abstract

Macroprudential policy is pre-emptive, aimed at preventing crises. An interpretation of this definition is a policy of tightening credit strongly during the boom phase of a cycle, but unwinding slowly thereafter. This policy is therefore asymmetric, and has been observed empirically. I study the implications of an asymmetric loan-to-value ratio rule during a housing boom-bust cycle, and find that while this rule dampens the boom, it introduces more volatility in the economy by exacerbating the correction that follows. This makes business cycles more volatile compared to symmetric policy, even when borrowing constraints are slack, and this volatility rises with asymmetry. Furthermore, I find that the asymmetric policy rule leads the borrowing constraint to become slack not just during a credit boom, but also during a credit bust. This is due to higher inflation volatility induced by the asymmetric policy. The higher is the policy asymmetry, the more frequently the economy visits this regime.

Keywords: *asymmetric macroprudential policy, house price expectations, news shocks, credit booms, time-varying LTV ratio*

JEL codes: C61, E32, E44, E61, R21

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2.1 Introduction

Writing in 2004, Ben Bernanke, then a member of the Board of Governors of the Federal Reserve System, noted how structural changes, better macroeconomic policies but also 'good luck' contributed to the macroeconomic stability witnessed over a period now referred to as the Great Moderation (Bernanke, 2004). Yet, the build-up and eventual bursting of the housing bubble and the financial crisis that ensued a few years later, notably in the US, the UK and Spain, suggest that there is much further improvement to be made. While structural reforms are feasible, they are long term measures which do little to stabilize short to medium term fluctuations until they take full effect. Luck, by definition, is random. This leads to a focus on better macroeconomic policies which can stabilize business cycles driven by financial factors. In this paper I analyse the role that macroprudential policy can play in this regard when it is asymmetric; that is, used mainly during the boom phase of the cycle.

2.1.1 Asset price cycles

Monetary policy has been effective in stabilizing inflation by anchoring inflationary expectations in many advanced economies, however it has been less successful in taming asset price swings. Gradual changes to the nominal interest rate do little to stabilize asset price boom-bust cycles, and nowadays there is widespread recognition that monetary policy is a blunt tool to address asset price booms (Trichet, 2005; Bernanke, 2010). Such policy, dubbed 'leaning against the wind', induces costs which are greater than the benefits (Svensson, 2017) and moreover seemingly violates the Tinbergen Principle since the nominal interest rate is a tool dedicated to promoting price stability, not financial stability (Galati and Moessner, 2013; Jordà et al., 2015a).

Asset price booms are frequently associated with an increase in credit through collateral (net worth) effects, and a booming literature on debt-fuelled crises unequivocally shows that highly leveraged economies develop a greater risk of experiencing heavy contractions and slow recoveries, often experienced as 'financial crisis recessions' (Reinhart and Rogoff, 2009, 2013; Schularick and Taylor, 2012; Jordà et al., 2015b, 2017). Two seemingly different narrations can explain this correlation. One is an exogenous increase in credit which leads to strong demand for assets, raising relative prices. This would support the hypothesis that in some countries asset price booms were driven by an increase in credit supply, brought about by changes to credit conditions (Mian and Sufi, 2009; Justiniano et al., 2019), deregulation (Favara and Imbs, 2015) or international capital inflows (Cesa-Bianchi et al., 2018). Another hypothesis reflects an endogenous process generated by collateralized borrowing, where any expected changes to the value of the underlying asset drives up borrowing, which further boosts the asset's price, and so on (Kiyotaki and Moore, 1997; Iacoviello, 2005; Liu et al., 2013). These two hypothesis are complementary, as the initial change can be brought about by credit supply factors or expected asset price changes, setting off the endogenous process. Indeed, while Jordà et al. (2015a) find a causal relationship flowing from loose monetary conditions to house price booms, Case and Shiller (2003) find that expectations of future house price appreciation in a number of US states were highest in 1988 and 2003, periods during which house prices and the credit to GDP ratio were at or close to peak levels around that time (Figure 2.1).

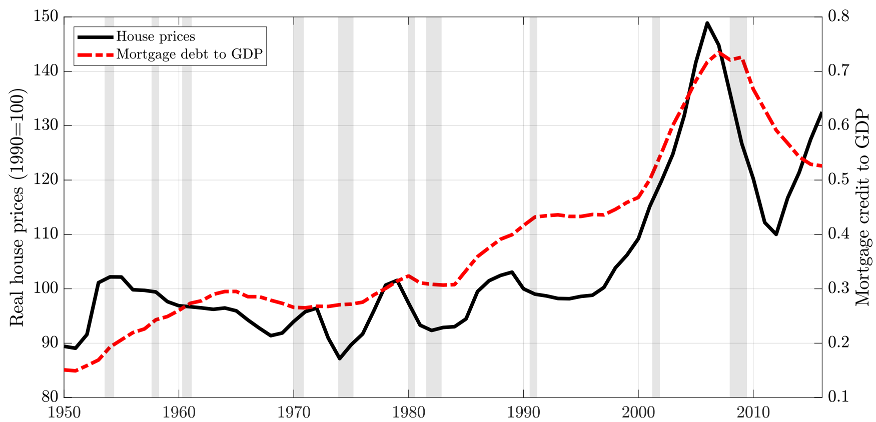

Figure 2.1: House prices and mortgage debt to GDP in the US

Notes: House prices are deflated using the CPI. Data are sourced from the FRED database and extended backwards using the data in Jordà et al. (2017) and Knoll et al. (2017). Data codes and further details are available in Appendix A2.1. Shaded regions represent recessions as dated by the NBER.

2.1.2 Macroprudential policy

Despite several rounds of monetary tightening, credit to GDP ratios have generally maintained an upward trend in several advanced economies, driven by financial liberalization in the 1980s and peaking around the onset of the financial crisis of 2007/8 (Figures 2.1 and 2.2). Goodhart (2009) notes that many major central banks and the Bank for International Settlements had been flagging the underpricing of risk and the build-up in excessive leverage several years prior to the crisis. However, at that time policymakers in these economies were lacking the regulatory framework to use macroprudential instruments suitable to counter the housing bubble and lax lending practices that led to the crisis. As discussed in Chapter 1, macroprudential policy tools are generally effective in dampening credit cycles. Such tools, such as caps on loan-to-value (LTV) ratios, reserve requirements and countercyclical capital adequacy requirement ratios, indeed seem like the way forward to promote financial stability and hence more stable business cycles. Macroprudential policies targeting real estate booms have been used in countries such as China, Hong Kong (SAR), Ireland, Korea, Sweden, Canada and New Zealand (Crowe et al., 2013; Krznar and Morsink, 2014; Rogers, 2014). However, experience with macroprudential policy in most advanced economies is relatively sparse (Cerutti et al., 2017). Furthermore, as discussed in Chapter 1, the macroprudential loss and policy reaction functions are still at an early stage of development.

The use of any policy instrument raises an important consideration on the potential for policy biases and mistakes. This is especially so when experience with such tools is limited.[1] For example, a number of authors find that the conduct of monetary policy has been shaped by a particular preference to avoid a certain outcome, such as a stronger preference to avoid a negative output gap.[2] In that case, such an asymmetry causes an inflation bias (Nobay and Peel, 2003; Surico, 2008).

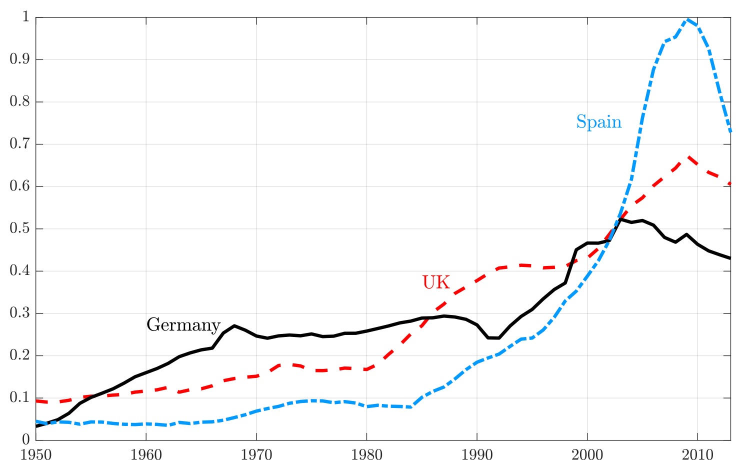

Figure 2.2: Mortgage debt to GDP in selected advanced economies

Note: Data are sourced from Jordà et al. (2017).

The same phenomenon can be extended to the conduct of macroprudential policy. Since the inherent task of macroprudential policy is to limit, *pre-emptively*, the build-up of systemic risk (Bank of England, 2009), it is reasonable to argue that there is an implicit, stronger focus on the

[1] Crowe et al. (2011) chronicle how some early LTV ratio policies were circumvented using clever tricks.

[2] Cukierman and Muscatelli (2008) show that prior to the shift to inflation targeting in the early 1990s, the Bank of England tended to want to avoid recessions rather than booms, and since the start of inflation targeting, had a stronger preference to avoid inflation overshooting rather than undershooting. Dolado et al. (2005) find that some of the major European central banks tended to place more weight on positive inflation and output gaps relative to negative gaps. More recently, Paloviita et al. (2017) show that the ECB's monetary policy reaction function was not symmetric, but that reactions to overshooting inflation were typically stronger, which could in part reflect the *"below, but close to, two percent"* emphasis in its definition of price stability. See also Surico (2003, 2008); Nobay and Peel (2003) and Dolado et al. (2004).

part of policymakers on the boom phase and associated tightening of credit conditions.[3] This is especially the case since, as discussed above, high leverage increases the probability of a financial crisis, making policymakers generally averse to credit booms.

Indeed, as discussed in Rogers (2014), this line of thought is reflected in the Reserve Bank of New Zealand's implementation of macroprudential policy: LTV policies are not routinely used to smoothen cycles, but *"to limit the extreme* ***peaks*** *in house price and housing credit cycles."* (p.5; emphasis added).[4] Lautenschläger (2018) makes the case for borrower-based LTV policies "*which come in handy at the upturn of the cycle*". Cerutti et al. (2017, p.215) argue that *"macroprudential policies are meant to be mostly ex-ante rules, that is, they should help reduce the boom part of the financial cycle"*. Using a large database of macroprudential policies from 119 countries for the period 2000-2013, they find that macroprudential policies tend to have an effect on real credit growth mostly during a boom. This reduced form evidence is open to at least two interpretations. The first could be that other factors, such as consumer and business confidence, are more important during busts. Another interpretation is that macroprudential policy loosening is typically weak during busts, possibly out of fear of re-igniting the boom while the economy is still deleveraging. In this paper I focus on the latter interpretation, as well as the implied strategy behind the definition for macroprudential policy, which I label as asymmetric macroprudential policy. I contribute to the literature by studying the success or lack thereof of asymmetric policy in stabilizing output over a boom-bust cycle.

I answer these questions using a DSGE model with representative saver and borrower households and housing, as in Iacoviello (2005) and Rubio and Carrasco-Gallego (2014). Housing is an important factor behind macroconomic fluctuations; Iacoviello (2015) finds that housing demand shocks explain about a third of the decline in output in the US during the financial crisis. Jordà et al. (2017) find that a significant proportion of credit growth is typically channelled to the housing sector, and financial liberalization coupled with rising LTV ratios have increased the length and amplitude of financial cycles.[5] The financial friction in the model originates from collaterized borrowing, giving rise to a financial accelerator which amplifies the effect of a shock to net worth on economic activity (Kiyotaki and Moore, 1997; Bernanke et al., 1999). This constraint motivates the use and effectiveness of macroprudential policy which controls leverage countercylically through adjustments to the maximum LTV ratio. These adjustments tame credit booms by weakening the financial accelerator, thus dampening boom-bust cycles when these are driven by inefficient or strong asset price and credit growth. Such policy is not micro-founded but taken as given in accordance with regulation.

[3] The Countercyclical Capital Buffer (CCyB) is one such example, since by design it raises capital requirements above a *floor* rate amount during credit booms, but does not lower these requirements *below* the floor during credit downturns.

[4] See Chapter 1 for an account of the setting up and implementation of macroprudential policy in New Zealand.

[5] See also Drehmann et al. (2014) and Borio (2014).

In this paper the driver of boom-bust cycles are unrealized *news shocks*, which give rise to the formation of asset price bubbles through expectations which are *ex-ante* rational but revealed *ex-post* to be disconnected from fundamentals. Such shocks have been recently included in models with a housing market as an additional driver of cycles (Lambertini et al., 2013b; Kaplan et al., 2020). The reaction to the news shock follows the literature on herd behaviour and information cascades in financial markets (Banerjee, 1992; Bikhchandani et al., 1992; Shiller, 2000, p. 151). It also follows Bernanke and Gertler (1999), who include asset price bubbles as a source of volatility in the celebrated model of Bernanke et al. (1999), and Christiano et al. (2008, 2010) who add unrealized news shocks to technology in a medium-sized New Keynesian model. More recently, Bruneau et al. (2018) estimate a model with both unanticipated and anticipated housing demand shocks, and Burlon et al. (2018) include a non-fundamental shock to house prices in a similar modelling framework.

I find that conducting macroprudential policy asymmetrically introduces more volatility in the economy, compared to a scenario in which the borrowing limit is revised symmetrically. Collateral constraints are kept relatively tighter during the bust, affecting mainly borrower households whose consumption dynamics are strongly influenced by their leverage. A greater drop in borrowers' consumption then further exacerbates the correction in output. These findings lend support to a policy prescription laid in a 2017 speech by Alex Brazier, who argues that *"[m]acroprudential policy must be fully countercyclical; not only tightening as risks build, but also loosening as downturn threatens."* (Brazier, 2017).[6]

I show that this increased volatility in output and inflation rises monotonically with the degree of asymmetry in the policy response (defined below). In addition, I find that since borrowers have a high marginal propensity to consume out of their wealth, they are hit particularly hard by such policy. Their consumption volatility is higher than that of savers and rises relatively faster as the degree of policy asymmetry intensifies. Furthermore, more volatile inflation results in a relatively quicker pick-up in inflation during the correction, leading to slack borrowing constraints during a bust, despite tight a LTV ratio. This paper therefore contributes to the debate on how macroprudential rules should be implemented, showing that it is equally important to consider the role of such policy during the *bust* phase of the cycle. This tends to receive less attention in the literature on macroprudential policy rules. I also contribute to the literature on the interaction between monetary and macroprudential policies, noting that while macroprudential policy reduces the strain on monetary policy during asset price driven booms, there are possibly negative spillovers from (asymmetric) macroprudential policy to monetary policy.

[6] It also echoes the suggestion made by Jean-Claude Trichet in 2005, speaking in the context of monetary policy which 'leans against the wind': *"By reacting more symmetrically - i.e. being tighter in booms as well as looser in busts - the central bank would discourage excessive risk-taking and thereby reduce over-investment already during the boom. This in turn would lead to a lower level of indebtedness and less severe consequences of a possible future bust."* (Trichet, 2005).

The rest of the paper is structured as follows. Section 2.2 describes the model, defines a competitive equilibrium and derives key steady state relationships. Section 2.3 emphasises the theoretical importance and empirical relevance of news shocks as driving forces in DSGE models, and explains the stochastic process of the key shock in the model. Section 2.4 discusses the benchmark calibration, while section 2.5 defines an asymmetric macroprudential rule and discusses how the model is solved. Section 2.6 presents impulse response analysis and compares symmetric and asymmetric macroprudential policy. In section 2.7 I allow the borrowing constraint to become slack, and study how this interacts with policy asymmetry. Section 2.8 discusses policy issues related to the use of macroprudential policies. Section 2.9 concludes.

2.2 The model

I derive a New Keynesian model with financial frictions originating from borrowing constraints, among the class of Two Agent New Keynesian (TANK) models. The setup is very similar to that in Rubio and Carrasco-Gallego (2014, 2016b) and Kanik and Xiao (2014) who build on Iacoviello (2005). It is also very similar to Liu et al. (2013), apart from the fact that in their model the financial friction is faced solely by the productive sector. There are six types of infinitely-lived agents in the model: patient households, impatient households, intermediate and final goods firms, the central bank and the financial regulator. The numeraire is the price of the final good, therefore wages and house prices are expressed in units of consumption goods.

Households consume the final good, hold housing as a durable good and supply labour to intermediate goods firms. Housing is fixed in supply and does not depreciate.[7] Intermediate goods firms use labour to produce differentiated goods, which are packaged and sold as a final homogeneous good by the final good firm.[8] Intermediate goods firms are subject to a price setting friction, which introduces nominal rigidities in the model, giving rise to real effects of monetary disturbances. This allows the study of macroprudential policy in the presence of monetary policy. Impatient households face a borrowing constraint. As this is binding, it introduces amplification of real disturbances via a financial accelerator effect through changes in net wealth (Bernanke et al., 1999). Given the presence of these two distortions, the central bank and the financial regulator are tasked with maintaining price and financial stability respectively using appropriate policy tools.

2.2.1 Households

The two household types in the model, each a continuum of size one, have almost identical preferences. The source of heterogeneity between them is the rate at which they discount the future.

[7] This is a simplification to guide intuition; see Iacoviello and Neri (2010) who allow for depreciation and model investment in the housing supply.

[8] To simplify the model I abstract from capital accumulation in the economy.

As is standard in the literature, households with the higher discount factor are termed patient and hence will in equilibrium save and receive interest on resources (Kiyotaki and Moore, 1997). On the other hand, households with the lower discount factor will in equilibrium want to consume more than their budget, and hence will borrow and pay interest on resources to finance spending. Both household types derive utility from consumption, housing and leisure, and take wages and the interest rate as given. On the basis of the behaviour type, household variables are denoted with a subscript $i \in \{s, b\}$ for savers and borrowers respectively. It is assumed that credit flows from savers to borrowers efficiently, so the presence of a financial intermediary is redundant.[9]

Patient households - savers

Savers aim to maximise lifetime utility subject to their per-period budget constraint, discounting future utility streams at $\beta_s \in (0,1)$. They choose consumption $C_{s,t}$, housing $H_{s,t}$ and labour supply in hours $N_{s,t}$, and form external habits in consumption governed by the parameter $\varrho \in (0,1)$. Their objective is

$$\max_{C_s, H_s, N_s} \mathbb{E}_0 \left\{ \sum_{t=0}^{\infty} \beta_s^t \left((1-\varrho) \log \left(C_{s,t} - \varrho C_{s,t-1} \right) + \mathrm{j}_t \log H_{s,t} - \tau \frac{N_{s,t}^{1+\varphi}}{1+\varphi} \right) \right\}$$

where $\tau > 0$ is a preference parameter which shifts the labour supply schedule, and $\varphi > 0$ is the inverse of the Frisch elasticity of labour supply. The process j_t is a shock to the marginal utility of housing, which is typically referred to as a housing demand shock in the literature, and is discussed further below.[10]

Patient households consume the final good, change their stock of housing at the current market price and save via a one-period loan instrument B_t. They earn labour income, and accrue savings from the previous period with interest. Furthermore, savers are assumed to own the production sector and hence receive lump-sum profits from intermediate goods firms. Their budget constraint is:

$$C_{s,t} + q_t(H_{s,t} - H_{s,t-1}) + B_t = w_{s,t} N_{s,t} + \frac{R_{t-1} B_{t-1}}{\pi_t} + \Pi_t \tag{2.1}$$

where q_t is the relative price of housing to consumption goods, $w_{s,t}$ is the real hourly wage rate, R_t is the gross nominal interest rate and $\pi_t \equiv \frac{P_t}{P_{t-1}}$ is the gross inflation rate for goods prices. Savers are assumed to lend in real terms in time t and receive back a nominal amount in time $t+1$, such that debt is not indexed, as in Iacoviello (2005).[11] The term Π_t represents profits from intermediate

[9] See Gerali et al. (2010) and Iacoviello (2015) for models with frictions in the banking sector.

[10] See Iacoviello and Neri (2010) for a discussion and possible interpretations of this shock.

[11] This implies that an increase in prices between period $t-1$ and t lowers the real return on saving.

goods producers, defined below.[12] The first-order conditions for this problem are:

$$\frac{1-\varrho}{C_{s,t}-\varrho C_{s,t-1}} = \beta_s \, \mathbb{E}_t \left\{ \left(\frac{1-\varrho}{C_{s,t+1}-\varrho C_{s,t}} \right) \frac{R_t}{\pi_{t+1}} \right\} \tag{2.2}$$

$$q_t \left(\frac{1-\varrho}{C_{s,t}-\varrho C_{s,t-1}} \right) = \frac{\mathrm{j}_t}{H_{s,t}} + \beta_s \, \mathbb{E}_t \left\{ q_{t+1} \left(\frac{1-\varrho}{C_{s,t+1}-\varrho C_{s,t}} \right) \right\} \tag{2.3}$$

$$w_{s,t} \left(\frac{1-\varrho}{C_{s,t}-\varrho C_{s,t-1}} \right) = \tau N_{s,t}^{\varphi}. \tag{2.4}$$

Equation (2.2) is the typical Euler equation over lending and equation (2.3) is the Euler equation specifying demand for housing. Savers aim to smoothen consumption by matching the return on saving to the cost of foregone consumption. Given that housing is a durable good, it not only increases utility in the current period but it also increases the amount of resources available in the next period, through its resale value. Equation (2.4) defines labour supply by equating marginal utilities over consumption and leisure.

Impatient households - borrowers

Impatient households have similar preferences as savers, with the exception of the discount factor $\beta_b \in (0,1)$, where by assumption $\beta_b < \beta_s$:

$$\max_{C_b, N_b, H_b} \; \mathbb{E}_0 \left\{ \sum_{t=0}^{\infty} \beta_b^t \left((1-\varrho) \log \left(C_{b,t} - \varrho C_{b,t-1} \right) + \mathrm{j}_t \log H_{b,t} - \tau \frac{N_{b,t}^{1+\varphi}}{1+\varphi} \right) \right\}.$$

They receive labour income and supplement their budget by obtaining an amount of borrowing B_t as a one-period loan at the gross rate R_t. These inflows finance the purchase of the consumption good and housing, and the repayment of the previous period's loan:

$$C_{b,t} + q_t (H_{b,t} - H_{b,t-1}) + \frac{R_{t-1} B_{t-1}}{\pi_t} = w_{b,t} N_{b,t} + B_t \tag{2.5}$$

taking the wage and interest rate as given. Note that the loan is written on the right hand side of the budget constraint. This implies a market clearing condition in every period such that the total saving by patient households through this loan instrument is equal to the total borrowing by impatient households.[13]

Following Kiyotaki and Moore (1997), savers can only enforce repayment of the loans by securing them against collateral. In this model housing is a durable good which can be pledged as collateral, and the fraction of borrowing relative to housing wealth is the LTV ratio. Therefore the maximum

[12] Profits in real terms are equal to the difference between price and marginal cost of output; $\Pi_t = (1 - MC_t) Y_t$.

[13] I use the terms loan, borrowing, credit and mortgage debt interchangeably in this paper since the latter is the only liability that borrowers hold.

borrowing for impatient households is limited by a collateral constraint, written in terms of a time-varying LTV ratio m_t of their expected nominal housing wealth in the next period:

$$R_t B_t \leq \mathsf{m}_t \, \mathbb{E}_\mathrm{t} \left\{ q_{t+1} \pi_{t+1} \right\} H_{b,t}. \tag{2.6}$$

Section (2.2.5) discusses how the LTV ratio m_t is used as a policy tool by the financial regulator to actively relax or tighten the collateral constraint to boost or reduce credit flows. Since house prices respond to economic conditions, the collateral constraint is endogenous and thus can generate a strong financial accelerator, leading to amplified responses of output to exogenous disturbances. Note that the borrowing limit can rise if either (a.) the value of housing wealth rises, (b.) the LTV ratio m_t rises, or (c.) the expected real interest rate $\widetilde{R}_t = \mathbb{E}_\mathrm{t} \left\{ \frac{R_t}{\pi_{t+1}} \right\}$ falls.

The FOCs for this problem are:

$$\frac{1-\varrho}{C_{b,t} - \varrho C_{b,t-1}} = \beta_b \, \mathbb{E}_\mathrm{t} \left\{ \left(\frac{1-\varrho}{C_{b,t+1} - \varrho C_{b,t}} \right) \frac{R_t}{\pi_{t+1}} \right\} + R_t \mu_t \tag{2.7}$$

$$\begin{aligned} q_t \left(\frac{1-\varrho}{C_{b,t} - \varrho C_{b,t-1}} \right) &= \frac{\mathsf{j}_t}{H_{b,t}} + \beta_b \, \mathbb{E}_\mathrm{t} \left\{ q_{t+1} \left(\frac{1-\varrho}{C_{b,t+1} - \varrho C_{b,t}} \right) \right\} \\ &\quad + \mu_t \, \mathbb{E}_\mathrm{t} \left\{ \mathsf{m}_t q_{t+1} \pi_{t+1} \right\} \end{aligned} \tag{2.8}$$

$$w_{b,t} \left(\frac{1-\varrho}{C_{b,t} - \varrho C_{b,t-1}} \right) = \tau N_{b,t}^{\varphi} \tag{2.9}$$

where $\mu_t > 0$ is the Lagrange multiplier on the borrowing constraint. Equations (2.7)-(2.9) are the Euler equations over borrowing and housing demand respectively and the intratemporal labour supply equation. The borrowing constraint introduces a wedge between the marginal benefit and marginal cost of decisions. Borrowers are constrained by their borrowing limit and are therefore not able to fully smoothen consumption, making them unable to adjust fully in the wake of shocks. This implies that they have a higher marginal propensity to consume out of current income than savers. Note that shocks to housing preferences j_t generate an immediate response in housing demand and house prices, for both household types.[14]

[14] Solving for H_s in (2.3), we get:

$$H_{s,t} = \mathsf{j}_t \left(\frac{\widehat{C}_{s,t}}{q_t} - \beta_s \, \mathbb{E}_\mathrm{t} \left\{ \frac{\widehat{C}_{s,t+1}}{q_{t+1}} \right\} \right)$$

where $\widehat{C}_{s,t} = \frac{C_{s,t} - \varrho C_{s,t-1}}{1-\varrho}$. Housing demand $H_{s,t}$ increases as the preference term j_t rises. The same holds for borrowers, although their housing demand function also includes the shadow price of the borrowing constraint. In that case an increase in the LTV ratio m_t or an increase in inflation π_t also increases housing demand by borrowers, as both of these variables relax the borrowing constraint. The former directly, by increasing outright the borrowing limit, and the latter by reducing the real burden of debt.

2.2.2 Firms

The supply side of the model is standard as in the New Keynesian model, featuring Dixit-Stiglitz monopolistic competition with price setting frictions. Production of the final consumption good involves two stages: the manufacture of intermediate goods by a continuum of firms and the packaging of all these intermediate goods into a final good by another. Both firms are owned by savers and thus use the corresponding stochastic discount factor in intertemporal decisions.

Final goods firm

The final consumption good is produced by a competitive firm that takes as inputs a continuum of intermediate goods $y_{j,t}$, where $j \in (0,1)$, and aggregates them using Dixit-Stiglitz CES technology with elasticity of substitution between varieties $\sigma > 1$:

$$Y_t = \left[\int_0^1 y_{j,t}^{\frac{\sigma-1}{\sigma}} dj \right]^{\frac{\sigma}{\sigma-1}}. \tag{2.10}$$

The firm aims to minimize the cost of a bundle $\int_0^1 p_{j,t} y_{j,t} dj$ in each period, subject to the technology described above. Demand for intermediate good $y_{j,t}$ is given by:

$$y_{j,t} = \left(\frac{p_{j,t}}{P_t} \right)^{-\sigma} Y_t \tag{2.11}$$

where the aggregate price P_t for the final good is a weighted average over the set of intermediate goods prices:

$$P_t = \left(\int_0^1 p_{j,t}^{1-\sigma} \, dj \right)^{\frac{1}{1-\sigma}}. \tag{2.12}$$

Intermediate goods firms

A continuum of intermediate goods firms indexed by $j \in (0,1)$ operate in a monopolistically-competitive market, and each firm faces the downward sloping demand curve (2.11) with an elasticity depending on the substitutability across goods. Production of each firm is based on constant returns to scale technology using labour from both household types. All firms are subject to an aggregate technology shock A_t, which evolves as $\log(A_t) = \rho_A \log(A_{t-1}) + (1-\rho_A)\log(\overline{A}) + \epsilon_{A,t}$, where $\epsilon_{A,t} \sim N(0, \sigma_A^2)$ is an i.i.d. shock. Each firms' production technology delivers constant returns to scale:

$$y_{j,t} = A_t n_{s,j,t}^{\alpha} n_{b,j,t}^{1-\alpha}$$

where $n_{s,j,t}$ and $n_{b,j,t}$ are labour input from savers and borrowers respectively and $\alpha \in (0,1)$ is the share of income from production of savers. Cobb-Douglas technology has some desirable features;

it allows for an analytical solution for the steady state of the model, and yields an interpretation for α and $1-\alpha$ as the relative economic size of saver and borrower households respectively.[15] Each firm j faces two optimization problems; a static choice over labour to minimize production costs in each period, and a dynamic choice for the price which maximises present and future discounted profits. Firms take wages as given in both these problems. Cost minimization by any firm j is given by

$$\min_{n_{s,j,t},n_{b,j,t}} \quad w_{s,t}n_{s,j,t} + w_{b,t}n_{b,j,t} + MC_{j,t}\left(y_{j,t} - A_t n_{s,j,t}^{\alpha} n_{b,j,t}^{1-\alpha}\right)$$

where MC_t are real marginal costs. The first order conditions characterising optimal labour demand are:

$$n_{s,j,t} = \alpha \frac{MC_{j,t}y_{j,t}}{w_{s,t}} \tag{2.13}$$

$$n_{b,j,t} = (1-\alpha)\frac{MC_{j,t}y_{j,t}}{w_{b,t}}. \tag{2.14}$$

Using these optimality conditions, we can define marginal costs as

$$MC_t = \frac{1}{A_t}\left(\frac{w_{s,t}}{\alpha}\right)^{\alpha}\left(\frac{w_{b,t}}{1-\alpha}\right)^{1-\alpha}. \tag{2.15}$$

As marginal costs of production do not depend on characteristics of any firm j, and since technology is symmetric across all firms, we can drop the subscript j in (2.13) and (2.14) to ease notation.

Intermediate goods firms are subject to the Calvo-Yun price setting friction in their profit maximisation. In any given period a random fraction of firms ω are not able to change prices. With this knowledge, the remaining $1-\omega$ of firms set prices such that they maximise present and expected future discounted profits:

$$\max_{p_{j,t}} \ \mathbb{E}_t\left\{\sum_{i=0}^{\infty}\omega^i\Lambda_{i,t+i}\left[\frac{p_{j,t}}{P_{t+i}}y_{j,t+i} - MC_{t+i}y_{j,t+i}\right]\right\}$$

where $\Lambda_{i,t+i} = \beta_s^i\frac{C_{s,t+i}-\varrho C_{s,t+i-1}}{C_{s,t}-\varrho C_{s,t-1}} = \beta_s\frac{\widetilde{C}_{s,t+i}}{\widetilde{C}_{s,t}}$ is the relevant stochastic discount factor and the term in square brackets is equal to profit in period $t+i$, which is rebated to savers. Using the demand curve faced by each firm $y_{j,t} = \left(\frac{p_{j,t}}{P_t}\right)^{-\sigma}Y_t$, we can write the above problem as:

$$\max_{p_{j,t}} \ \mathbb{E}_t\left\{\sum_{i=0}^{\infty}\omega^i\Lambda_{i,t+i}Y_{t+i}\left[\left(\frac{p_{j,t}}{P_{t+i}}\right)^{1-\sigma} - MC_{t+i}\left(\frac{p_{j,t}}{P_{t+i}}\right)^{-\sigma}\right]\right\}.$$

[15] Iacoviello and Neri (2010) find that changing the substitutability between saver and borrower labour hours yields similar results but complicates the analysis unnecessarily, since it introduces a feedback loop between labour supply decisions and borrowing constraints.

As shown in Christiano et al. (2011), the solution to this problem leads to the following system of equations:

$$\Upsilon_t = \left(\frac{\sigma-1}{\sigma}\right)\left(\frac{1-\omega}{1-\omega\pi_t^{\sigma-1}}\right)^{\frac{1}{\sigma-1}}\Phi_t \tag{2.16}$$

$$\Upsilon_t = \frac{Y_t}{\widetilde{C}_{s,t}}MC_t + \omega\beta_s\,\mathbb{E}_t\left\{\pi_{t+1}^{\sigma}\Upsilon_{t+1}\right\} \tag{2.17}$$

$$\Phi_t = \frac{Y_t}{\widetilde{C}_{s,t}} + \omega\beta_s\,\mathbb{E}_t\left\{\pi_{t+1}^{\sigma-1}\Phi_{t+1}\right\} \tag{2.18}$$

which characterise the non-linear formulation of the New Keynesian Phillips curve and jointly determine price dynamics.[16] See Appendix A2.2 for further details. Log-linearization of these conditions around a zero net inflation rate, combined with the dynamics of aggregate prices, yields the familiar New Keynesian Phillips curve:

$$\widehat{\pi}_t = \beta_s\,\mathbb{E}_t\{\widehat{\pi}_{t+1}\} + \frac{(1-\omega)(1-\omega\beta_s)}{\omega}\widehat{MC}_t$$

where variables with a hat denote percentage deviations from steady state.

2.2.3 Market clearing

The market for labour employed by intermediate goods firms clears:

$$N_{s,t} = \int_0^1 n_{s,j,t}\,dj = \alpha\frac{MC_tY_t}{w_{s,t}} \tag{2.19}$$

$$N_{b,t} = \int_0^1 n_{b,j,t}\,dj = (1-\alpha)\frac{MC_tY_t}{w_{b,t}}. \tag{2.20}$$

I keep the housing supply (H) fixed and normalized to 1, and the following housing market clearing condition holds in each period:

$$H_{s,t} + H_{b,t} = 1. \tag{2.21}$$

Following Yun (1996) and Christiano et al. (2011), let Y_t^* be the unweighed sum of output from intermediate goods firms. Since all firms use labour in the same proportions, this can be written as

$$Y_t^* = \int_0^1 y_{j,t}\,dj = A_t\int_0^1 n_{s,j,t}^{\alpha}n_{b,j,t}^{1-\alpha}\,dj = A_tN_{s,t}^{\alpha}N_{b,t}^{1-\alpha}.$$

[16] When there is no nominal rigidity ($\omega = 0$) we get the standard result that marginal costs are always constant ($MC_t = \frac{\sigma-1}{\sigma}$).

Alternatively, summing over the demand across all intermediate firms and equating Y_t^*:

$$
\begin{aligned}
Y_t^* &= \int_0^1 y_{j,t}\, dj = Y_t \int_0^1 \left(\frac{p_{j,t}}{P_t}\right)^{-\sigma} dj \\
\Rightarrow \quad Y_t &= \frac{Y_t^*}{s_t} = \frac{A_t}{s_t} N_{s,t}^{\alpha} N_{b,t}^{1-\alpha}
\end{aligned} \tag{2.22}
$$

where $s_t = \int_0^1 \left(\frac{p_{j,t}}{P_t}\right)^{-\sigma} dj > 1$ is the measure of output cost of price dispersion, which reduces aggregate output compared with an economy with flexible prices (Yun, 1996).[17] This measure can be written recursively as:

$$
\begin{aligned}
s_t &= (1-\omega)\left(\frac{p_t^*}{P_t}\right)^{-\sigma} + \omega \pi_t^{\sigma} s_{t-1} \\
&= (1-\omega)\left(\frac{1-\omega\pi_t^{\sigma-1}}{1-\omega}\right)^{\frac{\sigma}{\sigma-1}} + \omega \pi_t^{\sigma} s_{t-1}.
\end{aligned} \tag{2.23}
$$

The goods market clearing condition can therefore be written as:

$$
Y_t = C_{s,t} + C_{b,t} = \frac{A_t}{s_t} N_{s,t}^{\alpha} N_{b,t}^{1-\alpha} \tag{2.24}
$$

such that all output produced is consumed.

2.2.4 The central bank

The central bank implements monetary policy to ensure price stability. It steers the nominal interest rate in accordance with a standard Taylor rule, reacting to the deviations of inflation and output from their steady state values. The interest rate response is sluggish, reflecting the central bank's aversion to large rate revisions within a period. The interest rate evolves according to:

$$
R_t = \overline{R}^{(1-\rho_R)} \left(\frac{\pi_t}{\overline{\pi}}\right)^{\delta_\pi(1-\rho_R)} \left(\frac{Y_t}{\overline{Y}}\right)^{\delta_Y(1-\rho_R)} R_{t-1}{}^{\rho_R} \exp(\epsilon_t^R). \tag{2.25}
$$

The parameters δ_π, $\delta_Y > 0$ control the sensitivity of the interest rate to the deviation of gross inflation π_t and output from their steady state values ($\overline{\pi}$ and $\overline{Y}$ respectively). $\overline{R}$ is the interest rate in the steady state and ρ_R controls the smoothness of changes in the interest rate over a given period. $\epsilon_t^R \sim N(0, \sigma_R^2)$ is an i.i.d. monetary policy shock.

[17] Note that this variable drops out from any linear approximations of the model around a point, as the variance of prices has only second-order effects on output.

2.2.5 The financial regulator

Macroprudential policy is the prerogative of the financial regulator, with an objective of maintaining financial stability by taming excessive credit, or by supporting credit when it is anaemic. Some authors adopt a 'hybrid' approach to meet this objective, where a single institution implements monetary policy to maintain both price and financial stability (Gelain et al., 2013; Notarpietro and Siviero, 2015). However, using monetary policy to address financial stability concerns has been questioned by Svensson (2012, 2017). He argues that just as the monetary and the fiscal authorities operate taking each others' actions as given, the conduct of financial stability should follow in an analogous way. The hybrid approach can otherwise place a heavy burden on the central bank by requiring that it addresses two distortions using a single rule. This can be argued to go against the Tinbergen principle of using one tool to meet one policy objective (Galati and Moessner, 2013; Rubio and Carrasco-Gallego, 2014). Furthermore, monetary policy is relatively ineffective at controlling asset prices, necessitating large increases in the policy rate which would be highly contractionary (Gilchrist and Leahy, 2002; Trichet, 2005; Bernanke, 2010).

In view of the above, several studies have embedded a macroprudential reaction function acting as an additional policy response. As discussed in Weidmann (2017), there may also be conflict between the objectives of price and financial stability, which could put undue pressure on the central bank if it were also responsible for financial stability. Therefore in this model the macroprudential tool is administered by a separate authority - a financial regulator - which operates independently of the central bank.

As discussed in Chapter 1, typically a macroprudential tool is tailored specifically to control leverage countercyclically by reacting to credit growth as in Rubio and Carrasco-Gallego (2014, 2016b) and Kannan et al. (2012) or to measures of credit gaps, such as the deviation of the credit to GDP ratio from its long term trend or equilibrium, as in Angelini et al. (2014). The latter argue that macroprudential policy can be considered a reaction to abnormal developments in credit, that is, credit growing faster than output. The credit gap has been identified as a good early warning indicator for excessive growth in credit, and is also the reference indicator used in practice to operate the Countercyclical Capital Buffer for banks (Basel Committee, 2010).

I now specify a benchmark, symmetric macroprudential policy rule. Later I compare it to an alternate rule which reacts to credit conditions asymmetrically. The benchmark rule sets a time-varying LTV ratio m_t, which alters impatient households' borrowing constraint (2.6). The LTV ratio is pushed away from its steady state value $\overline{\mathsf{m}}$ countercyclically in response to the deviation of the credit to GDP ratio $\Omega_t \equiv \frac{B_t}{Y_t}$ from its value in the steady state $\overline{\Omega} \equiv \frac{\overline{B}}{\overline{Y}}$. As for monetary policy, it is assumed that the financial regulator is averse to making sharp changes to the LTV ratio, so it revises m_t progressively. The benchmark LTV rule is:

$$\mathsf{m}_t = \overline{\mathsf{m}}^{(1-\rho_{\mathsf{m}})} \left(\frac{\Omega_t}{\overline{\Omega}} \right)^{-\delta_{\mathsf{m}}(1-\rho_{\mathsf{m}})} \mathsf{m}_{t-1}^{\rho_{\mathsf{m}}} \tag{2.26}$$

where $\overline{\mathsf{m}}$ is the LTV ratio in steady state, $\delta_{\mathsf{m}} > 0$ is the sensitivity of the LTV ratio to deviations in the credit ratio, and ρ_{m} is the smoothing parameter over changes to the LTV ratio.

2.2.6 Equilibrium

A competitive equilibrium is defined as a sequence of prices $\{q, R, w_s, w_b, \pi\}$ and quantities $\{C_s, H_s, B, N_s, \mathsf{j}, C_b, H_b, N_b, \mathsf{m}, \mu, Y, MC, A, \Upsilon, \Phi, s\}$ that satisfy the dynamic system given by equations (2.1)–(2.9), (2.15)–(2.21), (2.23), (2.25), (2.26) and the shock processes for j (defined below) and A.[18] The difference in discount factors between savers and borrowers implies that the Lagrange multiplier on the borrowing constraint is positive and hence the borrowing limit binds both in the steady state and in small deviations from it. The borrowing constraint for impatient households (2.6) is therefore written as an equality. I relax this assumption in section 2.7. Monetary and macroprudential policies are implemented in an uncoordinated fashion, with either authority taking the actions of the other as given.[19]

2.2.7 The steady state

The analytic solutions for some variables and great ratios can be easily derived. Using the Euler equation for savers (2.2) we obtain the standard result for the equilibrium interest rate:

$$\overline{R} = \frac{1}{\beta_s}.$$

Plugging this result in the borrowing constraint (2.6), the level of credit in steady state is a proportion of housing wealth held by borrowers:

$$B = \overline{\mathsf{m}} \beta_s q H_b.$$

The Euler equations over credit supply and demand yield the value of the Lagrange multiplier on the borrowing constraint, which is a function of the difference between the discount factors of savers and borrowers:

$$\mu = \frac{\beta_s - \beta_b}{C_b}.$$

[18] Explosive paths in credit and house prices are ruled out through relevant transversality conditions.

[19] For a discussion and comparison of the performance of coordinated and uncoordinated policy actions see Rubio and Carrasco-Gallego (2014).

Since $\beta_s > \beta_b$ by assumption, and $C_b > 0$, the constraint is binding in steady state. The Euler equation for housing for savers (2.3) yields consumption for savers to be a proportion of their housing wealth:

$$C_s = \frac{1-\beta_s}{\bar{\mathsf{j}}} q H_s.$$

Using the definition for μ, the corresponding equation for borrowers is:

$$C_b = \frac{1-\widetilde{\beta}_b}{\bar{\mathsf{j}}} q H_b$$

where $\widetilde{\beta}_b = \overline{\mathsf{m}}\beta_s + (1-\overline{\mathsf{m}})\beta_b$. Since $\widetilde{\beta}_b < \beta_s$, borrower households have a higher propensity to consume out of their housing wealth than savers, and this propensity is a function of the LTV ratio. As $\overline{\mathsf{m}} \to 1$, borrowers' propensity to consume falls, approaching that of savers.[20]

Using these results, we get, after some algebra, key great ratios for credit to GDP, borrowers' consumption and housing shares, and borrowers' and total housing wealth to GDP:

$$\begin{aligned}
\frac{B}{Y} &= \frac{\bar{\mathsf{j}}\overline{\mathsf{m}}\beta_s(1-\alpha)\overline{MC}}{\iota} \\
\frac{C_b}{Y} &= \frac{(1-\widetilde{\beta}_b)(1-\alpha)\overline{MC}}{\iota} \\
\frac{H_b}{H} &= \frac{(1-\beta_s)(1-\alpha)\overline{MC}}{\iota - \overline{MC}(\beta_s - \widetilde{\beta}_b)(1-\alpha)} \\
\frac{qH_b}{Y} &= \frac{\bar{\mathsf{j}}(1-\alpha)\overline{MC}}{\iota} \\
\frac{qH}{Y} &= \frac{\bar{\mathsf{j}}(\iota - \overline{MC}(\beta_s - \widetilde{\beta}_b)(1-\alpha))}{\iota(1-\beta_s)}
\end{aligned}$$

where $\overline{MC} = \frac{\sigma-1}{\sigma}$ from the equations characterising price dynamics and $\iota = 1 - \widetilde{\beta}_b + \bar{\mathsf{j}}\overline{\mathsf{m}}(1-\beta_s)$. As the steady state LTV ratio increases, so does the maximum borrowing allowed for impatient households.[21] Borrowers use this additional credit to increase their holdings of housing, which pushes up house prices relative to consumption goods. This pushes up the borrowing limit further. The final effect is a rise in credit, a fall in borrowers' consumption share and a rise in their housing share and in their housing wealth relative to output.

Gross inflation in the steady state ($\overline{\pi}$) is 1, so net inflation is 0. The steady state level of technology $\overline{A}$ is normalized to 1.

[20] However note that the model has no stable solution for values of $\overline{\mathsf{m}}$ very close to 1.

[21] Note that as $\overline{\mathsf{m}}$ rises, $\widetilde{\beta}_b$ rises and ι falls.

2.3 News shocks

The standard driving forces in DSGE models are unanticipated shocks hitting technology, preferences or costs, which account for all of the variation in macroeconomic variables. However there exists evidence that *anticipated* shocks, that is, shocks expected to hit at some future period, are also equally important. Beaudry and Portier (2006) find that expectations about changes to future technology explain a significant proportion of consumption, investment and labour hours. Information about future changes in fundamentals is referred to as a *news shock*.[22] The possibility that changes in expectations about future fundamentals affect the economy today dates back to Pigou (1927), who argues that excessive optimism about the future which turns out to be false can cause households and firms to scale back on their expenditure, tipping the economy into recession. This process, termed a 'Pigou cycle', is consistent with rational expectations as optimism or pessimism is *ex-ante* an optimal reaction to a possibly imprecise signal (Beaudry and Portier, 2004).

Although news shocks have typically related to the supply side of the economy, a strand of the literature has recently extended the sources of uncertainty beyond future technology. For example, Schmitt-Grohé and Uribe (2012) find that anticipated shocks not only to productivity, but also to government spending, the wage markup and preferences explain about half the variance in output, consumption, labour hours and inflation. Angeletos et al. (2018) model 'higher-order beliefs' to emphasise the difference between news shocks about long-run (supply side) disturbances and *confidence shocks*, which reflect short-run (demand side) disturbances that generate waves of optimism and pessimism. In this paper, news shocks relate to short-run, demand-driven process.

Asset prices respond directly to perceived changes to fundamentals in the future. Notable studies on the effect of expectations on asset prices include those by Cochrane (1994), Bernanke and Gertler (1999), Gilchrist and Leahy (2002), Dupor (2005), Christiano et al. (2010), Lambertini et al. (2013a), Gomes and Mendicino (2015) and more recently Lambertini et al. (2017) and Kaplan et al. (2020). The mechanism in this literature is through optimistic expectations about the future state of technology, policy, cost shocks and preferences, fuelling an asset price bubble. When this eventually bursts, it causes a recession. Meanwhile, it is generally assumed that policymakers do not have superior information about the economy, and therefore cannot distinguish excessive optimism or pessimism from a true shock to fundamentals in some future date.[23]

---

[22] Beaudry and Portier (2004, 2007) show that news about a future improvement in technology actually triggers a recession in a model with household preferences given by standard constant relative risk aversion. This arises due to a strong wealth effect on labour supply, as households reduce their labour effort, which reduces output. Jaimovich and Rebelo (2009) show how this can be overcome by using different preference and technology specifications. Cochrane (1994) anticipates the literature by noting that a number of standard, observed shocks fail to properly account for economic fluctuations, and suggests the importance of *unobserved* 'consumption shocks' in setting off a chain of events which drive a business cycle. See the review in Lorenzoni (2011) for further discussion. News shocks have also been applied to understand the effects of anticipated changes to labour and capital taxes on business cycle volatility; see Mertens and Ravn (2011) and Born et al. (2013).

[23] Lorenzoni (2009) on the other hand assumes that agents receive imperfect signals about the current (and therefore

Are house prices driven by news shocks? Wheaton and Nechayev (2008) find that growth in US house prices during 1998-2005 was significantly higher than what time series models of the housing market could predict on the basis of fundamentals. Iacoviello and Neri (2010) back-out the sequence of housing preference shocks from an estimated DSGE model of the US economy and find that other relevant observables not included in their structural model, such as mortgage transactions costs, the share of population aged 25-39 and the share of subprime mortagages in total mortgage lending can only explain about 15% of the the variation in these shocks during the period 1975-2006. While the rise in the share of subprime mortgages explains some of the increased housing demand during 2003-2006, observables alone cannot account for all of housing demand disturbances.[24] This evidence lends support to the hypothesis that waves of consumer sentiment, namely optimism or pessimism about the future, are important drivers of house price dynamics (Piazzesi and Schneider, 2009). Lambertini et al. (2013a) find that indeed this is the case in episodes of housing booms, where expectations of rising house prices explain an important share of house price variation.

On the basis of the above discussion, in this paper optimism relates to expected future demand for housing that move housing preferences j_t. Therefore movements in this term could be explained, *inter alia*, by actual *or perceived* changing attitudes towards housing, such as a drive by government encouraging broader home ownership, or expected demographic pressure such as migration.[25] Positive *unanticipated* housing preference shocks increase the marginal utility of housing, stimulating demand. Since housing supply is fixed, the increase in demand maps directly into an increase in house prices. This boosts net worth and relaxes borrowers' borrowing constraint, triggering a boom. This is also the case for an *anticipated* future increase in demand which is driven by news, since households are forward-looking and react immediately.[26] When this news turns out to be false, households realise that high house prices are not supported by fundamentals, and therefore housing is overvalued. The 'housing bubble' bursts, house prices revert to their original level, borrowers de-leverage, and consumption and output drop. The fall in households' net worth then further amplifies the contraction, as the borrowing constraint tightens and consumption falls further, and so on.

future) state of technology, that is, 'noise shocks' rather than news of some event happening in time $t + n$. A positive noise shock causes expectations to temporarily stray off from fundamentals, leading to a boom. Agents solve a signal extraction problem, learn about the noise over the passage of time, correct their expectations and revise their allocations. Despite these differences, Chahrour and Jurado (2018) show that news and noise shocks are observationally equivalent, and each one has an equivalent representation of the other.

[24] See Figure 7 and Web Appendix D in Iacoviello and Neri (2010).

[25] The 'buy-to-let' phenomenon, which took off in the mid-1990s in the UK due to regulatory changes to the mortgage market, is one such driver of housing preferences, formed under the belief of a positive net return from such investment.

[26] The model is based on representative saver (s) and borrower (b) households since there is no idiosyncratic risk within each household type. Yet there is a continuum of households within each type. Expectations about future housing demand movements that each individual household of type $i \in \{s, b\}$ forms relate in turn to beliefs it forms about the beliefs of all other households. Intuitively this is similar to the 'higher-order beliefs' framework as in Angeletos et al. (2018).

The process j_t follows a first-order autoregressive process in logs around the steady state value $\bar{\mathrm{j}}$, with zero mean i.i.d shocks. In addition to unanticipated housing demand shocks $\epsilon_{\mathrm{j},t}$, households are hit with news about a housing demand shock n periods in advance $\widetilde{\epsilon}_{\mathrm{j},t-n}$:

$$\log(\mathrm{j}_t) = (1-\rho_\mathrm{j})\log(\bar{\mathrm{j}}) + \rho_\mathrm{j}\log(\mathrm{j}_{t-1}) + \epsilon_{\mathrm{j},t} + \widetilde{\epsilon}_{\mathrm{j},t-n} \tag{2.27}$$

where $\epsilon_{\mathrm{j},t} \sim N(0,\sigma_\mathrm{j}^2)$ and $\widetilde{\epsilon}_{\mathrm{j},t-n} \sim N(0,\sigma_\mathrm{j}^2)$ are uncorrelated i.i.d. shocks. The shock $\widetilde{\epsilon}_{\mathrm{j},t-n}$ represents a news (belief) shock, received at time $t-n$, about an event happening at t. If this news shock, which is an expectation, turns out to be unfounded, then $\epsilon_{\mathrm{j},t} = -\widetilde{\epsilon}_{\mathrm{j},t-n}$ and the housing demand term j_t never actually moves. This mechanism captures the expectations-driven cycle described above, and is similar to shock processes used in other recent studies on macroprudential policies (Lozej et al., 2018; Ferrero et al., 2018). I assume that any news that arrives is about events 1 year into the future, so $n = 4$, as in Lambertini et al. (2013b, 2017).

Following Lorenzoni (2009, 2010) and Lambertini et al. (2013b), households, firms, the central bank and the financial regulator cannot distinguish between a true shock to fundamentals and a non-fundamental expectations shock. This also follows views shared by policymakers, as discussed by Trichet (2005). News about the future arrives exogenously, and there is no way ex-ante to verify the reliability of such news. From the point of view of policy, the non-fundamental housing demand shock is a distortion as it gives rise to an inefficient boom and bust cycle. In this context, there is a strong scope for active macroprudential policy (Lambertini et al., 2013b; Burlon et al., 2018).

2.4 Calibration

A period in the model is a quarter. Most of the parameters are set at values typically used or estimated in the literature based on US data. I set the discount factor β_s at 0.9901, such that in the steady state the annualised net interest rate is 4%, and β_b at 0.96, which is at the lower end of the range typically used in the literature, yet within empirical estimates.[27] I set both the inverse of the Frisch labour supply elasticity and the external habit persistence parameter ϱ at 0.5, as estimated in Iacoviello and Neri (2010).[28] The preference parameter on labour τ is set at 0.845 such that steady state output is normalized at 1.

I set $\bar{\mathrm{j}}$ at 0.06 such that the steady state level of total housing wealth to annual output is at about 1.4, the long run average for the US (Iacoviello and Neri, 2010), and $\overline{\mathrm{m}}$ to 0.9, which is the same value used by Rubio and Carrasco-Gallego (2014) and Iacoviello (2015). This LTV ratio reflects borrower household leverage which is high but within ranges observed in the data.[29] The share

[27] See Lawrance (1991), Carroll and Samwick (1997) and Samwick (1998).

[28] Their estimates for ϱ differ between savers (0.33) and borrowers (0.58). I use a figure close to the latter for both households to limit differences between them.

[29] As at 2007, LTV ratios varied between 0.63 and 1.01 across 15 countries in the euro area, whereas at the beginning

Table 2.1: Parameter values

Parameter	Value	Description	Target/Source
β_s	0.9901	Discount factor – savers	$\overline{R} = 4\%$ (ann.)
β_b	0.96	Discount factor – borrowers	$\overline{\mu} > 0$
φ	0.5	Inverse of Frisch labour supply elasticity	Iacoviello and Neri (2010)
τ	0.845	Preference parameter on leisure	$\overline{Y} = 1$
$\bar{\mathsf{j}}$	0.06	Preference parameter on housing	$\frac{qH}{4\times Y} = 1.4$
ϱ	0.5	Habit persistence	Iacoviello and Neri (2010)
$\overline{\mathsf{m}}$	0.9	LTV ratio	data
σ	6	Elasticity of substitution	20% mark-up
α	0.64	Share of labour income (savers)	Iacoviello (2005)
ω	0.75	Calvo parameter	standard
δ_π	1.5	Taylor rule coefficient on inflation	standard
δ_Y	0.125	Taylor rule coefficient on output growth	standard
δ_{m}	1	LTV rule coefficient on credit to output	optimal simple rule
ρ_R	0.8	Smoothness parameter for monetary policy	McCallum (2001)
ρ_{m}	0.8	Smoothness parameter for LTV policy	Rubio and Yao (2019)
ρ_A	0.95	Persistence of technology shock	standard
ρ_{j}	0.96	Persistence of housing preference shock	Iacoviello and Neri (2010)
σ_A	0.01	Standard deviation of technology shock	standard
σ_{j}	0.054	Standard deviation of housing preference shock	$\Delta q_t = 1\%$
σ_R	0.00115	Standard deviation of monetary policy shock	$\Delta R^{ann.} = 0.25\%$

of income from production accruing to savers α is set at 0.64, as estimated in Iacoviello (2005). This implies that savers own about 75% of housing wealth.[30] This calibration ensures that the collateral effect is strong enough to generate a positive response of output to a house price shock as in Iacoviello (2005).

The parameters involving price setting are standard. I set the elasticity of substitution between intermediate good varieties σ at 6, which implies a steady state mark-up over marginal costs of 20%, and the Calvo parameter ω at 0.75, which implies that on average intermediate goods firms can reset prices once every four quarters.[31]

The persistence parameter on the technology shock ρ_A, at 0.95, is standard in the literature, and the variance of the shock is set such that a positive 1 standard deviation shock increases productivity by 1%. The persistence parameter for the housing shock ρ_{j} is the same as the estimate

of 2016 this ratio amongst 8 such countries varied between 0.7 and 1.01 (ECB, 2009, 2016). In the US, Iacoviello and Neri (2010) report that in 2004 a significant share of new home buyers took loans with high LTV ratios, at an average of 0.94. More recently, Zabai (2017) documents a range of maximum LTV ratios between a minimum of 70% and a maximum of 125%.

[30] This calibration yields an implied steady state annualised Loan-to-Income (LTI) ratio of 1 for borrowers, which is low empirically. The macroeconomic effects over different levels of steady state leverage are discussed further below.

[31] A higher degree of price rigidity, as estimated for example in Iacoviello and Neri (2010), would imply stronger responses of real variables to shocks.

in Iacoviello and Neri (2010) at 0.96.[32] The shock variance is calibrated such that a 1-standard deviation shock produces a 1% increase in house prices on impact. The news shock has the same variance.[33] The variance of the monetary policy shock is set such that a 1-standard deviation shock raises the annualized nominal interest rate by 25 basis points.

Turning to the policy reaction functions, the inertia in the Taylor rule on the interest rate ρ_R is set at 0.8 as in McCallum (2001), which reflects a strong preference for small changes in the policy rate from one period to another. The coefficients of the Taylor rule are also standard, where δ_π is set at 1.5, and δ_Y at 0.125 (a response of 0.5 to annualised output). Finally, the reaction parameter on the LTV rule δ_{m} is set by following the Optimal Simple Rule (OSR) literature, and therefore deserves some discussion. The objective of macroprudential policy is to reduce systemic risk, but the latter is unobservable. Following Kannan et al. (2012), Angelini et al. (2014) and Rubio and Yao (2019), I assume that a suitable proxy for systemic risk is the variability of the credit to output ratio. Lower variability in this ratio would then be synonymous with reduced systemic risk. In principle it is possible to meet this objective quickly and effectively by triggering large movements in the LTV ratio, that is, setting a very high δ_{m}. Yet in practice this behaviour is hardly observed and any regulatory authority in general would want to avoid drastic and unpalatable policy measures, so I assume that the second objective of policy concerns the variability of the instrument.

I therefore specify the macroprudential loss function as the sum of the variability in both the credit to output ratio and the LTV ratio:

$$L = \sigma_\Omega^2 + \sigma_{\mathsf{m}}^2.$$

This welfare criterion follows the "revealed-preferences" approach of Angelini et al. (2014) and is not microfounded but modelled on policy experience. In contrast with the studies listed above, I do not include the variability of output as this could create some overlap between the goals of monetary and macroprudential policy, as discussed in section 2.2.5. I assign equal weight to the two arguments in the loss function, and find the parameter δ_{m}^* in (2.26) which minimizes this loss:

$$\delta_{\mathsf{m}}^* = \arg\min L(\delta). \tag{2.28}$$

This minimization is subject to the structure of the economy as described above. It is also subject to a fixed persistence parameter in the macroprudential rule ρ_{m} of 0.8, as in the Taylor

[32] The corresponding estimate in Liu et al. (2013) is 0.9987, since land prices are very persistent. This is in line with the discussion in Drehmann et al. (2014), who find that financial cycles, which are driven by credit and asset prices, are longer than typical business cycles.

[33] This shock is small enough to keep the borrowing constraint binding. A 2-standard deviation shock, even in the absence of a time-varying countercyclical LTV ratio, is also not big enough to raise housing wealth such that the borrowing constraint becomes slack. Later in the paper I re-calibrate the model and use a solution method which allows the borrowing constraint to become slack. Qualitative results remain unchanged.

rule, to reflect the fact that the LTV ratio is not changed frequently in practice, but once changed, is kept lower or higher for some time.[34] The solution to (2.28), obtained while taking monetary policy (that is, the reaction parameters of the Taylor rule) as given and fixed at the benchmark calibration, yields $\delta^*_{\mathsf{m}} = 0.99$, which is rounded to 1. This value will be used in the benchmark calibration. Robustness checks presented in Appendix A2.5 show that relaxing the assumption of equal weight on the two arguments in the loss function does not affect the results.

2.5 An asymmetric macroprudential rule

This section describes the conduct of macroprudential policy that is asymmetric; aggressive during credit booms but relatively weak during credit busts. As discussed in the introduction, this policy response is inherent in the pre-emptive character of macroprudential policy. Empirical evidence also suggests that macroprudential policy is typically more effective during credit booms (Cerutti et al., 2017), likely on account of more intense implementation during the build-up phase. Intuitively, a strong reaction to credit booms may represent a willingness to dampen the build-up phase of the credit cycle, such that in the wake of a bursting bubble, the economy experiences a more muted correction.[35]

A macroprudential policy function which reflects this asymmetry is given by:

$$\mathsf{m}_t = \overline{\mathsf{m}}^{(1-\rho_{\mathsf{m}})} \left(\frac{\Omega_t}{\overline{\Omega}}\right)^{-\widetilde{\delta}_{\mathsf{m}}(1-\rho_{\mathsf{m}})} \mathsf{m}_{t-1}^{\rho_{\mathsf{m}}} \tag{2.29}$$

where $\widetilde{\delta}_{\mathsf{m}} = \mathbb{1}_H \overline{\delta_{\mathsf{m}}} + (1 - \mathbb{1}_H)\underline{\delta_{\mathsf{m}}}$, with $\overline{\delta_{\mathsf{m}}} > \underline{\delta_{\mathsf{m}}}$ and $\mathbb{1}_H$ is an indicator function for periods of credit booms:[36]

$$\mathbb{1}_H = \begin{cases} 1 & \text{if } \Omega_t > \overline{\Omega} \\ 0 & \text{otherwise.} \end{cases}$$

As in the symmetric rule, I allow the policymaker to adjust the LTV ratio around its steady state value, subject to the same degree of persistence ρ_{m}. I set the asymmetry in rule (2.29) around δ^*_{m},

[34] The variance of the LTV ratio m_t is also influenced by the persistence parameter in the macroprudential rule (2.26); higher persistence implies a higher variance. In fact a minimization involving a search over both δ_{m} and ρ_{m} yielded negative values for ρ_{m}, which does not make practical sense. I therefore fix this at the same value as in the Taylor rule, which is consistent with values used in other studies. Rubio and Yao (2019) use the same value in their robustness analysis, while Burlon et al. (2018) set this parameter at 0.99.

[35] Røisland (2017) assumes that central bank preferences are asymmetric around asset prices, favouring minimum deviations from a target, but more concerned with asset prices rising above rather than falling below target. See also Funke and Paetz (2018) for a non-linear LTV rule that adjusts the LTV after a threshold for an indicator has been breached, motivated by the use of LTV policy in Hong Kong.

[36] A subscript on $\widetilde{\delta}_{\mathsf{m}}$ indicating its conditional (state) dependence would complicate notation unnecessarily, so is not used.

the optimal value of the reaction parameter in the case of the symmetric rule (2.26). Specifically, the reaction parameters $\overline{\delta_{\mathsf{m}}}$ and $\underline{\delta_{\mathsf{m}}}$ are defined such that their weighted average is δ^*_{m}:

$$\lambda\overline{\delta_{\mathsf{m}}} + (1-\lambda)\underline{\delta_{\mathsf{m}}} = \delta^*_{\mathsf{m}} \tag{2.30}$$

for $\lambda \in (0,1)$.[37] This permits a clearer definition of asymmetry as a departure from the special case $\overline{\delta_{\mathsf{m}}} = \underline{\delta_{\mathsf{m}}} = \delta^*_{\mathsf{m}}$, and allows a like-for-like comparison across policy implementation and economic performance. It is useful to define the strength of the asymmetry, the 'kink', as $\kappa = \overline{\delta_{\mathsf{m}}}/\underline{\delta_{\mathsf{m}}}$, where $\kappa \in [1,\infty)$, which is a measure of how strong the response is during a boom relative to a recession. In what follows I fix λ at 0.5 and assume a strong asymmetric motive, setting $\kappa = 5$. Values for $\overline{\delta_{\mathsf{m}}}$ and $\underline{\delta_{\mathsf{m}}}$ which satisfy restriction (2.30) at this asymmetry are 5/3 and 1/3 respectively. Thus, the unconditional 'average' response to credit gaps is 1, as in the symmetric rule. Later I show results over varying degrees of asymmetry.

Since the asymmetric rule (2.29) is not differentiable at the kink, standard local solution approaches based on perturbation cannot be used to solve the model. Instead, by casting the asymmetric macroprudential rule as an occasionally-binding constraint (OBC), I use the method proposed by Guerrieri and Iacoviello (2015), who argue that OBCs can be thought of as defining two regimes of the same model. In one regime the constraint binds, and in the other it is slack. The solution is based on a piecewise linear approximation around the non-stochastic steady state of the model. This approach has also been used to simulate monetary policy at the zero lower bound (Guerrieri and Iacoviello, 2017; Rubio and Yao, 2019). To the best of my knowledge this is the first attempt at using this technique to solve and simulate a model in which the occasionally-binding constraint is a macroprudential policy reaction function.

As discussed in Guerrieri and Iacoviello (2015), this solution method is fast, it can handle models with several state variables and has been shown to be highly accurate in selected models, with very low Euler equation residuals compared to a global solution. Furthermore, even though the model is approximated at first order, the solution can deliver significant non-linearities as the coefficients of the decision rules are dependent on the time agents believe the economy will be in any particular regime, which in turn is a function of the state variables. The limitation of this approach is that, since it is nevertheless based on linear approximations, it cannot account for precautionary behaviour, and therefore is not suitable for welfare analysis, which requires at least second order perturbation.[38] Consistent with the temporary nature of a bubble in this model, the

[37] This parameterization is assumed and is not derived from microfoundations; δ^*_{m} can be considered the parameter that an econometrician would likely estimate from a linear regression model of the macroprudential policy reaction function if she had time series data on LTV ratio policy decisions and the credit to GDP ratio.

[38] Guerrieri and Iacoviello (2015) show that the main difference between the piecewise linear solution and a global solution in a standard Real Business Cycle model, due to the precautionary behaviour of households, is very small. They also show that in the case of a New Keynesian model with non-zero inflation in the steady state, an additional source of approximation error is the non-linearity due to price dispersion. In this paper the steady

solution assumes a return to the reference regime in finite time.

For the moment, shocks are small enough to guarantee that the *borrowing* constraint faced by impatient households (inequality (2.6)) is always binding.[39] Therefore the regimes relevant for this solution relate to leverage relative to its steady state value; credit booms represent one regime and credit busts another. Each regime is associated with a unique value for the macroprudential reaction parameter $\widetilde{\delta}_{\mathsf{m}}$. I allow borrowing constraints to be slack in section 2.7.

2.6 Housing demand shocks

I now study how the model economy reacts to exogenous disturbances. Section 2.6.1 below shows dynamic responses to housing preference shocks, both unanticipated and anticipated, under the presumption that macroprudential policy is not active. In this case the LTV ratio is fixed. This allows the study of the response of the economy when the transmission of policy through the collateral channel is switched off. I then assess the role of macroprudential policy to these shocks in section 2.6.2, comparing different specifications of the reaction function. I generalize the result over varying degrees of policy asymmetry in section 2.6.3.

2.6.1 Unanticipated shocks and news shocks

Shocks either hit in the first period and are thus unanticipated, or hit in the future with some anticipation. I refer to unanticipated shocks, which adopt the standard timing in the literature, as the benchmark shock in each case. I will then explore the response of the economy to a shock with a different timing profile. Next is a shock which is anticipated at time t to hit in a year's time ($t + 4$), a news shock. The third type is the case when such anticipation is incorrect, such that expectations are overly optimistic or pessimistic. This is an unrealized news or bubble shock. The size of the shock is the same in all scenarios. I report similar analysis for technology and monetary policy shocks in Appendix A2.3 to save space, where I show that neither disturbances are relevant for the analysis of boom-bust cycles in which asset prices also rise significantly.

Figure 2.3 shows the effect of a housing preference shock which pushes house prices up by 1% on impact. Refer first to the case of an unanticipated shock which hits at time t (red dotted line). This rise in house prices increases the collateral value against which borrowers obtain credit. Impatient households, who experience a strong collateral effect from this appreciation, increase both their consumption and their housing investment on account of higher borrowing. This stimulates output, and therefore labour demand, raising marginal costs of production and pushing up inflation, and

state net inflation rate is zero, such that price dispersion is constant up to first order.

[39] Jermann and Quadrini (2012) follow a similar procedure in a model with an enforcement constraint on firms' borrowing, and show that the local and global approximations are almost identical when the constraint is binding.

the economy experiences a boom.[40] The increase in credit is higher than the rise in output, so the credit to output ratio rises. Since only monetary policy is active, a rise in output and inflation trigger a relatively strong increase in the nominal (and real) interest rate. Patient households react by lowering consumption and working more. The model predicts that consumption and labour profiles for borrowers and savers (not shown) reverse by quarter 6, reflecting a deleveraging process. The aggregate effect on output from this period on is positive but small, as different consumption profiles largely offset each other. Since the shock is highly persistent, house prices and debt follow a slow return to their steady state values.

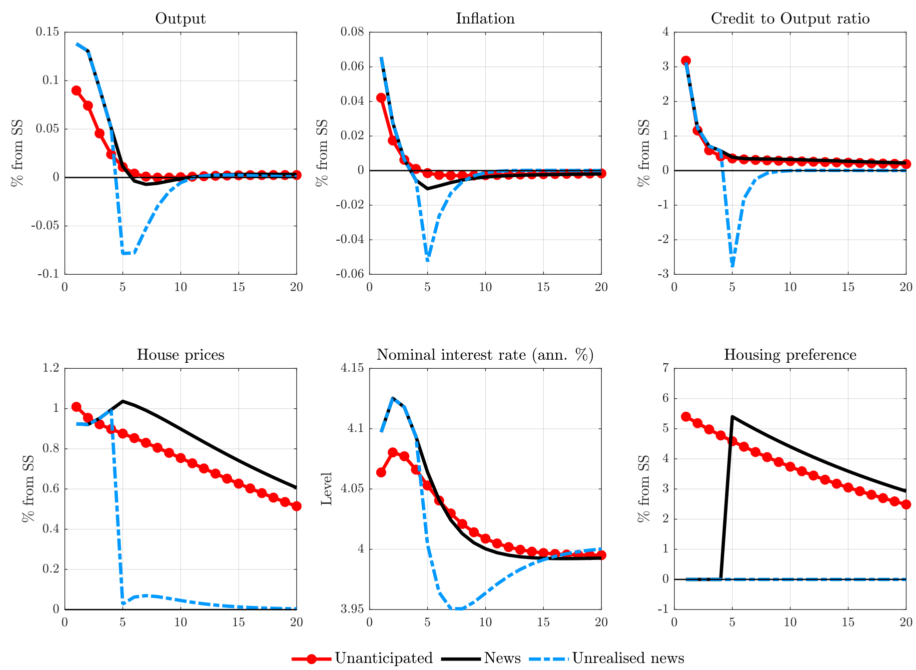

Figure 2.3: Impulse responses to housing preference shocks

Notes: Values on x-axis are time in quarters, on y-axis are percentage deviations from steady state, except for the interest rate.

The figure also shows the effect of a housing demand shock that is anticipated at time t to hit one year into the future (solid black line). This anticipation leads to a slightly stronger boom as output and inflation rise marginally higher than in the case of an unanticipated shock which is of the same magnitude but that hits immediately. Credit rises immediately, even though house prices in the first few quarters do not rise as much as in the benchmark case, since borrowers front-load the

[40] As shown in Iacoviello and Neri (2010), the response of the economy to a housing preference shock is more muted in the case of flexible wages, as is the case in this paper, compared to a model with both wage and price rigidity, since more adjustment has to be done by 'real' variable allocations.

wealth effect from the anticipated higher collateral value. The behaviour of the economy from the realization of the shock in quarter 5 onwards is very close to the case of an unanticipated shock.[41]

The third shock analysed is the case of an unrealized news shock. As discussed above, this reflects a scenario of excessive optimism about the future that generates a boom, in which housing experiences a bubble since the price does not reflect underlying fundamentals. Note also that the reaction of the economy in the first year is identical to that of the realized news shock. This is followed by a strong correction when agents do not observe a true shift in preferences after $t+4$ and realise that house prices are overvalued. House prices fall sharply, triggering a drop in impatient households' borrowing, consumption and housing investment via the collateral effect, tipping the economy into a recession.[42] Since borrowers have a much higher marginal propensity to consume, the drop in borrowers' consumption is about 5 times larger than the increase in consumption from savers, and this dominates the effect on output. This scenario is similar to the boom-bust cycle studied in Bernanke and Gertler (1999), although the latter achieve this by adding a corresponding negative asset price bubble to capture financial market panic once the positive bubble bursts.

The bust occurs in the context of a sharp 0.44 basis point cut in the nominal rate from peak to trough by the central bank. In further analysis (shown in appendix A2.3) I find that a higher coefficient on the output gap in the Taylor rule does not do much in dampening the boom and bust phase, illustrating the ineffectiveness of monetary policy during an asset price bubble. These results highlight the importance of having an additional lever on the economy, one more suited to mitigate the financial amplification that results from collateral effects, especially in the case of house price bubbles.

2.6.2 The role of macroprudential policy

Next I repeat the analysis of a boom-bust cycle driven by a house price bubble in the presence of an active macroprudential policy. I compare the outcomes under symmetric and asymmetric rules, and refer to the case of a fixed LTV ratio as shown in Figure 2.3. The benchmark case in this sub-section relates to the use of a symmetric LTV rule.

As discussed in section 2.3, in this model bubbles are irrationally exuberant only *ex-post*, leading to inefficient responses. Moreover, these inefficiencies are amplified by the financial accelerator. In such a case the need for a tool powerful enough to limit these inefficiencies is especially warranted. Figure 2.4 illustrates the usefulness of a time-varying LTV ratio as a tool in managing the economy during both boom and bust phases of the cycle. In the benchmark case, the peak and trough of the cycle are both dampened considerably by countercyclical movements in the LTV ratio. On

[41] The fact that the impulses for most variables are in phase with those in the benchmark case implies that these two shocks may be observationally equivalent, and therefore hard to identify when such models are estimated.

[42] Note how the housing preference term j_t never deviates from its steady state value in this scenario (dashed blue line).

the other hand an asymmetric countercyclical response to the same cycle reduces the build-up of credit and dampens the associated increase in demand that follows from the equity release of higher housing wealth. However, it can have undesirable side-effects during the bust that follows, since policy remains tight by keeping the LTV ratio relatively lower during the correction, causing a relatively bigger drop in credit and output. Figure 2.5 zooms in on these two scenarios.[43]

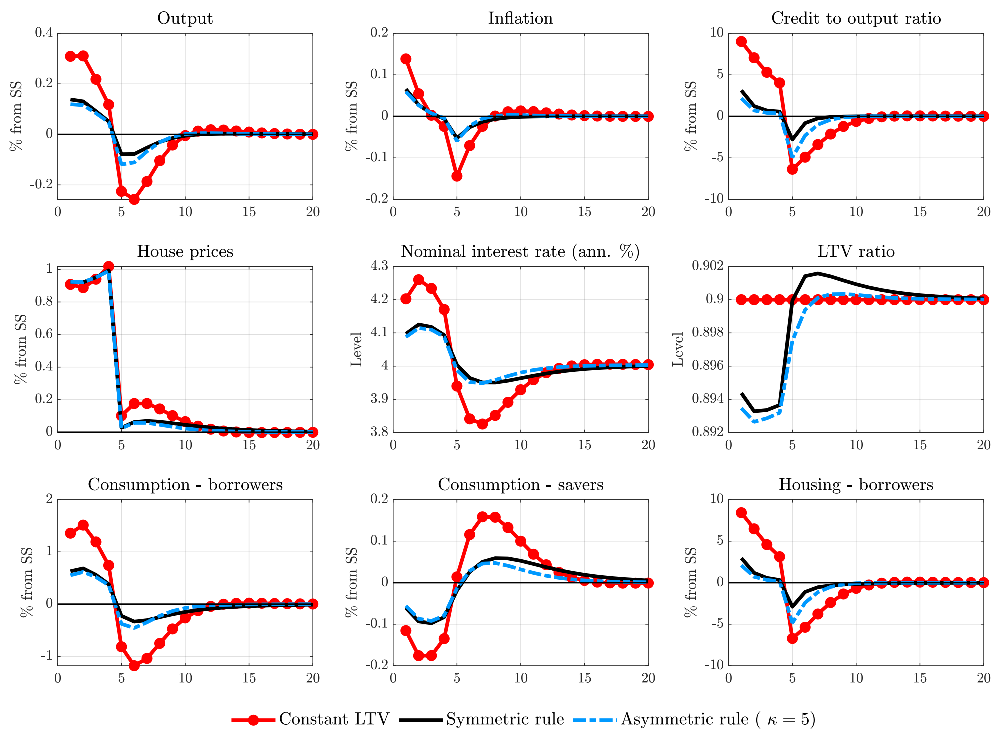

Figure 2.4: Impulse responses to an unrealized housing demand news shock

Notes: Values on x-axis are time in quarters, on y-axis are % deviations from steady state, except for the interest rate and the LTV ratio, which are in levels.

The lesson that can be drawn from this analysis is that although a time-varying LTV ratio can dampen an expectations-driven boom and bust cycle, it is important that macroprudential policy becomes accommodative as, and if, a bubble bursts. By *increasing* again the LTV ratio during the bust phase, the financial regulator can work against the collapse in housing wealth which tightens the borrowing limit. In contrast, by operating an asymmetric rule which is aggressive only during the build-up phase, the authority allows accelerator effects to worsen the bust. It is therefore more

[43] The calibrated steady state leverage is conservative, at a credit to GDP ratio of 30%. In Appendix A2.5 I show that these results are unchanged yet are more pronounced if leverage is closer to the levels observed in major advanced economies in the run-up to the 2008 financial crisis.

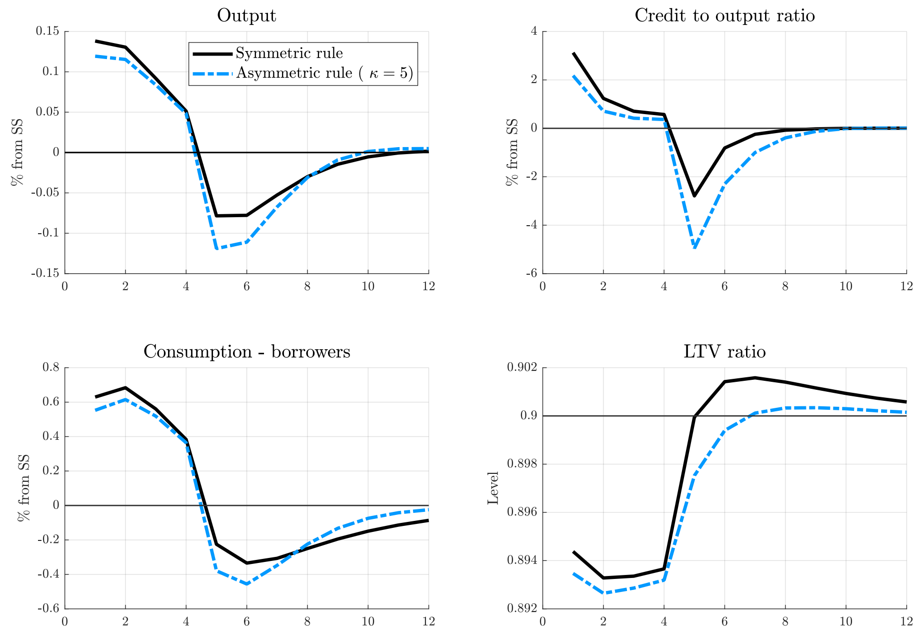

Figure 2.5: Responses across policy rules

Notes: Values on x-axis are time in quarters, on y-axis are % deviations from steady state, except for the LTV ratio.

desirable that the authority exploits the collateral constraint and associated accelerator effects by relaxing $\mathsf{m_t}$ *just as aggressively*, as soon as the data indicate a correction.

2.6.3 The relationship between asymmetry and volatility

The preceding analysis is based on an arbitrary kink κ in the macroprudential rule of 5, that is, a response which is 5 times stronger during credit booms than during credit busts. I now illustrate the general implications of asymmetric policy over a wide range for κ, in a setting in which all types of housing demand shocks can hit the economy at random. In a few instances all three shocks can be positive, big and hit at the same time – a housing demand shock that can be decomposed into an unanticipated component, an anticipated component, and a bubble component. When this happens their joint effect is strong and props house prices high enough such that the borrowing constraint becomes non-binding. To avoid this, I re-calibrate the variance of demand shocks σ_j^2 at 0.027 for this exercise, half the variance in the benchmark calibration. This ensures that, even in the case mentioned above, the increase in house prices does not render the borrowing constraint slack.[44] The re-sizing of the shock does not affect the results since under a first order perturbation the solution is in any case subject to certainty equivalence and is therefore scalable.

I simulate the model 1,000 times, for 100 years in each simulation, each time drawing random sequences of disturbances for the three housing shocks. This allows me to sample the average volatility of some variables within the model economy. I run these simulations for $\kappa \in [1, 10]$ in increments of 0.5 and compare, for each κ, the variance of saver and borrower consumption, output, inflation and the credit to output ratio relative to the benchmark case of symmetry (when $\kappa = 1$).[45] For comparability, I feed in the same sequence of shocks used over the 1,000 iterations for each value of κ.

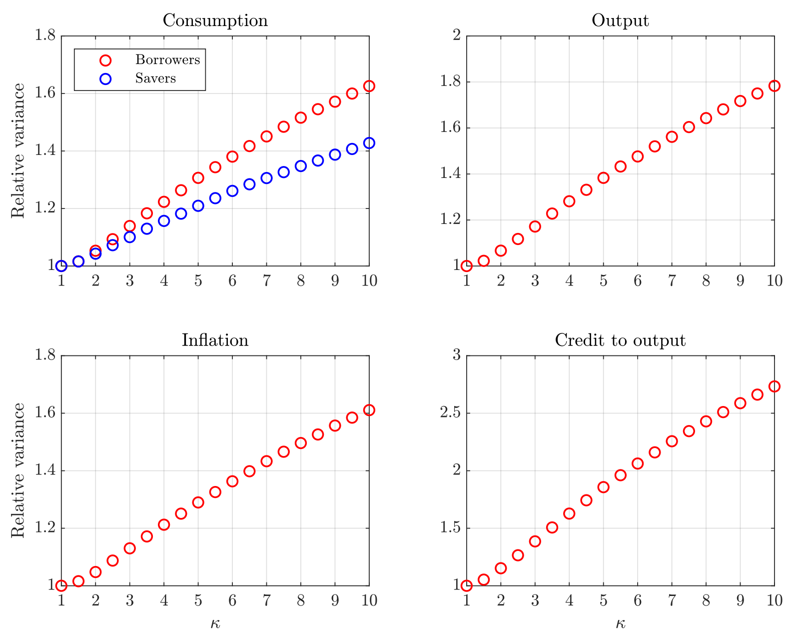

Figure 2.6: Relative volatility over the degree of asymmetry ($\kappa = \overline{\delta_m}/\underline{\delta_m}$)

The results, in Figure 2.6, display a clear monotone relationship between the degree of asymmetry in macroprudential policy and the relative variance of key variables. Stronger asymmetry on average leads to unequivocally higher output, inflation and credit volatility. The relationship between asymmetry and relative volatility is not linear; at low levels of κ the slope is high, falling over higher values. Asymmetric policy is never a superior policy to follow. A secondary but impor-

[44] I check that the Lagrange multiplier on the borrowing constraint μ_t is strictly positive throughout.

[45] The number of iterations, simulation length and increment in κ are influenced by the computational time required to complete one full round. The results indicate that these choices are sufficient to infer a clear pattern in the variance ratio.

tant consideration is that the higher induced volatility in inflation (and to a lesser extent, output) creates an exernality which may create tension between the goals of monetary and macroprudential policies. Asymmetric policy seems to partly undo the benefits that accrue under symmetric policy, in which small simultaneous movements in the nominal interest rate and the LTV ratio contribute collectively to greater macroeconomic stability.

In addition, the results also generalise the result that borrowers are hit worse by asymmetric policy. Their consumption variance rises at a faster rate over κ, reflecting the increased variability in credit, since they are credit constrained. While savers' consumption variance also rises, it does so at a slower rate, since they can optimise their consumption path. Therefore, the implementation of asymmetric macroprudential policy not only leads to inferior business cycle stabilization and negative spillovers to monetary policy, but also generates non-trivial differentials between savers and borrowers in the economy. The policy recommendation is clear: policymakers are ill-advised to follow such a strategy.

2.7 Asymmetries due to a slack collateral constraint

The asymmetric macroprudential rule (2.29) introduces a non-linearity in borrowing dynamics, leading to different regimes for positive and negative credit growth episodes. This non-linearity is reflected in policy functions that are kinked around the steady state. However, as discussed in Guerrieri and Iacoviello (2017), models with collateral constraints introduce another source of non-linearity since the constraint may not always bind. The interaction of this inequality with the asymmetric policy rule can give rise to interesting dynamics.

In models of the type explored in this paper, shocks that cause an increase in house prices q_t above some threshold will push the Lagrange multiplier on the borrowing constraint to zero, implying a slack collateral constraint. Borrowing is then strictly *less* than the future collateral value multiplied by the LTV ratio. This reduces the propensity of borrower households to consume out of rising housing wealth, dampening the financial accelerator. Consequently, output rises by less. To capture this in my analysis, I re-solve the model using the same piecewise linear perturbation approach as for the baseline model (in which the borrowing constraint always binds), but this time I write the collateral constraint as an inequality. There are now two such occasionally-binding constraints, one relating to the asymmetric response of the regulatory LTV ratio, as before, and another relating to the borrowing limit. In this analysis I re-calibrate the discount factor for impatient households β_b to 0.98. This allows the borrowing constraint to become slack without the need for excessively large shocks to housing preferences.[46] All other parameters, including the arbitrary asymmetric response $\kappa = 5$, are unchanged.

[46] This calibration implies that the borrowing constraint is slack about 14% of the time when the economy is perturbed by housing demand shocks, when policy is symmetric. See Table 2.2 below for more details.

This additional source of non-linearity leads to policy functions with *two* noticeable kinks, at different points on the state-space. Figure 2.7 shows policy functions over shifts in housing preferences, one for each policy regime. The slope first changes as we move from values for j below to values above the steady state level (diamond marker), which is due to asymmetric LTV policy. The more pronounced non-linearity occurs at the point when the borrowing constraint becomes slack (circle marker). There are actually more kinks in the policy functions at higher values of $\mathsf{j}/\bar{\mathsf{j}}$. These are changes in behaviour driven by the expectation by impatient households that the borrowing constraint will remain slack for an extended period before it becomes binding again. Hence, they become progressively less affected by changes in collateral values, leading to flatter policy functions.

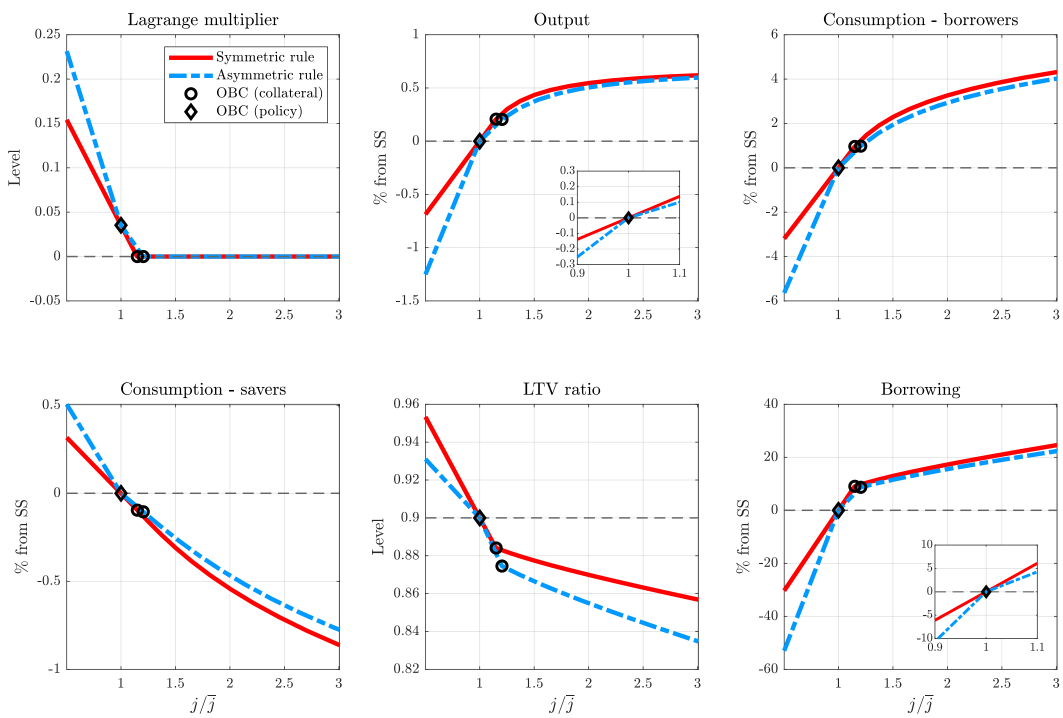

Figure 2.7: Policy functions over housing preferences j

Notes: Values on x-axis denote multiples of the steady state housing preference parameter $\bar{\mathsf{j}}$ ($\mathsf{j_{ss}}$ in the figure). Responses are based on the calibration $\beta_s = 0.9901$ and $\beta_b = 0.98$. The steady state on the grid is the point $\mathsf{j}/\bar{\mathsf{j}} = 1$. The inserts in the upper middle and lower right panels zoom in on the range $0.9 \leq \mathsf{j}/\bar{\mathsf{j}} \leq 1.1$ to highlight more clearly the change in slope due to asymmetric LTV policy.

Figure 2.8 shows the interaction of LTV policy and the collateral constraint following a housing demand bubble shock which pushes up peak house prices by 5% and creates a boom-bust cycle. The key result of this paper is unchanged; asymmetric LTV ratio policy, while helping to dampen the rise in credit and output during the boom, inevitably exacerbates the correction by keeping borrowing constraints tight. Borrowing constraints are slack in the first three of the four 'boom phase' periods of the bubble in the symmetric policy regime, and in the first period in the asymmetric policy regime. I show in Appendix A2.4 that the story is also unchanged under a larger shock which makes the borrowing constraint slack in all 4 periods under *both* policy regimes. In this case, the responses of credit and output are quantitatively very similar in the boom phase, since policy does not have a bearing on credit dynamics, but the correction under asymmetric policy is even more significant.

In the asymmetric policy regime the Lagrange multiplier reaches and stays at zero for the same number of periods as in the symmetric response, only following a stronger shock to housing demand. This is a direct consequence of tighter policy in the boom phase, which tightens the borrowing constraint, and works against the expected rise in house prices. Indeed, it can be argued that an additional motivation for asymmetric policy in this regard is precisely the nature of the occasionally-binding borrowing constraint – an increase in response asymmetry leads to collateral constraints binding more frequently.

To explore the link between how frequently the constraint binds with a rise in asymmetry, I simulate the economy over a grid for $\kappa \in [1, 20]$ with a long sequence of shocks as in the previous section and track the average number of periods in which the borrowing constraint is binding in each case. Since the range for κ is large, this exercise is computationally expensive. I therefore choose a non-uniform grid with more simulation points in regions around which there is relatively more curvature, interpolate between points using a cubic spline. A priori we expect a positive, monotonic relationship between these two factors. The economy can in principle be in any one of the four regimes at any point in time; positive or negative credit gaps (strong or weak LTV policy) in which the constraint can be binding or slack. However, it is unlikely for an households to be off their constraint during a credit bust (henceforth referred to as regime 4), since collateral values are typically low. I run these simulations for the baseline calibration of the model, as well as for an economy termed 'high leverage', in which the long run LTV ratio is 0.95 and steady state debt to output is 46% .[47]

As a benchmark, Table 2.2 shows the average number of periods spent in each of the four regimes under symmetric policy.[48] Note that, as expected, the economy never visits regime 4. The same holds for economy with higher leverage, although in this setting the constraint is slack more frequently since steady state house prices, and therefore borrowers' housing wealth, are both relatively higher.

Figure 2.9 breaks down the number of times the economy is in each regime as policy asymmetry

[47] More details on the high leverage calibration can be found in the robustness checks in Appendix A2.5.

[48] These numbers can be viewed as the stationary probability of being in any of the four 'states'.

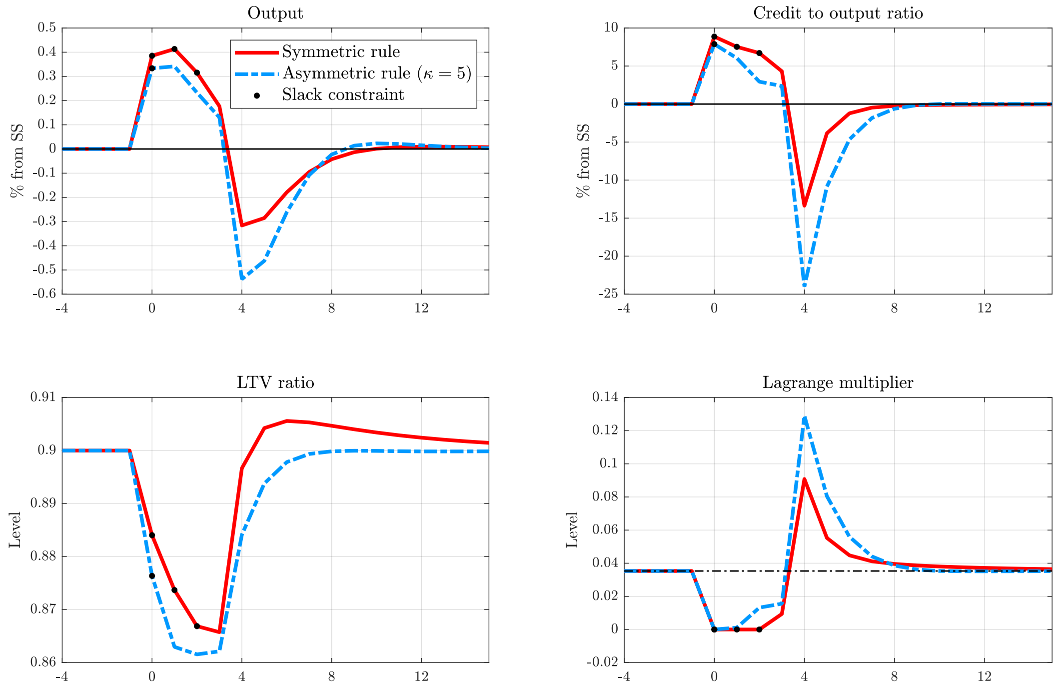

Figure 2.8: Dynamic effects of LTV ratio policy with slack borrowing constraints

Notes: Values on x-axis are quarters. Responses to a housing demand bubble shock which pushes up peak house prices by 5%, based on the calibration $\beta_s = 0.9901$ and $\beta_b = 0.98$. The news shock is received at time 0, and is corrected in quarter 4. The black circles indicate periods in which the borrowing constraint is slack.

Table 2.2: Frequency in each regime, symmetric policy (%)

	Constraint		Total
	Binding	**Slack**	
Benchmark calibration			
Credit boom	37.1	14.4	51.5
Credit bust	48.5	0.0	48.5
High leverage			
Credit boom	20.6	34.8	55.4
Credit bust	44.6	0.0	44.6

rises. Perhaps contrary to expectations, the relationship between κ and frequency of the constraint binding is not monotone. As LTV policy becomes slightly asymmetric, the borrowing constraint binds more frequently on average, as expected. However, the constraint starts to become *less* binding again at $\kappa \approx 4$. At the same time, we observe that the economy starts to experience a slack constraint during credit busts with some frequency greater than 0. This effect is stronger with higher leverage.

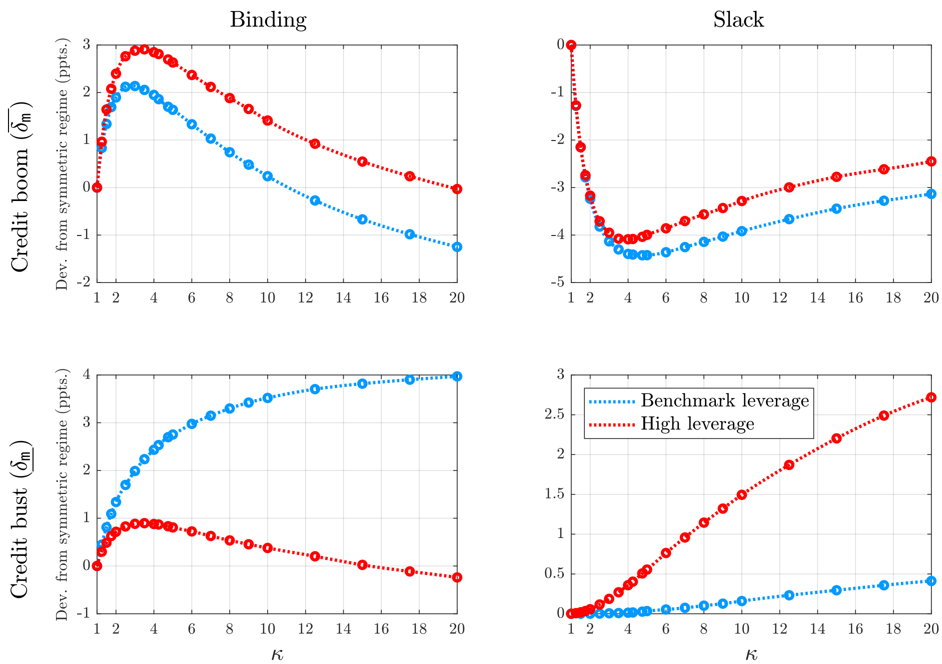

Figure 2.9: Policy asymmetry and regimes visited

Notes: Values on x-axis are the strength of the asymmetry $\kappa = \overline{\delta_m}/\underline{\delta_m}$. The y-axis measures the frequency in percentage that the economy is in any of the 4 regimes, expressed as a deviation from the frequency in the benchmark symmetric case $\kappa = 1$ as documented in Table 2.2.

These unexpected dynamics reflect a tug between two forces. The first is the fact that, with tighter policy (due to asymmetry), the LTV ratio is raised by less in a credit bust, yielding a relatively tighter constraint. This causes the economy to experience relatively longer credit contractions as policy asymmetry rises. The second force is increased inflation volatility when κ is high (as shown in the previous section), causing a stronger inflation pickup in a recovery, which lowers the cost of borrowing *ceteris paribus*. This latter force causes borrowers to increase their consumption and housing investment. These households increase their stock of housing not to increase current borrowing but to increase their resources, including the borrowing limit, in the future. Relatively lower real interest rates and higher housing wealth result in a slack constraint, despite the lower LTV ratio. The first force dominates for κ up to about 4, and the second for all higher values. As a result, asymmetric LTV ratio policy can control collateral constraints only to a limited extent over the credit cycle.

2.8 Policy implications

There are a number of policy issues relating to the implementation of macroprudential policies, not covered above, which deserve further discussion. Firstly, I put aside social considerations related to housing, and in the model I assume that all households have access to a minimum unit of housing. Since financial amplification is a function of net wealth, I also assume that utility is derived from owning a house, ignoring the rental market. Therefore, macroprudential policy as described in this paper operates on households which already own a housing unit, that is, those which are non-first time buyers. While it is possible in practice to operate a time-varying LTV ratio that affects *all* households, for social and distributional considerations it may be more palatable either to lower borrowing limits faced by *non*-first time buyers first, to target households which are already highly indebted or to lower LTV ratios for first time buyers less severely.[49]

Secondly, in addition to an LTV limit, caps on loan-to-income (lTI) or debt service-to-income ratios can also be used as other complementary tools to manage credit growth.[50] These tools add another layer of policy intervention when the LTV constraint does not bind in a boom. Yet, Cerutti et al. (2017) document very poor use of DTI instruments in advanced economies in the early 2000s, rising only after the crisis. In this paper no constraints on credit supply, such as a minimum capital-to-assets ratio, are made since credit intermediation is assumed to be frictionless. In practice the implementation of the Countercyclical Capital Buffer as prescribed by Basel III in Europe is indeed another tool which can curb credit and asset price growth. Policymakers can therefore select from a range of tools and coordinate their implementation to contain risks stemming in the financial sector more effectively.

A third consideration is the celebrated discussion on rules versus discretion, applied to macroprudential policy. Lim et al. (2011) note that most countries prefer to operate macroprudential tools on a discretionary basis, subject to a routine review and judgement on the state of financial risks. For instance, the Reserve Bank of New Zealand lists both the complexity of assessing risk that is not suitably captured by defining simple thresholds, and limited knowledge about the effectiveness of such policy, as key reasons to opt for discretion (Rogers, 2014). Although discretion gives policymakers flexibility in their decisions, it is likely to be less transparent than a rules-based approach and harder to communicate to the public. Discretion also implies that the public may

[49] The Reserve Bank of New Zealand operates a 'speed limit' restriction on the *share* of loans with an LTV ratio higher than a threshold, that is, it allows banks to issue only a limited number of loans with a high LTV ratio (Reserve Bank of New Zealand, 2013b). Its policies also distinguish between owner-occupied and rental investment house purchases.

[50] See the discussion in Chapter 1.

engage in a guessing game of timing exit strategies.

Nonetheless, regulators should not operate macroprudential policy mechanically, disregarding any other relevant information about the state of the economy. Communication on macroprudential policy measures is particularly important in this regard because, besides guiding expectations, it also preserves accountability by relating revisions to policy to the state of the economy. Financial stability reports and related publications do exactly this. For example, in addition to the Macro Financial Review, the Central Bank of Ireland publishes a bi-annual 'Systemic Risk Pack' which shows a heatmap over a broad range of indicators of risk. This is an effective way of communicating potential build-up of risk in a relatively simple way.

However, referring to a single, observable variable as key indicator projects a strategy and therefore helps shape expectations about the start of both tightening and loosening phases. Especially when experience is limited, such an indicator also allows policymakers to learn about the strength of the link between the tool and the indicator and fine-tune their strategies over time. As in the conduct of monetary policy, macroprudential policy decisions which appear to be inconsistent with that indicator can then be substantiated and justified by referring to more extensive analysis. This policy prescription finds middle ground between rules and discretion, so-called 'constrained discretion' (Bernanke, 2003).

2.9 Conclusion

In this paper I argue that the character of macroprudential policy is such that it can give rise to asymmetric responses during the boom and bust phases of an asset price bubble. I use a New Keynesian DSGE model with a financial friction that requires borrowing to be secured by housing collateral up to an LTV ratio. A housing bubble generates a boom-bust cycle in the real economy, due to the financial accelerator that is introduced by the financial friction. Policymakers intervene by varying the LTV ratio as a macroprudential tool to stabilize the cycle. Symmetric and asymmetric responses in the LTV ratio are compared.

While asymmetric policy helps to tame the increase in credit during the boom phase, relative to symmetric policy, it causes the economy to experience a deeper recession by not relaxing borrowing constraints at the same rate during the correction. I show that asymmetric policy hits borrowers proportionately harder since they are generally credit constrained and cannot smoothen consumption as efficiently as savers in the wake of shocks. The magnitude of both unfavourable outcomes also rises with the degree of asymmetry in the policy response. In this regard, policymakers are advised to unwind tight policy as soon as a bubble bursts, such that they work against and dampen the vicious downward collateral cycle, stabilizing business cycles better.

Appendix to chapter 2

A2.1 Data

The data used in Figure 2.1 are obtained from the FRED database. House prices are sourced from the U.S. Federal Housing Finance Agency (code: `USSTHPI`), and are deflated using the CPI sourced from the U.S. Bureau of Labour statistics (code: `CPIAUCSL`). Mortgage debt is sourced from the Board of Governors of the Federal Reserve System (code: `HMLBSHNO`). All annual series are end-of-period values. GDP is sourced from the U.S. Bureau of Economic Analysis (code: `GDPA`).

A2.2 Price setting

The maximisation problem faced by price setting firms is:

$$\max_{p_{j,t}} \mathbb{E}_t \left\{ \sum_{i=0}^{\infty} \omega^i \Lambda_{i,t+i} Y_{t+i} \left[\left(\frac{p_{j,t}}{P_{t+i}} \right)^{1-\sigma} - MC_{t+i} \left(\frac{p_{j,t}}{P_{t+i}} \right)^{-\sigma} \right] \right\}$$

Maximising with respect to $p_{j,t}$, and multiplying out all constants with respect to the sum:

$$\mathbb{E}_t \left\{ \sum_{i=0}^{\infty} \omega^i \Lambda_{i,t+i} Y_{t+i} (1-\sigma) \left(\frac{p_{j,t}}{P_{t+i}} \right)^{-\sigma} \left[\left(\frac{p_{j,t}}{P_{t+i}} \right) - \frac{\sigma}{\sigma-1} MC_{t+i} \right] \right\} = 0$$

$$\Rightarrow \mathbb{E}_t \left\{ \sum_{i=0}^{\infty} \omega^i \Lambda_{i,t+i} Y_{t+i} P_{t+i}^{\sigma} \left[\left(\frac{p_{j,t}}{P_{t+i}} \right) - \frac{\sigma}{\sigma-1} MC_{t+i} \right] \right\} = 0$$

Using the definition for the stochastic discount factor, and noting that $\widetilde{C}_{s,t}$ is constant with respect to the problem, we get:

$$\mathbb{E}_t \left\{ \sum_{i=0}^{\infty} (\omega\beta)^i \frac{Y_{t+i}}{\widetilde{C}_{s,t+i}} P_{t+i}^{\sigma} \left[\left(\frac{p_{j,t}}{P_{t+i}} \right) - \frac{\sigma}{\sigma-1} MC_{t+i} \right] \right\} = 0.$$

The price p_t^* which solves this can be written as:

$$p_t^* = \left(\frac{\sigma}{\sigma-1}\right) \frac{\mathbb{E}_t \left\{\sum_{i=0}^{\infty} (\omega\beta_s)^i \frac{Y_{t+i}}{\widetilde{C}_{s,t+i}} MC_{t+i} P_{t+i}^{\sigma}\right\}}{\mathbb{E}_t \left\{\sum_{i=0}^{\infty} (\omega\beta_s)^i \frac{Y_{t+i}}{\widetilde{C}_{s,t+i}} P_{t+i}^{\sigma-1}\right\}}$$

where the subscript j is dropped since all firms have the same technology and face the same demand curve, and hence will optimise in the same way. Multiplying both sides by P_t^{-1} we get relative prices:[51]

$$\frac{p_t^*}{P_t} = \left(\frac{\sigma}{\sigma-1}\right) \frac{\mathbb{E}_t \left\{\sum_{i=0}^{\infty} (\omega\beta_s)^i \frac{Y_{t+i}}{\widetilde{C}_{s,t+i}} MC_{t+i} \left(\frac{P_{t+i}}{P_t}\right)^{\sigma}\right\}}{\mathbb{E}_t \left\{\sum_{i=0}^{\infty} (\omega\beta_s)^i \frac{Y_{t+i}}{\widetilde{C}_{s,t+i}} \left(\frac{P_{t+i}}{P_t}\right)^{\sigma-1}\right\}}.$$

Following Christiano et al. (2011) and Ascari and Sbordone (2014), it is useful to represent the New Keyesian Phillips curve as

$$\frac{p_t^*}{P_t} = \left(\frac{\sigma}{\sigma-1}\right) \frac{\mathbb{E}_t \left\{\sum_{i=0}^{\infty} (\omega\beta_s)^i \frac{Y_{t+i}}{\widetilde{C}_{s,t+i}} MC_{t+i} \Theta_{t,t+i}^{\sigma}\right\}}{\mathbb{E}_t \left\{\sum_{i=0}^{\infty} (\omega\beta_s)^i \frac{Y_{t+i}}{\widetilde{C}_{s,t+i}} \Theta_{t,t+i}^{\sigma-1}\right\}} = \left(\frac{\sigma}{\sigma-1}\right) \frac{\Upsilon_t}{\Phi_t} \tag{A2.1}$$

where $\Theta_{t,t+i}$ represents cumulative gross inflation between two periods:

$$\Theta_{t,t+i} = \begin{cases} 1 & \text{if } j = 0 \\ \frac{P_{t+1}}{P_t} \times \cdots \times \frac{P_{t+i}}{P_{t+i-1}} & \text{if } j \geq 1. \end{cases}$$

The numerator Υ_t and denominator Φ_t can be written in recursive form:

$$\Upsilon_t = \frac{Y_t}{\widetilde{C}_{s,t}} MC_t + \omega\beta_s \, \mathbb{E}_t \left\{\pi_{t+1}^{\sigma} \Upsilon_{t+1}\right\} \tag{A2.2}$$

$$\Phi_t = \frac{Y_t}{\widetilde{C}_{s,t}} + \omega\beta_s \, \mathbb{E}_t \left\{\pi_{t+1}^{\sigma-1} \Phi_{t+1}\right\}. \tag{A2.3}$$

Since the probability of adjusting prices is independent of a firm's history, from the law of large numbers the aggregate price[52] is a weighted average of optimised prices and previous period prices:

$$P_t^{1-\sigma} = (1-\omega)(p_t^*)^{1-\sigma} + \omega P_{t-1}^{1-\sigma} \tag{A2.4}$$

[51] I use the algebraic trick $P_t^{-1} \equiv P_t^{(-1+\sigma-\sigma)}$.

[52] The aggregate price is a CES aggregate of prices over the continuum of firms:

$$P_t = \left(\int_0^1 p_{j,t}^{1-\sigma} \, dj\right)^{\frac{1}{1-\sigma}}.$$

which can be used to solve for relative prices as a function of inflation:

$$\frac{p_t^*}{P_t} = \left(\frac{1-\omega}{1-\omega\pi_t^{\sigma-1}}\right)^{\frac{1}{\sigma-1}}. \tag{A2.5}$$

This can be used to eliminate p^*, and the optimal pricing equation can therefore be written as:

$$\Upsilon_t = \left(\frac{\sigma-1}{\sigma}\right)\left(\frac{1-\omega}{1-\omega\pi_t^{\sigma-1}}\right)^{\frac{1}{\sigma-1}}\Phi_t. \tag{A2.6}$$

Equations (A2.2), (A2.3) and (A2.6) jointly determine price dynamics.[53]

A2.3 Other shocks and monetary policy

A2.3.1 Technology shock

Figure A2.1 shows the response to a positive technology shock. An unanticipated increase in productivity boosts output, demand and income, while inflation falls, due to the drop in marginal costs. Falling prices cause the monetary authority to cut the nominal interest rate. However, since the drop in inflation is more pronounced than in the benchmark case, the real interest rate rises strongly, increasing the cost of borrowing. Therefore impatient households do not increase their consumption initially, despite the increase in house prices, and actually reduce their holdings of debt and housing (not shown). Hence the increase in output is driven largely by savers in the first year of the boom. Subsequently the nominal interest rate falls further, while deflation slows down, lowering the real interest rate. Borrowers increase their consumption and borrowing in the second year following the shock. In sum, an unanticipated shock to technology raises output and house prices but does not generate a strong increase in credit. There is then little scope for macroprudential policies in this case, which is the conclusion reached by Kannan et al. (2012) in the wake of productivity shocks.[54]

The response of some variables to a technology news shock is the opposite of those discussed above. In the case of an anticipated improvement to technology a year into the future, impatient households increase their borrowing and consumption immediately, the latter by several orders of magnitude greater than savers. Furthermore there is now a steady *increase* in credit which is driven

[53] This specification nests the familiar log-linearized version but has the advantage that it can be used to study dynamics based on higher order perturbations (Schmitt-Grohé and Uribe, 2006) or simulations around a non-zero steady state inflation rate (Ascari and Sbordone, 2014).

[54] Liu et al. (2013) show that permanent or temporary shocks to Total Factor Productivity do not lead to amplification in the case when it is firms which face the borrowing constraint, as neither shock in their model leads to sizeable changes in land prices. While in this paper technology shocks do raise house prices, amplification is muted by the strong rise in the real interest rate.

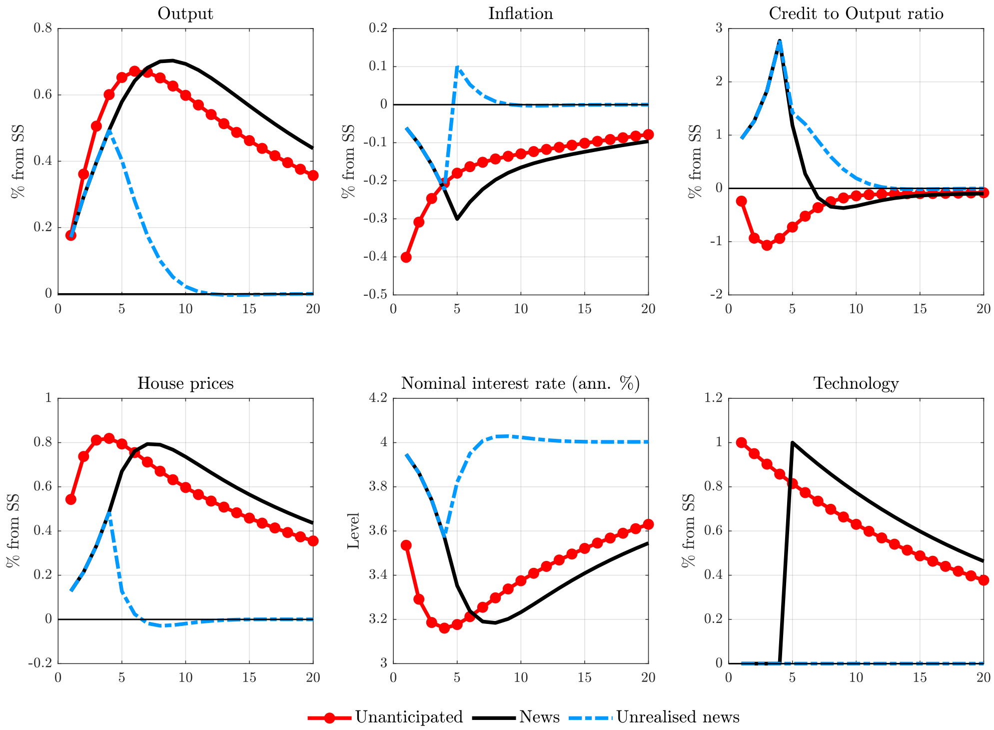

Figure A2.1: Impulse responses to technology shocks

Notes: Values on x-axis are quarters.

by a corresponding increase in house prices. The dynamics of the real interest rate play an important role in explaining these differences. Inflation starts falling despite increases in marginal costs, on account of an expected reduction in future marginal costs from the improvement in productivity, and bottoms out upon the realisation of the higher productivity. Meanwhile the response of the nominal interest is more muted, since inflation falls only gradually, and the nominal rate is subject to some inertia. As a result the rise in the real interest rate is contained, which explains the increase in credit. As in the case of a housing demand shock, anticipation effects again lead to a slightly stronger boom than in the benchmark case. This is because house prices peak towards the end of the second year following the shock, which keep borrowers' consumption buoyant over a longer period.[55]

In the event that the anticipated productivity shock does not occur, the boom in the economy stops abruptly and output falls back to its pre-shock level. Inflation shoots up since the rise in

[55] The cumulated increase in output is about 16.9% higher than the steady state for the benchmark case, compared to about 19.2% in the case of a news shock.

marginal costs in the anticipation stage is not reversed by an actual improvement in productivity, and this reduces the real interest rate temporarily. As a result borrowers reduce their consumption and deleverage at a slower rate, even though house prices fall back to their original level very quickly. Although the boom in output and house prices is short-lived, optimistic expectations about productivity fail to generate a boom-bust cycle.

A2.3.2 Monetary policy shock

An unanticipated negative shock to nominal interest rates, defined as a nominal interest rate below what the Taylor rule prescribes, is expansionary. This is a basic feature of the short-run non-neutrality of monetary policy due to nominal rigidities, present even in 'first-generation' New Keynesian models that are void of any financial frictions (Binder et al., 2017). The drop in the nominal rate boosts demand by lowering the real interest rate thereby reducing the opportunity cost of saving. In this model most of the increase in output is not driven by consumption smoothing from patient households, but by consumption from impatient households, whose borrowing limit rises as the real interest rate falls. The increase in demand for the final good pushes up marginal costs and hence inflation, driving the real interest rate further down. Borrowers find it optimal to use part of the increase in credit to invest in more housing, while savers respond primarily by increasing their labour supply. Since the shock is not intrinsically persistent, the boom lasts only for about 2 years, at which time credit, house prices and output are at their steady state values.

Anticipation of an interest rate cut one year in the future is also expansionary, however the model predicts a smaller initial impact on output. This is because while anticipation of a lower nominal rate stimulates demand before the rate has moved, borrowing is at a relatively higher real interest rate than in the benchmark shock. Moreover, the increase in demand and inflation stimulates an immediate *increase* in the nominal rate, as the monetary authority responds to a perceived demand shock. As a result impatient households' credit, consumption and housing investment rise by less. As monetary policy actually cuts the nominal rate in quarter 5, the real cost of borrowing falls, which supports higher credit relative to the benchmark case. This however has a small effect on house prices. As a result output and inflation remain higher for a few additional quarters. In sum, both unanticipated and anticipated monetary policy shocks are both expansionary and generate a boom in output and credit.

If the expected monetary loosening does not take place in quarter 5, the model predicts a sharp correction in output, inflation and credit, arising from a revision to expectations. Since the nominal rate does not fall, current levels of consumption, borrowing and labour are out of line with optimal decisions and hence are all revised. Impatient households deleverage, cutting back on their consumption and run down their debt. The drop in demand lowers inflationary pressures, causing the real interest rate to rise, which further depresses consumption and borrowing. The economy

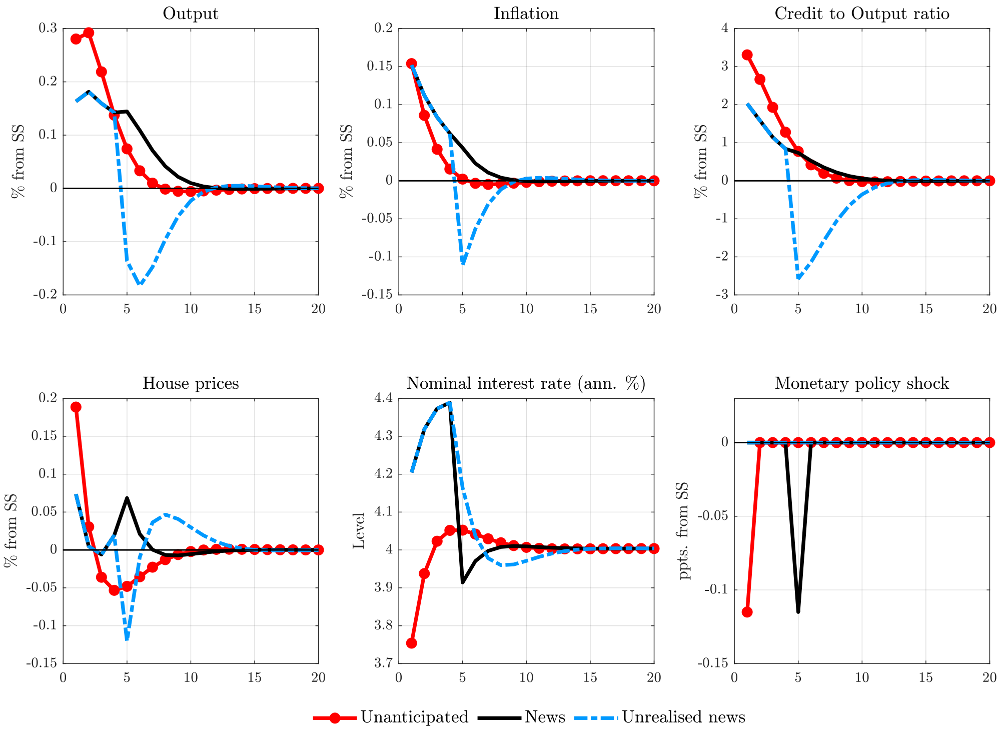

Figure A2.2: Impulse responses to monetary policy shocks

Notes: Values on x-axis are quarters

experiences a short recession as a result of the excessive optimism on borrowing conditions.

While an unrealized monetary policy shocks can give rise to a boom-bust cycle, the effect comes mainly from the dynamics of the real interest rate, with little amplification and feedback between house prices and credit, and consequently house prices do not deviate too much from fundamental value. The only shock that can generate amplification and feedback between credit and house prices is a housing demand shock. Because of this, only excessively optimistic expectations about future asset prices can generate a sizeable boom-bust episode reminiscent of the development and bursting of a bubble. For this reason I restrict my attention to housing demand shocks.

A2.3.3 A stronger Taylor rule response to the output gap

Figure A2.3 below follows on the analysis in section 2.6.1, where the economy is subject to housing preference shocks with different timing structure, but with a Taylor coefficient that is twice as strong, i.e. $\delta_Y = 0.5$. The figure shows that despite reacting much more aggressively, monetary policy is relatively ineffective in dampening the boom. Inflation rises by less than in the case of a standard Taylor rule, but the strong boom-bust cycle in credit materializes nonetheless.

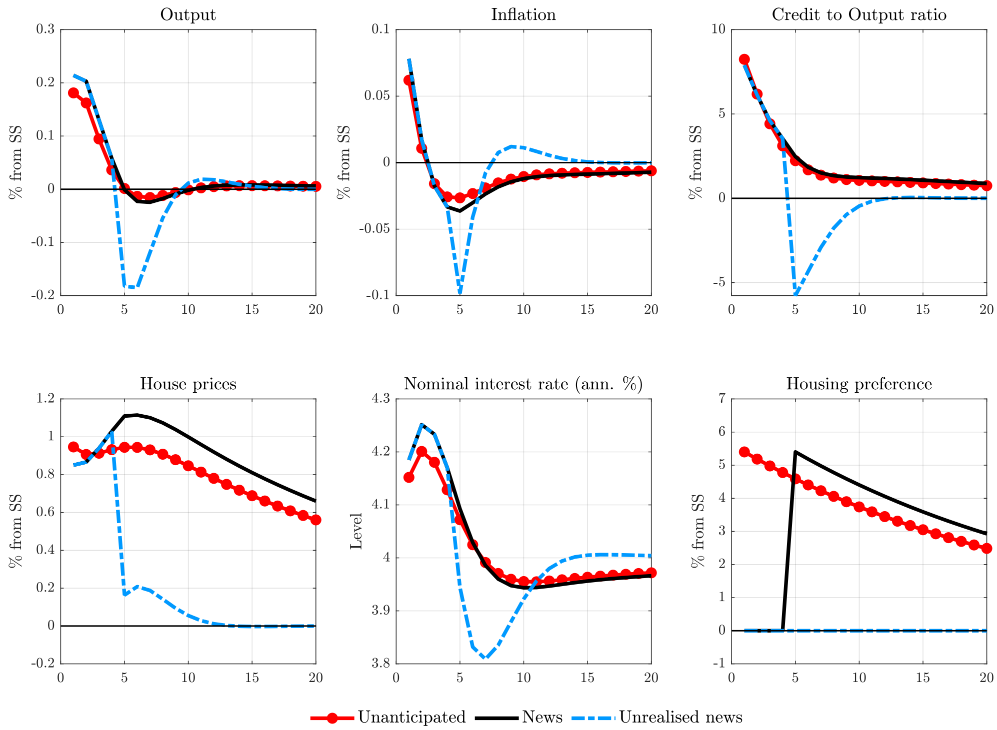

Figure A2.3: Impulse responses to housing preference shock, with $\delta_Y = 0.5$ in the Taylor rule
Note: Values on x-axis are quarters.

A2.4 Allowing for slack borrowing constraints

Figure A2.4 shows the dynamic response of the model over different policy regimes during a boom-bust cycle which raises peak house prices by 10%. The collateral constraint is slack throughout the boom phase of the cycle in both policy regimes. While the responses of credit and output are quantitatively similar during the boom phase, the differences in the bust phase are pronounced.

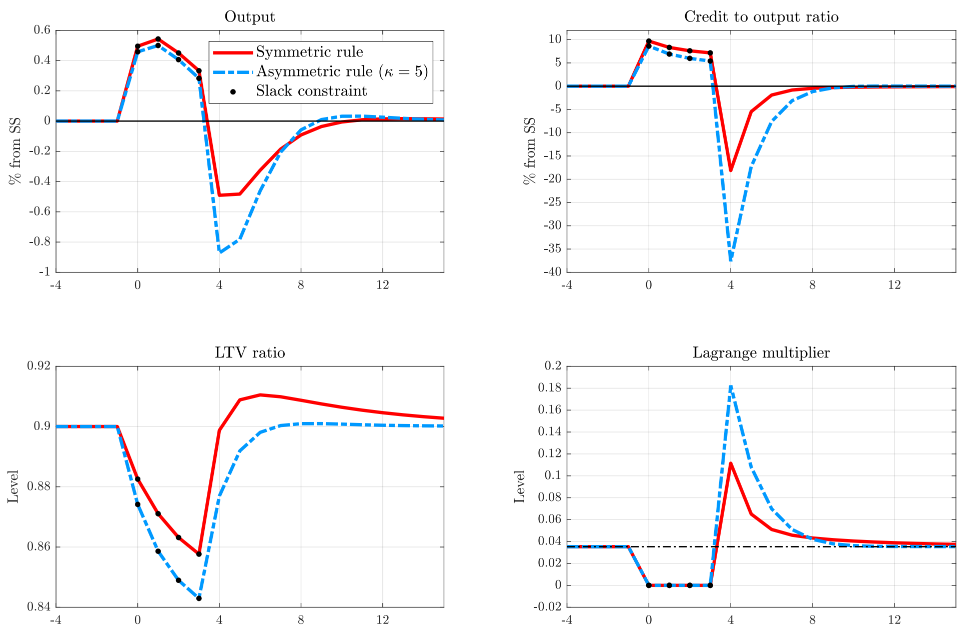

Figure A2.4: Dynamic effects of LTV ratio policy with slack borrowing constraints

Notes: Values on x-axis are quarters. The news shock is received at time 0, and is corrected and quarter 4. The black circles indicate periods in which the borrowing constraint is slack. Responses to a housing demand bubble shock which pushes up peak house prices by 10%, based on the calibration $\beta_s = 0.9901$ and $\beta_b = 0.98$.

A2.5 Robustness checks

A2.5.1 The optimal simple macroprudential rule

In the benchmark calibration for the reaction parameter δ_{m}, the weights in the loss function $L = \sigma^2_{\Omega} + \Theta\sigma^2_{\mathsf{m}}$ on the variance of credit to output and on the variance of the LTV ratio are assumed to be equal ($\Theta = 1$). The value which minimizes this loss is $\delta^*_{\mathsf{m}} = 1$. To assess the sensitivity of my results to this assumption, I re-compute the optimal reaction parameter for over a wide range for Θ.[56] Figure A2.5 shows the optimal value of the reaction parameter δ^*_{m} for weights on the variance of the policy tool Θ ranging between 0.2 to 2 ($\Theta = 1$ is represented by the dashed red line). As the financial regulator becomes more concerned with the variance of the tool, the value of the reaction parameter that minimizes the loss falls. Note that the overall loss is minimized when no consideration is given to strong movements in m_t, yielding a very high reaction parameter. In this case policy would tighten the borrowing constraint significantly, minimizing the variance in credit.

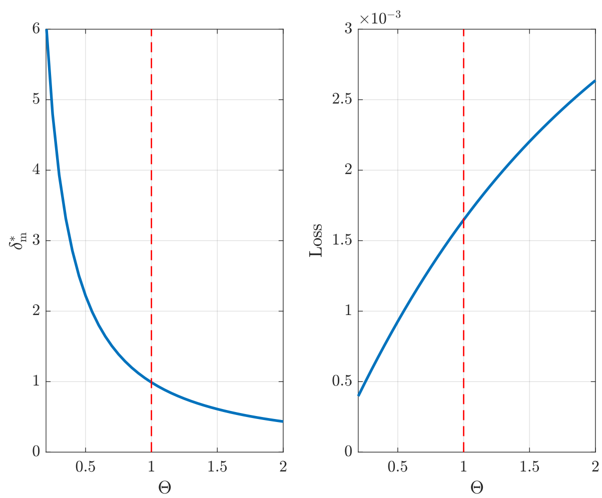

Figure A2.5: Optimal values of δ_{m} and associated minimum loss at different weights on the variance of the LTV ratio

Figure A2.6 compares the dynamics of output and credit following a housing bubble shock for optimal values of δ_{m} that correspond to Θ at 0.5 and 2 (2.22 and 0.434 respectively) with those under the benchmark assumption of $\Theta = 1$ (the same responses as in Figure 2.5, shown in

[56] The relationship between the weight on the variance of the LTV ratio and the optimal reaction parameter and associated loss are document in Appendix A2.5.

gray lines). Although the magnitudes of the responses of output and credit change with different macroprudential response parameters, the key conclusion that asymmetric policy exacerbates the recession holds. The stronger the weight on the LTV ratio in the loss function, the lower is the response parameter in the symmetric rule, over which the asymmetric rule is calibrated. A weaker response, under both symmetric and asymmetric policy, leads to a stronger (inefficient) boom but also a deeper bust. Moreover, the weaker is the response, the more pronounced is the difference in the output drop between the two policy regimes.

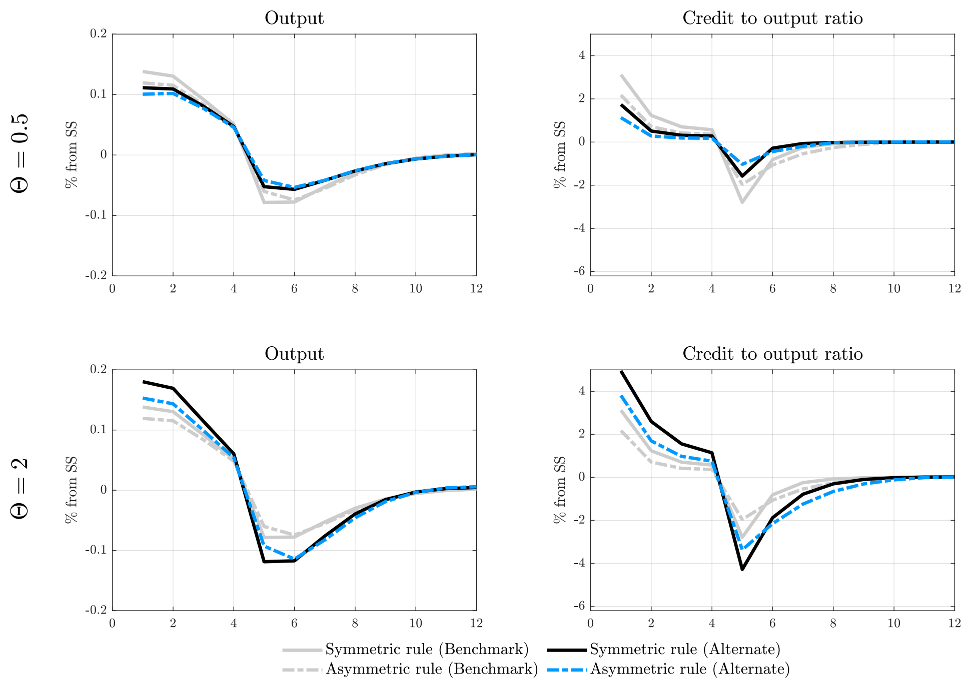

Figure A2.6: Responses across policy rules with different optimal δ_m

Notes: Values on x-axis are time in quarters, on y-axis are % deviations from steady state.

A2.5.2 The role of leverage

The economy described by the benchmark calibration is not highly leveraged when compared to the average levels observed in major advanced economies over the last 20 years. As shown in section 2.2.7, the steady-state LTV ratio $\overline{m}$ and housing preference term $\bar{j}$ control the aggregate housing wealth to output and the credit to output ratio. The simulations carried out above are conditional on housing wealth to (annualised) output $\frac{qH}{4\times Y} = 1.4$ and credit to (annualised) output ratio $\frac{B}{4\times Y} = 0.3$ in the steady state. Such levels of mortgage debt to GDP were observed in the US, UK and Germany during the liberalization of financial markets in the mid-1980s (see Figures 2.1 and 2.2). The extent by which the impact of symmetric and asymmetric macroprudential policies on the economy differs is conceivably also affected by the level of steady state leverage since, as Iacoviello (2005) shows, financial amplification is a function of leverage. To examine these differences I repeat the boom-bust simulation above for an economy with both higher and lower steady state credit to output ratios. In the case of higher leverage, I set $\overline{\mathsf{m}}$ at 0.95 and $\bar{\mathsf{j}}$ at 0.08, which yield an annualised credit to output ratio of 46%, a scenario termed 'High leverage'. This is a level observed in the US, UK, Germany and Spain in the early phase of the property price boom that preceded the crisis of 2007/2008. In the case of lower leverage, I set $\overline{\mathsf{m}}$ at 0.75 and $\bar{\mathsf{j}}$ at 0.04, yielding an annualised credit to output ratio of 13% (termed 'Low leverage'). This is a level observed in the US and Germany in the mid-1950s and in the UK in the mid-1960s.[57] Table A2.1 shows comparative statics over these parameter configurations.[58]

Table A2.1: Comparative statics over the steady state LTV ($\overline{\mathsf{m}}$) and housing preference weight ($\bar{\mathsf{j}}$)

	$\bar{\mathsf{j}}$	$\overline{\mathsf{m}}$	$\frac{qH}{4\times Y}$	$\frac{B}{4\times Y}$
Leverage				
Low	0.04	0.75	0.88	0.13
Benchmark	0.06	0.90	1.41	0.30
High	0.08	0.95	1.93	0.46

Figure A2.7 show comparative statics over these parameter configurations, and illustrate the non-linearity in the steady state debt to output ratio over high levels of the LTV ratio and housing preference term. The simulations under low and high leverage are shown in Figure A2.8, against the responses in the benchmark calibration. When leverage is low, the reaction of the economy to the bubble shock is muted, and the difference in the profile for output over symmetric and asymmetric policy is minimal. This difference is noticeable at the benchmark calibration. At high levels of credit to output, the response of output is stronger due to higher amplification, and the implementation of asymmetric policy leads the economy into a deeper recession as the bubble bursts. In fact, the difference in the profile for output over the two policy regimes is positively related to the degree of leverage, as shown in Figure A2.9. Higher leverage leads to a stronger financial accelerator, causing the economy to react more strongly to the shock. These results confirm the main finding that

[57] These LTV ratios are very close to the 'low' and 'high' values used by Iacoviello and Neri (2010) when they estimate their model over two sub-samples, 1965–1982 and 1989–2006.

[58] More information on the relationship between preferences, regulatory LTV ratios and leverage are shown in Appendix A2.5.

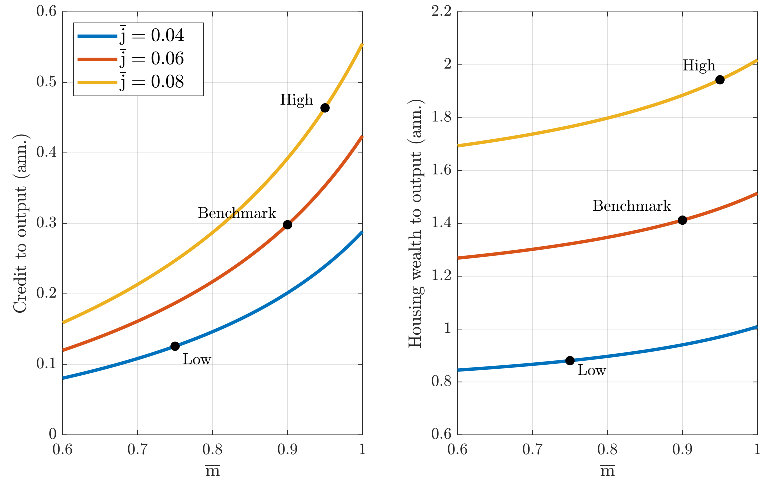

Figure A2.7: Comparative statics over $\overline{\mathrm{m}}$ and $\bar{\mathrm{j}}$

asymmetric policy exacerbates a recession upon the bursting of a bubble, and the more leveraged the economy, the deeper the recession.

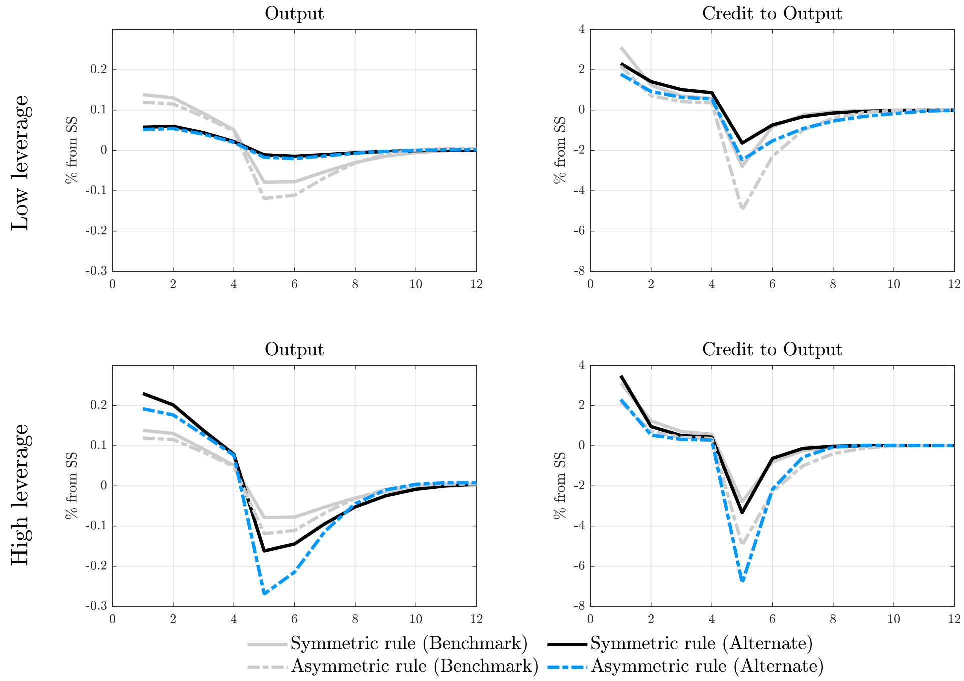

Figure A2.8: Responses across policy rules

Notes: Values on x-axis are time in quarters, on y-axis are % deviations from steady state.

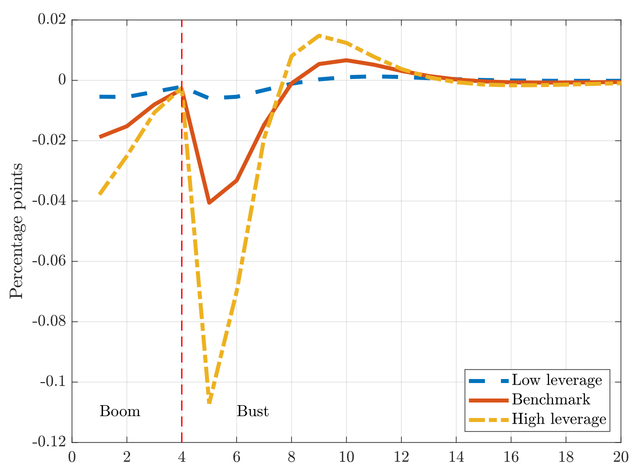

Figure A2.9: Difference in output responses across policy regimes

Notes: Values on x-axis are time in quarters, on y-axis the response of output under asymmetric policy less that under symmetric policy.

Chapter 3

Wealth inequality and the distributional effects of maximum loan-to-value ratio policy*

Abstract

Are there unintended long run consequences to the introduction of a macroprudential policy regime, and are these consequences conditional on the a priori level of wealth inequality? I answer these questions by looking at the effect of a reduction in the maximum loan-to-value (LTV) ratio on homeownership rates, house prices and housing wealth inequality across two economies with different intial wealth dispersion. I use a heterogeneous agent model in which households face uninsurable income risk and an endogenous borrowing limit in the form of a collateral constraint. This constraint is initially loose, allowing households to lever up against the collateral value of their housing. A lower LTV limit tightens the borrowing constraint, and lowers homeownership as a greater share of households no longer afford the downpayment. I find that initial conditions matter; the lower is wealth inequality *ex-ante*, the higher is the fall in house prices and the gearter is the rise in the share of constrained homeowners and housing wealth inequality *ex-post*. The effects are also non-linear in the LTV ratio, with progressively stronger effects at lower LTV ratios, especially when inequality is comparatively low.

Keywords: *wealth distribution, housing, macroprudential policy, loan-to-value, housing inequality*
JEL codes: E21, G11, G28, G51, R21

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3.1 Introduction

Macroprudential policy regimes were introduced in several countries in the wake of the financial crisis, with the aim of stabilizing financial cycles and discourage excessive risk-taking. Maximum loan-to-value (LTV) limits for household credit is one such policy that belongs to this toolkit. An LTV cap limits the leverage that a household can build and encourages saving by requiring households to put up a higher downpayment when purchasing real estate. For example, the Reserve Bank of New Zealand introduced a maximum LTV ratio of 80% for most households, allowing only a 'speed limit' of 10% of transactions to be at a higher LTV ratio.[1] The experience so far seems to have been positive, however it is clear to policymakers that these policies can have unintended consequences (Cassidy and Hallissey, 2016; Lu, 2019).[2] A household is prevented from buying a house if it does not have enough equity, even if it can service the debt. Besides forcing such a household to rent, this policy limits the household's asset portfolio, and can potentially deprive the wealth gains brought about by house price appreciation.

In this paper I focus on the long-run unintended consequences of LTV policies. The discussion on unintended consequences is especially relevant since housing tends to be the largest asset holding of the 'middle class' households (Piketty, 2014, p.260). In the US, for example, wealth of the bottom 90% of households is composed mainly of housing as the main asset, and very few financial holdings, while liabilities constitute primarily of housing debt and other debt, such as student and car loans (Kuhn et al., 2020).[3] Meanwhile, renters account for about a third of all households in the UK and US and tend to have little wealth (Davis and Van Nieuwerburgh, 2015; Cloyne et al., 2020). Cloyne et al. (2019) show that the collateral channel of housing is important for explaining movements in household borrowing in the UK.

The literature on macroprudential policies is growing but most studies focus on short to medium term business cycle frequencies, while the long term effects of such policies are less explored. Baker (2017) argues that the potential for distributional effects stemming from macroprudential policy is high. Frost and van Stralen (2018) look at the empirical link between macroprudential policy tools and measures of income inequality over the period 2000–2016. They find a positive, although not necessarily causal, relationship between the use of the LTV ratio and other policies and income inequality. However, results for advanced economies are mostly not statistically significant, likely due to their relatively limited experience with LTV policy prior to the financial crisis. In emerging and developing economies the use of LTV ratio policy seems to be more strongly associated with higher income inequality. Carpantier et al. (2018) focus instead on wealth inequality. Using data for the euro area, they find that higher LTV ratios are associated with an increase in wealth inequality.

[1] The speed limit is reviewed and tightened or eased countercyclically, depending on a number of indicators.

[2] See the discussion in Chapter 1.

[3] This means that the portfolio of the absolute majority of households is highly specialized and, especially for the bottom 50%, also highly leveraged.

These authors also stress that their results are not causal, and note that most households with high LTV mortgages tend to be on the lower part of the wealth distribution.[4]

The contribution of this paper is to study the long run distributional effects of LTV ratio policies as a function of initial wealth inequality, focusing on changes to housing wealth inequality and homeownership. To answer this question I use a heterogeneous agent model with a housing tenure choice and a collateral constraint. The introduction of a macroprudential policy, reflected in a reduction in the maximum LTV ratio, lowers the homeownership rate, house prices and aggregate leverage. At the same time, it raises the share of homeowners who are up against the borrowing limit, despite the fall in house prices, and housing wealth inequality rises. This is in line with the findings of other studies in the literature. My key finding is that the effects on house prices, leverage and housing wealth inequality are conditional on the initial state; the lower is initial wealth inequality, the stronger the effects. This is because policy tends to have an effect on a bigger share of the population when wealth inequality is lower, since *ex-ante* households are relatively less heterogeneous in their wealth holdings. The same policy applied to two countries with different levels of wealth inequality affects them differently. These findings are robust to the level of the long run interest rate and the initial homeownership rate. These results highlight the importance of relaxing the representative agent assumption in models and instead cater for agents on the entire distribution, especially when using such models for policy.

There are several studies that model movements in the LTV ratio and analyse the associated implications on the housing market and aggregate outcomes. Favilukis et al. (2017) study financial liberalization in the US by simulating an increase in the LTV ratio from 75% to 99%. They find that this causes a reduction in housing wealth inequality in the long run but an increase in financial wealth inequality. However they do not include a rental market in their model, and this could have important implications for the results. Kiyotaki et al. (2011) and Sommer et al. (2013) also study the effects of a relaxation in the collateral constraint in a model in which households can choose to either rent or buy a house. They show that lowering the downpayment requirement (raising the LTV) increases homeownership as it enables renters to enter the housing ladder through a highly leveraged house purchase. However, they find a small effect on aggregate rents and house prices, attributed to the fact that the share of wealth of such households in the economy is low. These studies do not look at inequality measures before and after the relaxation of borrowing limits.[5]

Similarly, Iacoviello and Pavan (2013) study the effects of an increase in the LTV ratio on the rate of homeownership and household indebtedness. They find that the increase in the LTV ratio

[4] Richter et al. (2019) show that the output costs of LTV policies are small and not statistically significant in advanced economies.

[5] Kiyotaki et al. (2011) also show that the result carries through when the collateral constraint is tightened completely, requiring all housing to be purchased using own resources. In this case, the resulting effect on aggregate prices and quantities is also limited, even though about half of households become renters. The risk-free interest in these two models is exogenous and does not adjust.

increases homeownership and aggregate debt relative to output. However, this shock is neutral in wealth inequality since the authors assume that house prices are exogenous and therefore do not respond to the increase in housing demand.[6]

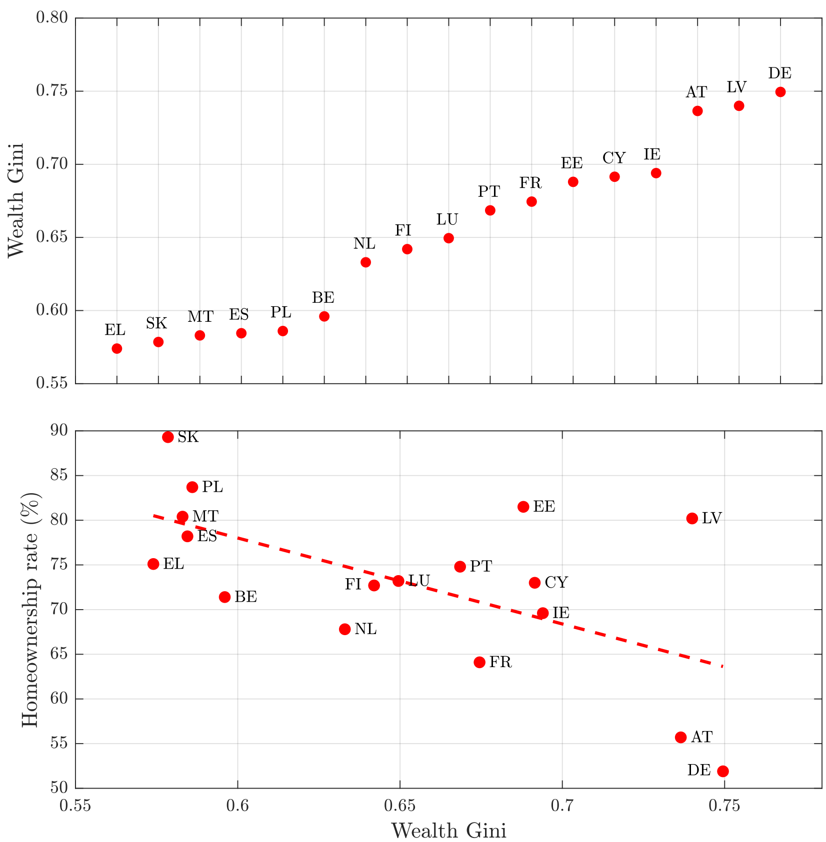

Figure 3.1: Wealth inequality (top) and homeownership rates (bottom) in selected European countries

Notes: Data is for the year 2015. EL – Greece, SK – Slovakia, MT – Malta, ES – Spain, PL – Poland, BE – Belgium, NL – Netherlands, FI – Finland, LU – Luxembourg, PT – Portugal, FR – France, EE – Estonia, CY – Cyprus, IE – Ireland, AT – Austria, LV – Latvia, DE – Germany. Source: Eurostat (experimental statistics and EU-SILC). The dashed red line in panel (b) denotes the line of best fit based on a linear OLS regression ($R^2 = 0.37$), for illustration purposes.

Although several countries have introduced similar macroprudential policies over the past years, it is not clear whether the expected long run effect of these policies is homogeneous. This is because

[6] Other noteworthy studies on this topic are Ortalo-Magne and Rady (2006) and Kaplan et al. (2020). A summary of earlier work can be found in Jeske (2005). Other studies which study distributional implications of different policies on the housing market are Gervais (2002), Jeske et al. (2013), Floetotto et al. (2016), Sommer and Sullivan (2018) and İmrohoroğlu et al. (2018).

countries are heterogeneous along several dimensions, and differ *inter alia* in wealth inequality and homeownership rates. For example, wealth Gini coefficients range from less than 0.6 to more than 0.7 across several European countries (Figure 3.1), while homeownership rates vary from under 50% to over 80%. Moreover, 19 European countries had an LTV cap by mid-2018, most varying between 60–95% (Arena et al., 2020). It is therefore important to understand to what extent heterogeneity in initial conditions matters for the long run unintended consequences of such policies.

At this stage a caveat is in order. A complete discussion of macroprudential policy would weight the costs of action with the costs of inaction. This paper however is not on optimal policy, as it completely sidesteps the benefits brought about from greater financial stability. As a result, any welfare implications derived from the results of the analysis that follows would miss an important element that motivates the implementation of such a policy in the first place. Therefore, in this paper policy is taken as given and the analysis is on how it affects the housing market by reallocating portfolios. The rest of the paper is organised as follows. Section 2 goes through the model and section 3 reports simulation results following a tightening of the LTV ratio. Section 4 discusses sensitivity analysis and section 5 concludes.

3.2 The model

I use a framework similar to Gervais (2002), Silos (2007), Kiyotaki et al. (2011) and Iacoviello and Pavan (2013), although I abstract from life-cycle profiles as in Carroll and Dunn (1997) and Guerrieri and Lorenzoni (2017).[7] In the presence of borrowing constraints, a share of households finds it optimal to rent rather than own a house. To preview results, renters will be wealth-poor households while owners represent the wealthier cohort of society, consistent with the data.

3.2.1 Households

Time is continuous and the economy is populated by a continuum of infinitely lived dynastic households of mass one, which receive stochastic income endowments which transition between two states $y_j \in \{y_1, y_2\}$, denoting bad and good states respectively. There is no aggregate uncertainty. In the absence of complete asset markets, households are unable to perfectly insure against this risk, so their earnings fluctuate over time. Households have CRRA preferences over total consumption C, which is a Cobb-Douglas aggregate of non-durable consumption goods c and housing services s, and discount the future at the rate ρ. A household derives housing services by either owning a house of size h or by renting one; however, renting incurs a utility loss $\psi > 0$, representing the

[7] The framework is general and has also been used by Chambers et al. (2009), Cho and Francis (2011), Berger et al. (2018) and İmrohoroğlu et al. (2018).

tenant's limited control over the asset.[8] I assume housing is fully divisible and freely adjustable, as in Kiyotaki et al. (2011) and Jeske et al. (2013).A house yields a service that is linearly related to its size ($s = h$). To simplify notation I do not index households by a subscript. Household utility is given by:

$$u(c, s, \mathbf{1}_{\text{rent}}) = \frac{1}{1-\sigma}\left[\left(\frac{c_t}{\alpha}\right)^{\alpha}\left(\frac{(1-\psi\mathbf{1}_{\text{rent}})s_t}{1-\alpha}\right)^{1-\alpha}\right]^{1-\sigma} \tag{3.1}$$

where the indicator function $\mathbf{1}_{\text{rent}}$ takes a value of one when a household is renting and zero otherwise. Non-seperable preferences across consumption goods and housing services imply that households maintain constant expenditure shares α and $1-\alpha$ respectively across these two components. This follows the preference structure commonly used in the literature, as it simplifies the solution of the model as it seperates the intertemporal consumption-saving problem over the aggregate consumption bundle C from the intratemporal allocations over non-durable consumption c and durable goods s.[9] Besides housing, households have access to a riskless liquid asset $b > 0$ yielding a return r.[10] A household with $b < 0$ is in debt, and r is then the interest on such debt. Only households who own a house can borrow. Current and prospective homeowners face a borrowing limit, in the form of a collateral constraint over the value of the durable asset (housing), priced in q units relative to the consumption good price, and is governed by a Loan-to-Value (LTV) ratio $\theta \in (0,1)$:

$$-b_t \leq \theta q h_t.$$

The LTV ratio is common to all households. An individual household's assets evolve as

$$db_t + (1-\mathbf{1}_{\text{rent}})q dh_t = (y_j + rb_t - \mathbf{1}_{\text{rent}} p s_t - c_t)dt$$

where p is the rental price. Income endowments $\{y_1, y_2\}$ are indexed by j and follow a two-state Poisson processes with intensities $\lambda_j \in \{\lambda_1, \lambda_2\}$ respectively.[11] Households convert income into a consumption good costlessly using linear technology, and therefore the endowments $\{y_1, y_2\}$ can also be thought of as productivities. Prices are determined in equilibrium and households take these as given. Households cannot default on their debt and the borrowing constraint implies that they cannot have net liabilities ($b + qh \geq 0$).

In this paper I focus on the stationary equilibrium of the model. In order to reduce the dimensionality of the problem it is useful to work in terms of wealth. Following Achdou et al. (2017) and

[8] This follows Kiyotaki et al. (2011), Iacoviello and Pavan (2013) and Floetotto et al. (2016), who use this parameter to pin down the equilibrium homeownership rate.

[9] See, *inter alia*, Kiyotaki et al. (2011) and Sommer et al. (2013).

[10] Therefore, the interest rate on liquid assets and debt is the same.

[11] This is a continuous time jump process, analogous to a two-state Markov process in discrete time. Income jumps from the bad to the good state with Poisson flow intensity λ_1 and from the good to the bad state with intensity λ_2.

Fagereng et al. (2019), I define household wealth as $W = qh + b$. Since in a stationary equilibrium aggregate prices are constant, the evolution of wealth is given by $dW = qdh + db$. The constraints conditional on income can therefore be re-written as:

$$dW = (y_j + rW - (1 - \mathbf{1}_{\text{rent}})rqh_j - \mathbf{1}_{\text{rent}}ps_j - c_j)dt \tag{3.2}$$

$$W \geq \begin{cases} 0 & \text{if renter} \\ (1-\theta)qh & \text{if owner.} \end{cases} \tag{3.3}$$

The modified collateral constraint (3.3) states that the minimum wealth that households have to hold to become or remain homeowners needs to be enough to cover the downpayment $(1-\theta)$ on housing. To anticipate results, this constraint will lead to a density of agents who are up against the borrowing constraint on the wealth distribution. Meanwhile, renters store their wealth solely through liquid assets.

Similar to the discussion in Gervais (2002), there are financial intermediaries in the background which take deposits from some households and issue loans to others and hold the unowned stock of housing, which they rent out at the rental rate p. There are no frictions in this process. As a result, a no-arbitrage condition in the housing market holds such that in equilibrium the rental rate is equal to the opportunity cost of buying a house:[12]

$$p = rq. \tag{3.4}$$

Households must decide whether to rent or buy a house, a decision that involves a trade-off. Owning incurs a higher utility benefit for a given level of housing services but, when households have little wealth, they might be up against their borrowing constraint, limiting the size of the house that they can buy. On the other hand, renters face no additional constraints on the size of the house to live in, yet renting incurs a utility loss. Denote by $V^o(W)$ and $V^r(W)$ the lifetime value of owning and renting respectively. The problem of a given household is to choose its housing tenure at every level of wealth for a given income level:

$$\max_{\{s,h\}} \left\{ V^o_j(W), V^r_j(W) \right\}, \; j = 1, 2. \tag{3.5}$$

This problem can be cast as an *optimal stopping time problem* (Stokey, 2009). Assume a given household is an owner. It chooses optimal consumption, the size of the house to own and the stopping time τ at which it switches from owning to renting. An optimal stopping time translates to a wealth threshold W^o below which it is optimal to rent rather than own. The value function of

[12] Since I define the sum of liquid and housing assets in terms of wealth, this expression captures the opportunity cost of buying a house instead of investing in the liquid asset, or the user cost. Furthermore, since in a stationary equilibrium prices are constant, this relation does not include the expected growth of house prices.

an owner is:

$$V_j^o(W) = \max_{c,s,\tau} \mathbb{E}_t \left\{ \int_0^\tau e^{-\rho t} u(c, s|_{\mathbf{1}_{\text{rent}=0}}) dt + e^{-\rho\tau} V_j^r(W) \right\} \tag{3.6}$$

subject to the constraints (3.2)-(3.3). The household problem separates into a dynamic intertemporal consumption-saving problem and a static intratemporal problem over non-durable and durable goods for a given level of total expenditure. It is convenient to discuss these separately, starting with the dynamic problem.

Denote by P the aggregate price index corresponding to the consumption bundle C, then total expenditure for a given income realisation j is given by:

$$PC_j = c_j + rqs_j. \tag{3.7}$$

Note that by the no-arbitrage condition (3.4), it is irrelevant for total expenditure whether the household is a renter or an owner, since the cost of a unit of housing services is the same in equilibrium.[13] The intertemporal problem is solved using a recursive formulation. Following Achdou et al. (2017), Kaplan et al. (2018) and Nuno and Moll (2018), the associated Hamilton-Jacobi-Bellman (henceforth HJB) equation for owning is given by

$$\rho V_j^o(W) = \max_C \; u(C|_{\mathbf{1}_{\text{rent}=0}}) + \frac{dV_j^o(W)}{dW}(y_j + rW - PC_j) + \lambda_j(V_{-j}^o(W) - V_j^o(W)) \tag{3.8}$$

with the constraint that

$$V_j^o(W) \geq V_j^r(W) \tag{3.9}$$

where the argument C in the utility function is the Cobb-Douglas aggregate over c and s defined in (3.1). When constraint (3.9) holds as an equality it is referred to as the value matching condition, which serves as a boundary condition. There is an HJB for each income state $y_j, \; j = 1, 2$. The notation in the HJB is such that $-j = 2$ when $j = 1$ and vice versa. Therefore, the last term on the right captures the expected change in lifetime utility following a jump to other income state.[14] The HJB equation associated with renting is given by:

$$\rho V_j^r(W) = \max_C \; u(C|_{\mathbf{1}_{\text{rent}=1}}) + \frac{dV_j^r(W)}{dW}(y_j + rW - PC_j) + \lambda_j(V_{-j}^r(W) - V_j^r(W)). \tag{3.10}$$

The system can be written as an HJB variational inequality (HJBVI) (Bensoussan and Lions, 1982;

[13] Furthermore, one unit of owned housing derives one unit of housing services. On the other hand, it matters for utility whether the household is a renter or borrower.

[14] Derivations are provided in Appendix A3.1. See Achdou et al. (2017) for further details.

Øksendal, 1998):

$$\min\left\{\rho V_j^o(W) - \max_C \ u(C|_{\mathbf{1}_{\text{rent}=0}}) - \frac{dV_j^o(W)}{dW}(y_j + rW - PC_j) - \lambda_j(V_{-j}^o(W) - V_j^o(W)),\right.$$
$$\left. V_j^o(W) - V_j^r(W)\right\} = 0. \tag{3.11}$$

The solution to this problem yields the policy function for total consumption $C_j(W)$, the resulting saving policy function $S_j(W)$ and a wealth ownership threshold W_j^o. For homeowners, the first order condition for total consumption conditional on a given income realisation is given by:

$$C_j(W)^{-\sigma} = P\frac{dV_j^o(W)}{dW}. \tag{3.12}$$

Optimal saving is then $S_j(W) = y_j + rW - PC_j(W)$, namely the accumulation of wealth that results from following policy $C_j(W)$. An analogous first order condition holds for renters.

The static problem of a household is to choose the optimal bundle $\{c, s\}$ subject to the constraint (3.7) for a given level of expenditure. Optimal allocations for owners are:

$$s_j(W) = \min\left\{(1-\alpha)\frac{PC_j(W)}{rq}, \frac{W}{(1-\theta)q}\right\} \tag{3.13}$$
$$c_j(W) = PC_j(W) - rqs_j(W) \tag{3.14}$$

where a household can be either on the collateral constraint (3.3) or have an unconstrained house purchase. Denote the cutoff at which this occurs as W_j^u, with $W_j^u > W_j^o$. On the other hand, renters have unconstrained allocation shares α and $1-\alpha$ of total expenditure for consumption of the non-durable good and housing services, respectively. These conditions define the price of the unconstrained bundle C as:

$$P = p^{1-\alpha}. \tag{3.15}$$

3.2.2 The distribution of households

The distribution of households over wealth for a given endowment j is denoted by $G_j(W)$, and this has a density on wealth $g_j(W)$. The law of motion for the stationary distribution satisfies the Kolmogorov Forward (KF) equation:[15]

$$0 = -\frac{d}{dW}\left[S_j(W)g_j(W)\right] - \lambda_j g_j(W) + \lambda_{-j}g_{-j}(W). \tag{3.16}$$

[15] This is also known as the Fokker-Planck equation; see Achdou et al. (2017) for more details.

The right hand side states that a density of households moves continuously off (on) a given wealth level conditional on income through saving (dissaving), as well as by jumping to (from) the other income state depending on the Poisson intensities. In the stationary equilibrium the distribution is time-invariant and these forces are equal. Hence the left hand side, which corresponds to the time derivative of $g_j(W)$, is equal to zero. See Appendix A3.1 for more details. The densities are normalized to integrate to 1:

$$\int_0^\infty g_1(W)dW + \int_0^\infty g_2(W)dW = 1. \tag{3.17}$$

It is useful to define the aggregate share of homeowners who are constrained by the borrowing limit μ^{co}:

$$\mu^{co} = \frac{\sum_j \int_{W_j^o}^{W_j^u} dG_j(W)}{\sum_j \int_{W_j^o}^{\infty} dG_j(W)} = \frac{1}{1 - G_1(W_1^o) - G_2(W_2^o)} \sum_j \int_{W_j^o}^{W_j^u} dG_j(W) \tag{3.18}$$

and the share of households who are either renters or constrained owners μ^{rco}:

$$\mu^{rco} = \sum_j \int_0^{W_j^u} dG_j(W). \tag{3.19}$$

3.2.3 Market clearing

I close the model by assuming a fixed aggregate housing supply which is normalized to 1. Equilibrium in the housing market implies all houses are either rented or owned:

$$\sum_{j=1}^{2} \int_0^\infty \mathbf{1}_{\text{rent}} s_j(W) dG_j(W) + \int_0^\infty (1 - \mathbf{1}_{\text{rent}}) s_j(W) dG_j(W) = 1. \tag{3.20}$$

The interest rate r is fixed and exogenous, and in the background a central bank provides enough liquidity into the economy to maintain this rate.

3.2.4 Boundary conditions, equilibrium and solution method

Note that despite the inequality constraint (3.3) in the optimization problem, the first order condition (3.12) for households holds as an equality in the interior of the state space.[16] The problem is then subject to a *state constraint boundary condition* when individual wealth falls to the minimum

[16] This is a feature of the continuous time framework. In a discrete time framework optimality conditions are inequalities that only hold exactly when the constraint is binding.

level permissible $\underline{W} = 0$ given by (3.3):

$$\frac{dV_j(\underline{W})}{dW} \geq P^{\sigma-1} y_j^{-\sigma}. \tag{3.21}$$

This boundary condition implies that the return to saving at $\underline{W}$, as measured by the change in the value function, is equal to or better than the marginal utility of consuming all available resources. It ensures that any household whose wealth is driven towards $\underline{W} = 0$ through a long spell of low income shocks abides by the non-negativity constraint on wealth and adjusts its consumption.[17]

A stationary equilibrium is defined as a set of prices $\{q, p\}$, value functions $\{V_j^r(W), V_j^o(W)\}$, policy functions $\{c_j(W), s_j(W), C_j(W), S_j(W)\}$ and distributions $G_j(W)$ for each income state j that satisfy the HJBVI (3.11), the KF equation (3.16), the market clearing condition (3.20) and the boundary condition (3.21). I solve the model numerically on a fine wealth grid $W \in [0, \overline{W})$ with 7,500 points, where $\overline{W}$ is a level of wealth that is high enough such that the density of households at this level is zero. The approach is based on a finite difference method to approximate the derivative of the value function using an upwind scheme, see Achdou et al. (2017) for further details.[18] For a given house price q (and implied rental rate p) and guesses of the value functions for renting $V^r(W)$ and owning $V^o(W)$ for each income state, I cast the HJBVI (3.11) as a Linear Complementarity Problem and solve it. I then solve the KF equation as an eigenvalue problem using the transpose of the transition matrix used to solve the HJBVI, and check for equilibrium in the housing market. I update the guess for q using a bisection algorithm and re-solve the system until the price clears the market. See Appendix A3.2 for more details.

3.2.5 Calibration

I calibrate the model parameters partly to replicate key stylized facts as discussed in Davis and Van Nieuwerburgh (2015) and as well as to generate a wealth Gini coefficient that is close to that observed for most advanced economies. To this end, I study two economies in parallel, one with a wealth Gini of 0.7, and another of 0.6, which I label as high wealth gini (HWG) and low wealth gini (LWG) respectively. These levels capture the environment across several European countries, as shown in Figure 3.1, and are comparable to values for advanced economies which are targeted in some of the studies listed above. The expenditure share for non-durable consumption goods α

[17] Saving has to be strictly positive when households hit the constraint, as dissaving reduces their wealth further, violating the constraint. Positive saving implies that $y_j + r\underline{W} \geq PC_j(\underline{W}), \forall j \in \{1, 2\}$. Furthermore, the optimality condition (3.12) holds everywhere, both within and on the boundary of the state space. Combining these two requirements yields the boundary condition (3.21).

[18] Although the grid is large, a solution is feasible as continuous time introduces a lot of sparsity and first order conditions hold with equality. As a result, a solution can be obtained in less than a minute on a personal machine. The high number of grid points results in smooth policy functions and distributions but does not materially increase accuracy. In the robustness checks reported below I use a smaller grid with 3,500 points since I only focus on comparing aggregate variables.

is set to 0.8, consistent with the discussion in Davis and Van Nieuwerburgh (2015). I set the risk aversion parameter σ to 1, as logarithmic preferences simplify the computation and improve the stability of the solution algorithm. The utility cost of renting ψ is set at 0.155, which delivers a homeownership rate of about 65%.

Next is the income process, which is the key source of heterogeneiety. The two income states $\{y_1, y_2\}$ do not represent states of unemployment and employment as is customary in the literature. Rather, the first income state y_1 represents income of a 'typical' household, whereas the second income state y_2 is a catch-all state for being hit by a rare but very good shock.[19] The corresponding Poisson intensities $\{\lambda_1, \lambda_2\}$ over these income states are set such that households spend most of the time in income state y_1 but with a low probability receive the high endowment.[20] Therefore, the calibration of these values does not follow estimated income processes as in the literature, but is set such that the model generates high wealth inequality. The flow probability λ_2, which denotes a jump to income state y_1, is set at 0.6 in the HWG economy, and at 0.1 in the LWG economy. The flow probability λ_1 is 0.05 in both economies. These imply that a given household is expected to be in the high income state only about 8% of the time in the HWG economy, and about 33% in the LWG economy. I normalize average income $\overline{y}$ to 1 as in Guerrieri and Lorenzoni (2017) and Fernández-Villaverde et al. (2019), and set the low income level $y_1 = 0.35$. This and the Poisson intensities imply a value for y_2 of 8.8 (HWG) and 2.3 (LWG) respectively. The implied income process then delivers a wealth Gini of 0.7 and 0.6 in the HWG and LWG economies, respectively. The discount rate ρ is set to 7.1%. Although higher than in the standard representative agent literature, it is common in models with even a minimum level of heterogeneity, such as two-agent models, to have some households in the economy which discount the future more heavily in order to generate wealth holdings that come close to the inequality observed in the data.[21]

The last set of parameters relate to the financial market. I fix the benchmark maximum LTV ratio θ at 90%, reflecting relatively loose borrowing constraints. This parameter will be the focus of the analysis. I set the interest rate at 2%. The fact that $r < \rho$ puts an upper bound on the wealth distribution, such that even high income households do not accumulate wealth above an upper threshold $\overline{W}$ (Huggett, 1993; Quadrini and Ríos-Rull, 1997). The wealth density is therefore bounded with support $[0, \overline{W}]$.[22] The parameter values, written in annual terms, are summarized in

[19] This is similar to Bayer et al. (2020) who include a low probability high income 'entrepreneur' state for households to generate high income and wealth distribution.

[20] A household expects to remain in state j with duration $1/\lambda_j$.

[21] See, for instance, Iacoviello and Pavan (2013), Guerrieri and Lorenzoni (2017) and Auclert et al. (2020). It is known that standard incomplete market models with limited sources of heterogeneity fail to generate a fat (Pareto) right tail, as observed in the data (Quadrini and Ríos-Rull, 1997). This is because households in the upper wealth percentiles are not driven by precautionary savings motives (Carroll, 1997). Heterogeneity in discount factors, amongst other factors, helps to generate a skewed distribution; see Krusell and Smith (1998), Krueger et al. (2016), Toda (2018) and Epper et al. (2020). The income process calibration in this paper generates a reasonable skew in the wealth distribution without the need for discount factor shocks, which add another state variable.

[22] Achdou et al. (2017) derive closed form expressions for the wealth distribution in an incomplete markets model

Table 3.1.

Table 3.1: Benchmark calibration

Parameter	**Value**
Discount rate (ρ)	0.071
Risk aversion (σ)	1
Utility cost of renting (ψ)	0.155
Non-durable consumption share (α)	0.8
Maximum LTV ratio (θ)	0.9
Risk-free interest rate (r)	0.02
Low income (y_1)	0.35
Poisson rate: low to high income (λ_1)	0.05
High Gini	
High income (y_2)	8.8
Poisson rate: high to low income (λ_2)	0.6
Low Gini	
High income (y_2)	2.3
Poisson rate: high to low income (λ_2)	0.1

3.3 Steady state analysis

I now describe household behaviour which is conditional on a low downpayment requirement, focusing on the HWG economy. I do not show the corresponding functions for the LWG economy when the results are quantitatively similar. Figure 3.2 shows the value functions associated with being a renter and an owner for the income endowment y_1. Since owning is prefered to renting, the value of being an owner is always greater or equal to that of being a renter. The point at which the two value functions are equal is the threshold cutoff point W_1^o. At this point, the solution satisfies equation (3.9) as an equality - the value matching condition - as well as a *smooth pasting* condition associated with stopping time problems (Dixit and Pindyck, 1994).[23] The solution for households on the high income state does not yield a corresponding threshold; given their high income flow, they find it optimal to always buy their house. As a result, the value function for owning dominates

with only idiosyncratic labour income risk, cast in continuous time. They show that the stationary density of the high income households is bounded both at the borrowing constraint $\underline{W}$ and also the right tail of the density ($\overline{W} < \infty$).

[23] Value matching implies that a household is indifferent between renting or owning exactly at the cutoff. Smooth pasting states that the derivatives of the value functions are also the same at the cutoff. As discussed in Achdou et al. (2017), smooth pasting is typically imposed as a boundary condition, but when a problem is posed as an HJB variational inequality it obtains as part of the solution (Øksendal, 1998).

that for renting over all wealth levels.

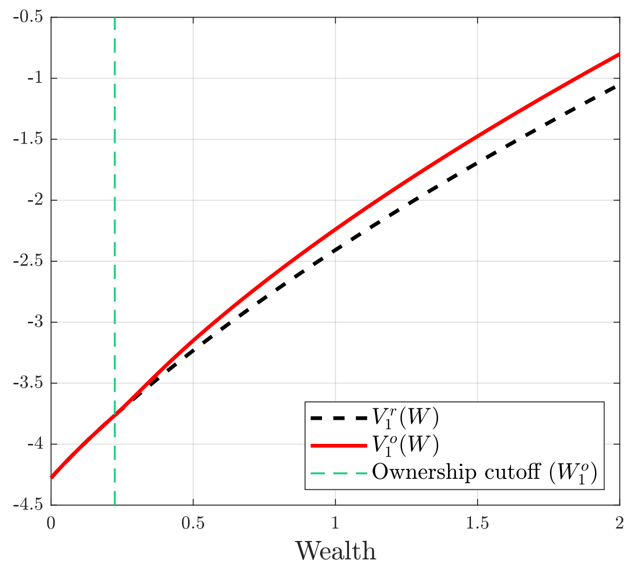

Figure 3.2: Value functions for income state y_1 (HWG)

Note: Wealth is a multiple of average income $\overline{y}$.

Figure 3.3 shows the policy functions for total expenditure, saving, and the allocation between non-durable consumption and housing services for households in income state y_1. In particular, it shows *two* sets of policies; one while renting to the left of the cutoff point W_1^o, and another while owning. Consumption of the non-durable good (c) and housing services (s) rise monotonically with wealth for renters, who rent a moderately-sized house. A common result in heterogeneous agent models is that households on the lower income endowment decumulate assets, whereas those on a high income endowment accumulate assets in good times.[24] Saving for households on y_1 however tends to zero as wealth approaches zero, with a corresponding dip in total expenditure, reflecting precautionary behaviour at low wealth levels and the boundary condition (3.21).

As wealth rises to the cutoff W_1^o, households switch to owning through a credit-constrained house purchase. The LTV constraint limits the size of the house that they can buy, and they switch to living in a house that is smaller than what they rent just below W_1^o. This down-sizing reflects the fact that households get a higher utility from owning, and owning the smaller house more than compensates for the loss of higher housing services from renting. The point at which the house purchase becomes unconstrained, W_1^u, is also shown. Although households buy smaller houses in the interval $W \in [W_1^o, W_1^u)$ relative to what they were renting, they cut back on total expenditure

[24] See, for example, the discrete time analogue in Imrohoroğlu (1989, Figure A.1).

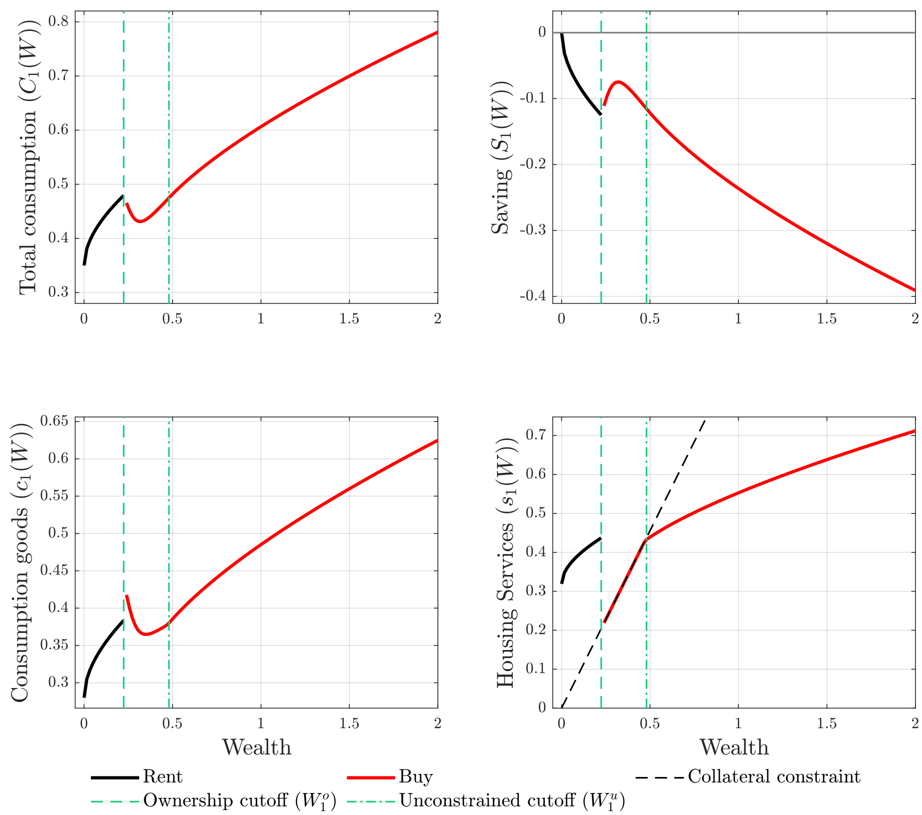

Figure 3.3: Policy functions for income state y_1 (HWG)

Note: Wealth is a multiple of average income $\overline{y}$.

to increase (reduce) their saving (dissaving). This captures an effort to remain an owner (that is, to have $W \geq W^o$) as well as to move off the collateral constraint (to have $W \geq W^u$). The behaviour of households in the LWG economy is very similar.

Households in the income state y_2 are owners throughout the wealth domain.[25] Their expenditure, as expected, is higher at all wealth levels, and they accumulate wealth through positive saving. High income households remain constrained at up to higher levels of wealth compared to those on a low income ($W_2^u > W_1^u$), since they have a higher demand for housing at each level of wealth compared to low income households. They register a high saving rate in order to move off

[25] I do not show their respective policy functions in the interest of space.

the constraint and allocate expenditure optimally between consumption goods and housing.

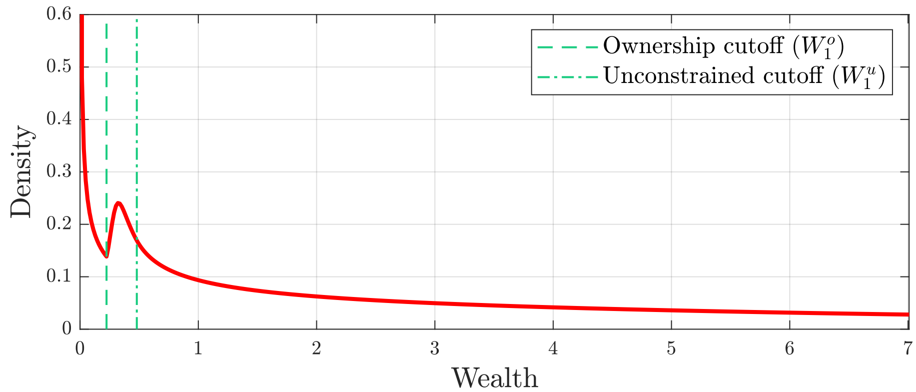

Figure 3.4: Unconditional density $g(W)$ (HWG)

Notes: The ownership and unconstrained cutoffs relate to households in the low income state. Wealth is a multiple of average income $\overline{y}$. The upper support of the density is close to 120 times average income.

Figure 3.4 plots the unconditional density for part of the domain on wealth, representing about 75% of all households in the HWG economy. As already mentioned, the Poisson flow rates for income in the HWG calibration imply that around 92% of households will belong to the density conditional on state y_1. Therefore, the unconditional density $g(W)$ mirrors the shape of $g_1(W)$. The density has a Dirac point mass at $W = 0$ and a fat right tail, bringing it close to empirical wealth distributions.[26] The Poisson intensities $\{\lambda_1, \lambda_2\}$ allow a few households to accumulate a relatively high level of wealth, generating significant wealth inequality despite the simplicity of the income process. The density on support $[0, W_1^o)$ represents the renters in the economy, in line with the stylized facts showing that renters tend to have little wealth. The region $[W_1^o, W_1^u)$ is populated by a density of constrained households in state y_1, where the rise in the density in this region reflects the accumulation of households driven by the change in saving behaviour. The share of LTV-constrained owners μ^{co} in this benchmark calibration is around 8%, whereas the share of renters and constrained owners μ^{rco} is about 40% (of which about 35% are renters). The model is also able to generate a sizable share of households (about 30% in both economies) who are hand-to-mouth, that is, households with zero wealth which consume all their endowment. This is close to the figure targeted in Kaplan and Violante (2014) and Kaplan et al. (2018).[27]

[26] A fraction of households in various countries have negative wealth, but the model is unable to capture this due to the state constraint $\underline{W} \geq 0$.

[27] These studies discuss poor and wealthy hand-to-mouth households, with the latter having zero liquid wealth but positive illiquid wealth. In this paper there is no such distinction since all wealth is liquid.

3.4 Comparative statics: tightening the borrowing limit

The results above are based on a relatively high LTV ratio $\theta = 0.9$ in the collateral constraint (3.3).[28] I now study the scenario where a policymaker cuts the LTV ratio by 10 percentage points and keeps it fixed indefinitely at 0.8. This could reflect the introduction of a macroprudential policy framework in which the regulator sets a minimum downpayment that is higher than what financial intermediaries ask for. Such a limit was imposed in New Zealand in 2013, where the LTV for most borrowers was and remains capped at 0.8 (Rogers, 2014). This policy action is known to all households, and is not expected to be revised in the future, so households do not face any uncertainty about future borrowing conditions. I therefore introduce the regime change as a so-called 'MIT' shock; a zero-probability event that cannot be anticipated and is not expected to hit again in the future. Upon being hit by the shock, the economy follows a deterministic adjustment path to the new stationary equilibrium at $\theta' < \theta$.

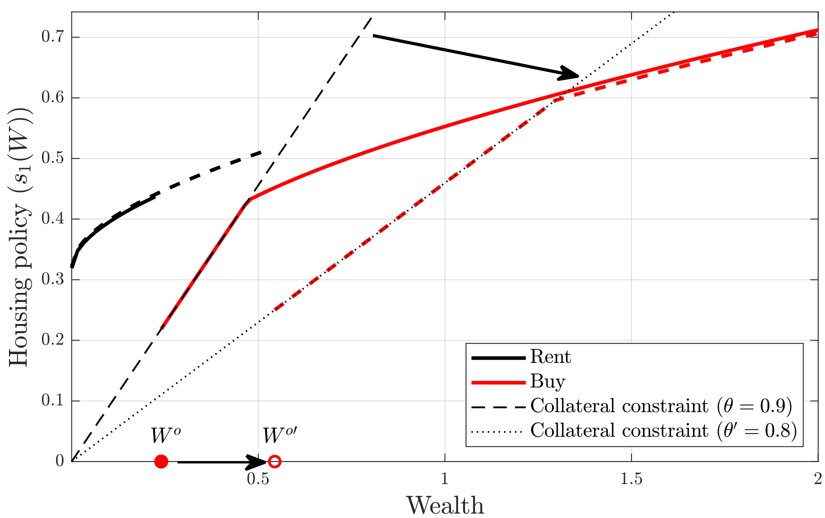

Figure 3.5: Housing policies before and after the LTV reduction for income state y_1 (HWG)

Notes: The solid lines are for an LTV ratio of 0.9, and the dashed lines for an LTV ratio of 0.8. The arrows show the clockwise rotation of the collateral constraint about the origin. The solid and empty dots represent the ownership cutoffs at the initial and terminal LTV ratios, respectively. Wealth is a multiple of average income $\overline{y}$.

This policy affects the borrowing limit and housing demand through the collateral constraint. All else equal, a drop in the borrowing limit reduces demand for housing, at least by those households

[28] Maximum LTV ratios vary across countries. In the euro area, they varied between 70% and 100% in 2016 (ECB, 2016, p.41). Furthermore, countries tend to have different LTV ratios depending on whether a household is a first time buyer or not, and in the case of buy-to-let, lower LTV ratios apply. See (Hallissey et al., 2014) for a discussion on different LTV limits for borrowers in Ireland.

that are either on the limit or close to it. This exerts downward pressure on house prices, and causes unconstrained households to re-optimise, possibly increasing their holdings of housing. The net effect on house prices depends on the aggregate demand for housing. Figure 3.5 shows the resulting change in behaviour as the LTV is lowered. The new ownership threshold for low income households $W_1^{o\,\prime}$ shifts up, and renters require more wealth to optimally switch to owning. The range over wealth across which the constraint binds is wider for all constrained households, irrespective of which income state they are in. Furthermore, households on the high income state have a slightly higher demand for housing services than before at wealth levels above the new unconstrained cutoff $W_2^{u\prime}$. Integrating over the entire wealth distribution, these changes lead to an aggregate drop in housing demand, which causes house prices to fall by about 0.8% in the HWG economy. Figure 3.6 shows that the aggregate demand curves are almost linear in the vicinity of the market equilibrium.

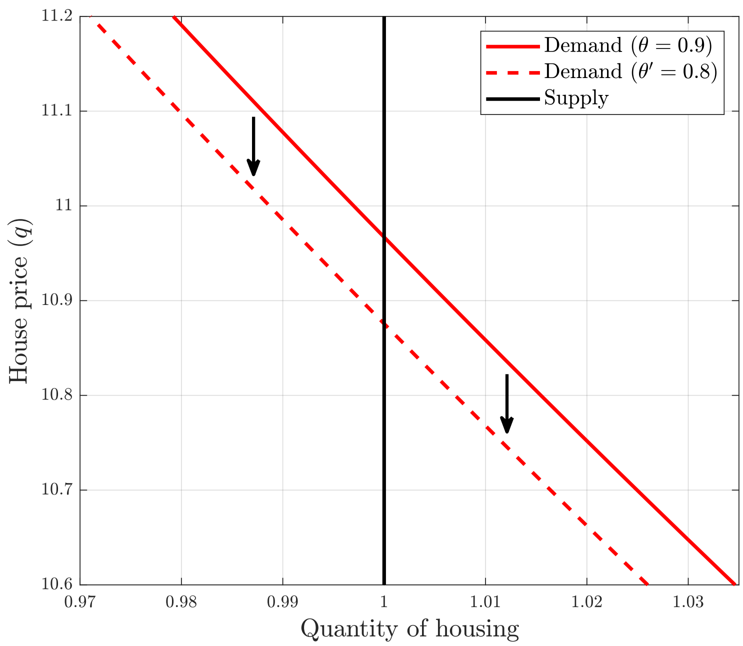

Figure 3.6: Comparative statics in the housing market (HWG)

Note: The x-axis denotes the quantity of housing, and supply is normalized to 1.

The story is the same in the LWG economy, but since this economy has a higher concentration of households on or close to the borrowing limit, the reduction in the LTV ratio induces a bigger drop in aggregate housing demand. Consequently, house prices in this economy drop by 3.4%, more than four times the drop in the HWG economy. This result affirms that the potential for distributive effects of macroprudential policy can hinge greatly on initial conditions.

Table 3.2 shows the changes in housing tenure, as well as aggregate measures including the wealth and housing wealth gini coefficients. At a lower borrowing limit a higher fraction of low income households rent, and the corresponding ownership rate falls from 65.2% to 59.4%. Moreover, the share of owners on the borrowing limit (μ^{co}) almost doubles from 7.8% to 14%. As a result, about 49% of households become either renters or constrained owners, up from 40%. Although a lower LTV ratio causes a significant proportion of the population to either rent or become constrained, it seems to have a negligible effect on wealth inequality as measured by the Gini coefficient. Figures 3.7 and 3.8 shed some light on why this is the case.

Table 3.2: Initial and terminal steady states

	High Wealth Gini			Low Wealth Gini		
	$\theta = 0.9$	$\theta' = 0.8$	Δ	$\theta = 0.9$	$\theta' = 0.8$	Δ
Household shares (%)						
Renters	34.8	40.6	5.8p.	34.4	40.0	5.6p.
Owners	65.2	59.4	-5.8p.	65.6	60.0	-5.6p.
Constrained owners (μ^{co})	7.8	14.0	6.2p.	11.8	27.2	15.4p.
Renters and constrained owners (μ^{rco})	39.9	48.9	9.0p.	42.2	56.3	14.1p.
Hand-to-mouth	30.0	31.9	2.0p.	29.6	31.2	1.6p.
Aggregates						
House price (q)	10.97	10.88	-0.8%	10.29	9.94	-3.4%
Leverage (%)	38.3	32.4	-5.9p.	49.2	42.8	-6.4p.
Wealth Gini	0.701	0.701	-0.1%	0.604	0.600	-0.6%
Housing Wealth Gini	0.582	0.609	4.6%	0.535	0.570	6.5%

Notes: Constrained owners is the fraction of owners that are on the collateral constraint. Leverage is calculated as the ratio of debt to housing wealth of owners. Δ denotes changes between the two LTV scenarios in percentage points (p.) or percentage rates (%). Numbers may not add up due to rounding.

Figure 3.7 shows the wealth accumulation policy averaged over the two income states. The LTV ratio tightening lowers saving at low levels of wealth but raises it at higher levels. This implies that there will be a relatively greater share of households at low wealth levels (since they save less and run down their wealth relatively faster), *and* a slightly greater density of households at higher wealth levels, since the latter are accumulating wealth at a slightly faster pace. The higher downpayment requirement causes the Lorenz curve to rotate slightly counter-clockwise about the fifty fifth percentile of households, meaning that households below this percentile hold a slightly lower share of wealth than before, and households above this percentile holding a higher share. Figure 3.8 shows a higher share of households at very low wealth levels and as a result, the new

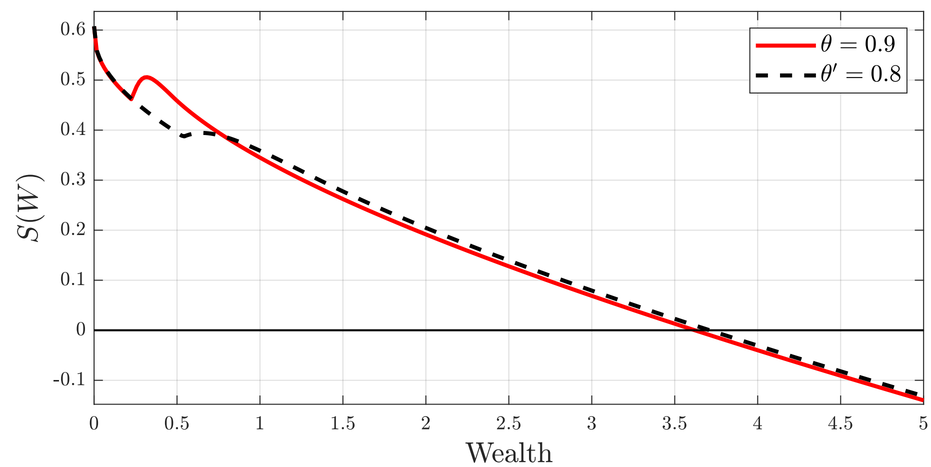

Figure 3.7: Saving policy functions averaged over y (HWG)

Note: Wealth is a multiple of average income $\overline{y}$.

steady state preserves the area between the line of perfect equality and the Lorenz curve, keeping the wealth Gini coefficient virtually unchanged.

However, the macroprudential regime induces significant changes in the housing market. First, it alters the asset portfolio of the subset of households that is forced to switch to renting. Second, it limits the size of the house that can be purchased by a household that becomes constrained. Third, it also affects households that were and remain unconstrained, as it causes them to reduce their total consumption and save more, translating to a slight downsizing of their house.[29] Although overall wealth inequality is virtually unchanged as houses can be converted into bonds at no cost, the combined effect increases housing wealth inequality, raising the housing wealth gini by 4.6% in the HWG economy.[30] Effectively this concentrates housing wealth amongst the richer households.

The effect in the LWG economy is even greater, where the housing wealth Gini increases by 6.5%, despite the same terminal homeownership rates. This is because since households are relatively less heterogeneous in their wealth *ex-ante*, the policy affects a bigger share of households. Figure 3.9 shows the Lorenz curves for HWG economy, before and after the regime change.[31] The distributions of housing wealth at the high LTV *Lorenz dominates* those at the low LTV (Zoli, 2002). These clearly illustrate how, as discussed in Guerrieri and Lorenzoni (2017), policy affects most households

[29] Admittedly, the last effect may be due to the lack of adjustment costs in the model, which would otherwise create a zone of inaction.

[30] These changes in housing wealth inequality are in line with the findings of Favilukis et al. (2017).

[31] The corresponding Lorenz curves for the LWG economy look similar, although in this economic the gap between the curves is slightly larger given the higher increase in the housing wealth gini.

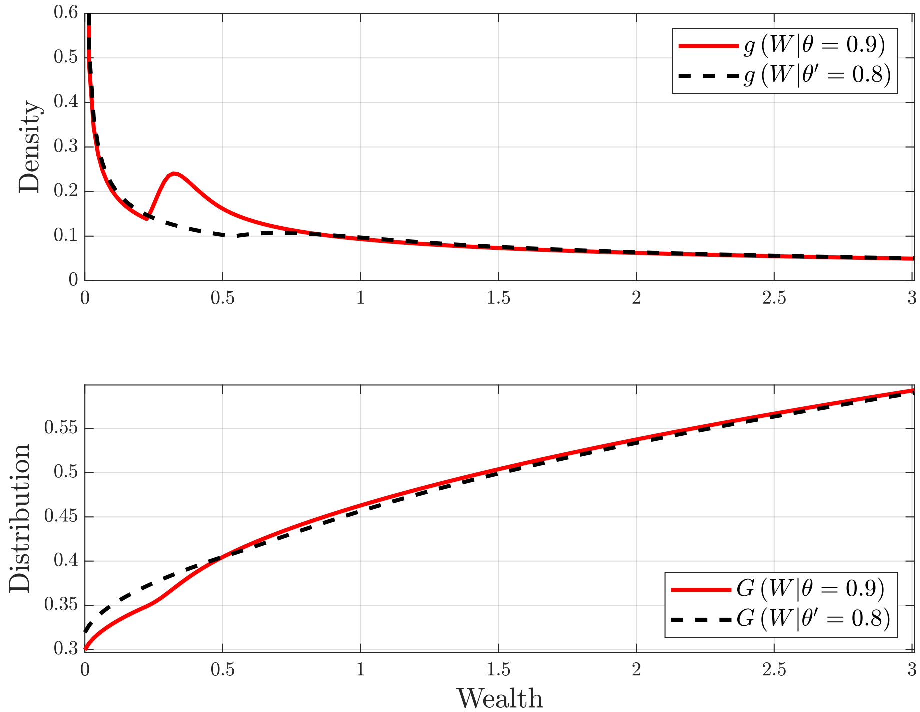

Figure 3.8: Unconditional wealth distributions for the two steady states (HWG)

Note: Wealth is a multiple of average income $\overline{y}$.

along the distribution, not just those on the borrowing constraint or those who switch to renting. In sum, while a drop in the LTV ratio does not change the overall wealth gini, it lowers homeownership and therefore increases housing wealth inequality. These effects are stronger the lower is initial total wealth inequality.

3.5 Sensitivity and robustness checks

3.5.1 A range of LTV values

Are these findings sensitive to the level of the maximum LTV ratio? To answer this, I solve the model over the range of LTV values $\theta \in \Theta = [0.65, 0.9]$. A lower LTV ratio always leads to a fall in house prices and increases the ownership cutoff (and, as a result, the share of renters the economy), as well as the share of constrained owners. In particular, the ownership cutoff increases by several factors over the level in the benchmark calibration, and at an LTV of 0.7 households

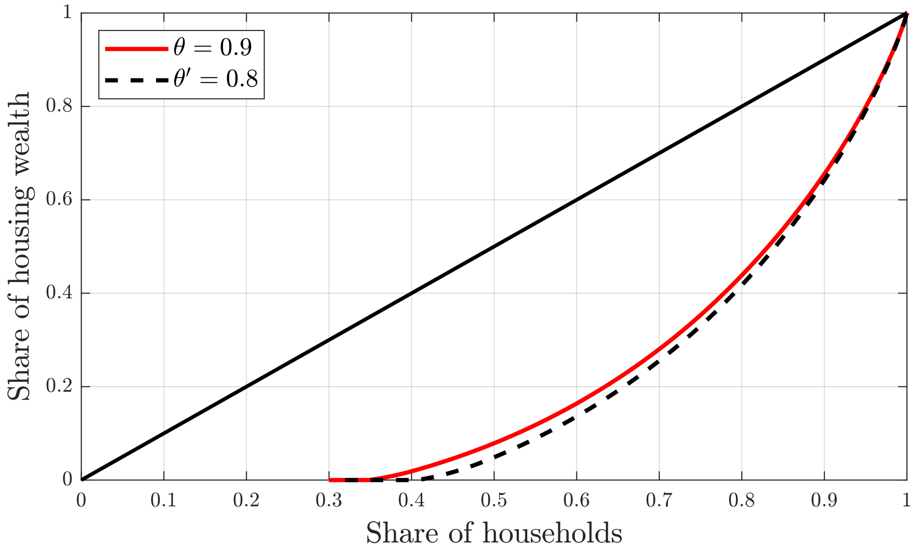

Figure 3.9: Lorenz curves for housing wealth (HWG)

Notes: The solid diagonal black line denotes the line of perfect equality. The curve for a given LTV ratio starts from the share of households that are hand-to-mouth and who have zero wealth, including no housing wealth. It rises above zero for households on and above the ownership cutoff.

on income state y_1 require four times as much wealth to find it optimal to switch to owning in both settings. Moreover, a few households on the high income state y_2 in the LWG economy also switch to renting as the LTV ratio falls below 0.8. As discussed in Sommer et al. (2013), there is a strong link between down payment requirements and the homeonwership rate, and LTV policies matter greatly for households that are on the borrowing limit. Figure 3.10 shows that while the homeownership rate falls by about the same irrespective of the initial shape of the wealth distribution, the dynamics in the share of constrained owners and equilibrium house prices differ a lot. Housing wealth inequality, although lower in the LWG economy, rises at a faster rate and approaches the level of the HWG economy at low LTV ratios.[32] As a result, the same policy can have different outcomes across countries with ex-ante different levels of wealth dispersion. This again emphasizes the point that the distribution can have a huge bearing on the outcome, and models which impose limited ex-ante heterogeneity miss these changing compositions by definition.

[32] Remember that total wealth inequality is virtually unchanged over the two steady states for each economy.

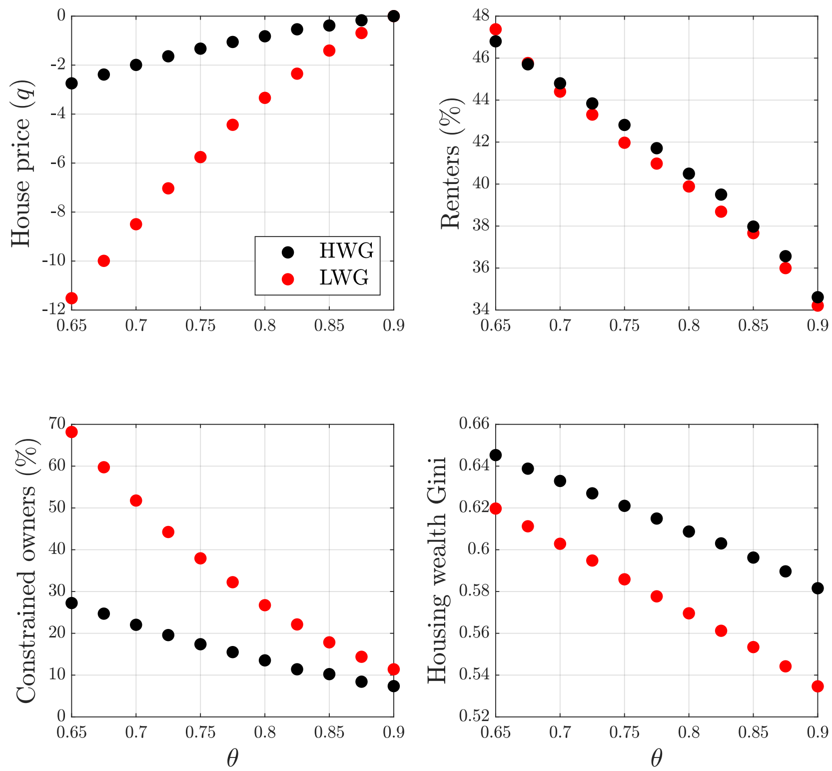

Figure 3.10: Comparative statics over a range of LTV values

Note: House prices are expressed in percentage deviation from their benchmark value at an LTV ratio of 0.9.

3.5.2 The long-run interest rate

The interest rate is exogenous at 2% in the analysis so far, but this parameter plays an important intertemporal role in the accumulation of wealth. I repeat the LTV ratio tightening in the context of a lower and higher long run interest rate of 1.5% and 4% respectively. In the case of a lower interest rate I re-calibrate only the utility cost of renting ψ to 0.22 and 0.21 for the HWG and LWG economies respectively so that the initial steady states in these lower interest rate economies are close to those in the benchmark economies. The steady state moments that I focus on are a wealth Gini of 0.7 and 0.6 respectively, and about 65% homeownership rate, at an LTV of 0.9. The re-calibration also delivers housing wealth Gini coefficients similar to the benchmark. Obtaining similar steady state moments when the interest rate is 4% is harder and requires tweaking more parameters. I re-calibrate the Poisson flow rate into income state y_1, the utility cost of renting and the share of housing in total expenditure in both the HWG and LWG economies. The values

$\{\lambda_2 = 0.38, \psi = 0.12, \alpha = 0.75\}$ in the HWG economy and $\{\lambda_2 = 0.093, \psi = 0.11, \alpha = 0.75\}$ in the LWG deliver steady state moments close to those in the benchmark economies.

As I conduct the comparative statics exercise I run into convergence problems when the interest rate is 1.5% and the LTV ratio falls below 0.75. Yet we can still observe differential long run impacts over the restricted LTV range $\theta \in \widetilde{\Theta} = [0.75, 0.9]$, where $\widetilde{\Theta} \subset \Theta$. In Figures 3.11 and 3.12 I show the mapping between aggregate house price and quantities at the two alternative interest rates respectively and θ, and also superimpose the corresponding mappings from the benchmark cases (hollow markers) for reference. At all interest rate levels, house prices fall as the LTV ratio is lowered and the share of constrained owners rises in both economies, relative to their values at an LTV of 0.9. Housing wealth inequality also rises. The main difference is the magnitude of changes. The lower the interest rate, the larger are the differences in steady state house prices and the share of constrained owners. For instance, at an LTV of 0.75, house prices in the LWG economy are about 12.2% lower when r is 1.5%, compared to about -5.8% when r is 2% and -3% when the r is 4%. This pattern also extends to the share of renters in the economy and therefore the housing wealth gini. For instance, in the LWG economy, the share of renters rises by 9, 8 and 6.5 percentage points over when r is 1.5%, 2% and 4% respectively. Similarly, the housing wealth gini rises by 0.062, 0.051 and 0.036 points respectively as the LTV is reduced from 0.9 to 0.75.

Since some parameters are not set at the same values in these scenarios as in the benchmark case – especially when r is 4% – it is not totally innocuous to attribute the differential variation in house prices and share of constrained ownership over the LTV range wholly to different interest rates. Nevertheless, a higher interest rate induces households to save (dissave) relatively more (less), such that they become unconstrained at lower wealth levels and try harder to escape the zone at which they are constrained. Indeed, when r is 4% (1.5%), an LTV reduction causes a smaller (larger) increase in the share of constrained owners compared to when r is 2%. With a lower (higher) share of households on the borrowing constraint, a tightening of the LTV reduces housing demand relatively by less (more), and hence has a relatively weaker (stronger) effect on equilibrium house prices.

These additional findings are especially relevant in the current context of a low interest rate environment. The model suggests that using the LTV ratio as a macroprudential policy tool to meet financial stability objectives is likely to have stronger long run effects on the housing market if long term interest rates are low. It follows that if the objective is to increase resilience to shocks by permanently reducing household leverage, then policymakers need to tighten the borrowing constraint by less relative to a scenario of high long term interest rates.[33]

[33] On the other hand, a low interest rate environment may be associated with a higher absolute level of household leverage, as is the case in this paper. The discussion here is on the absolute reduction in leverage; a smaller drop in the LTV ratio is needed to reduce leverage by 10 percentage points when interest rates are low.

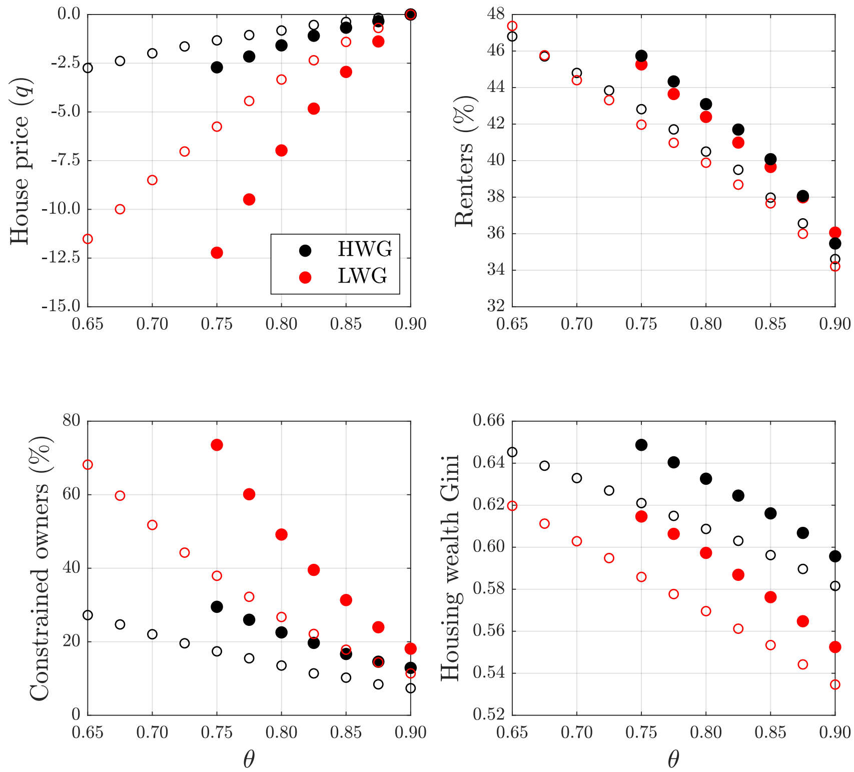

Figure 3.11: Comparative statics over a range of LTV values at $r = 1.5\%$

Notes: House prices are expressed in percentage deviation from their benchmark value at an LTV ratio of 0.9. The hollow markers denote the values from the benchmark calibration as shown in Figure 3.10. Aggregate quantities are only available for $\theta \in [0.75, 0.9]$.

3.5.3 The initial homeownership rate

The homeownership rate in the benchmark scenario is calibrated to around 65%, which is the average discussed in Davis and Van Nieuwerburgh (2015) and Cloyne et al. (2019) for the US and UK and is the number most commonly used in the literature. Although the average rate across all 28 EU countries is also close to this level, there is significant heterogeneity in homeownership rates within the EU. For instance, in 2015 homeownership rates across the countries shown in Figure 3.1 were as low as 52% in Germany but exceeded 80% in Poland, Estonia, Malta and Latvia. Since the results may hinge on the *a priori* share of renters in the economy, I repeat the main experiment with a higher initial homeownership rate close to 75% in both economies.[34] A reduction in the LTV

[34] I am unable to increase homeownership by raising the utility cost of renting ψ higher than in the benchmark calibration as the numerical algorithm runs into convergence issues. I instead lower the discount rate ρ from 0.071

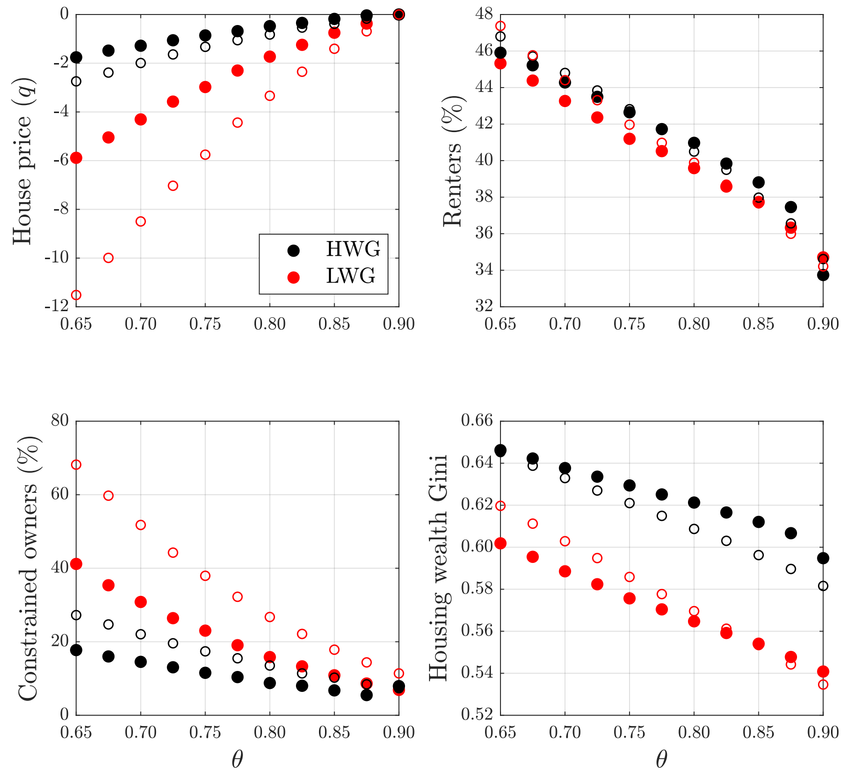

Figure 3.12: Comparative statics over a range of LTV values at $r = 4\%$

Notes: House prices are expressed in percentage deviation from their benchmark value at an LTV ratio of 0.9. The hollow markers denote the values from the benchmark calibration as shown in Figure 3.10.

from 0.9 to 0.8 causes about the same drop in homeownership rates in both economies, and causes a larger fall in house prices and increase in the share of constrained owners in the LWG economy (Table 3.3). There is also a stronger rise in housing wealth inequality in the LWG economy. These results are in line with those in the benchmark scenario.

to 0.06 in both economies, and in the LWG economy, I reduce the share of housing expenditure α from 0.8 to 0.75. These produce the same homeownership rate of about 74% both economies.

Table 3.3: Initial and terminal steady states – higher initial homeownership

	High Wealth Gini			Low Wealth Gini		
	$\theta = 0.9$	$\theta' = 0.8$	Δ	$\theta = 0.9$	$\theta' = 0.8$	Δ
Household shares (%)						
Renters	26.2	34.1	7.9p.	26.5	34.7	8.3p.
Owners	73.8	65.9	-7.9p.	73.5	65.3	-8.3p.
Constrained owners (μ^{co})	6.3	10.6	4.4p.	12.2	25.5	13.3p.
Renters and constrained owners (μ^{rco})	30.8	41.1	10.3p.	35.5	51.4	16.0p.
Hand-to-mouth	23.1	27.6	4.4p.	22.8	26.8	3.9p.
Aggregates						
House price (q)	11.21	11.14	-0.6%	13.11	12.72	-3.0%
Leverage (%)	39.5	31.6	-7.9p.	55.1	46.1	-9.0p.
Wealth Gini	0.671	0.672	0.1%	0.577	0.575	-0.2%
Housing Wealth Gini	0.528	0.560	6.1%	0.488	0.533	9.2%

Notes: Constrained owners is the fraction of owners that are on the collateral constraint. Leverage is calculated as the ratio of debt to housing wealth of owners. Δ denotes changes between the two LTV scenarios in percentage points (p.) or percentage rates (%). Numbers may not add up due to rounding.

3.6 Conclusion

Are there distributive effects arising as unintended consequences of borrower-based macroprudential policy tightening? Does the extent of these effects hinge on the initial wealth distribution? This paper answers ‘yes’ to both of these questions. A reduction in the LTV ratio tightens households’ borrowing limit, causing some households which could just afford to buy a house against a mortgage to deleverage and switch to renting. It also causes households who were unconstrained before the policy to be up against their borrowing limit and reduce the size of their house. This causes an increase in housing wealth inequality, and wealthier households end up owning more of the housing stock ex-post. These effects are stronger when wealth is more equally distributed ex-ante, as in this case the policy has an effect on a greater share of households and the jump in housing inequality is higher. The same policy therefore has different outcomes across countries with different levels of wealth dispersion. Moreover, the effect of LTV policy on the housing market is inversely related to long term interest rates, as a lower interest rate amplifies the drop in house prices and the rise in the share of constrained households, irrespective of the initial wealth inequality in the economy. Although homeownership rates vary significantly across Europe, I show that these findings are robust to the initial homeownership rate and therefore apply to many of these countries.

Appendix to chapter 3

A3.1 Key derivations

The main derivations presented in this appendix follow Sennewald and Wälde (2006) and Achdou et al. (2017).

A3.1.1 Hamilton-Jacobi-Bellman Equation with Poisson uncertainty

I first derive the HJB equation from its counterpart in a discrete time version of the model for an owner, written in its stationary form and taking prices as given.[35] Income fluctuates between two states: $y_j \in \{y_1, y_2\}$. The problem is:

$$\begin{aligned} &\max_{c,h} \sum_{t}^{\infty} u(c_t, h_t) \\ \text{s.t.} \quad & b_{t+1} + q(h_{t+1} - h_t) = y_j + (1+r)b_t - c_t \\ & - b_{t+1} \leq \theta q h_{t+1}. \end{aligned}$$

Let $W_t = b_t + qh_t$ denote wealth; then the constraints can be written as:

$$W_{t+1} - W_t = y_i + rW_t - PC_t \tag{A3.1}$$

$$W_{t+1} \geq (1-\theta) q h_{t+1} \tag{A3.2}$$

where $PC_t = rqh_t + c_t$. The Bellman equation associated with this problem in the stationary equilibrium is:

$$V_j(W_t) = \max_{C} \; u(C_t) + \beta \left(\Pr(y_j) V_j(W_{t+1}) + (1 - \Pr(y_j)) V_{-j}(W_{t+1}) \right)$$

subject to the constraints (A3.1)–(A3.2), and where C_t is the Cobb-Douglas bundle of non-durable goods and housing services, $\Pr(y_j)$ is shorthand notation to denote the conditional probability that

[35] See Sennewald and Wälde (2006) for the derivation of the HJB along a transition path.

households draw the same income y_j also in period $t+1$, $\Pr(y_{t+1} = y_j | y_t = y_j)$, and $-j = 2$ when $j = 1$ and vice versa. The Bellman equation and associated constraints in time steps of Δ are given by:

$$V_j(W_t) = \max_C \ \Delta u(C_t) + \beta(\Delta) \left(\Pr(\Delta, y_j) V_i(W_{t+\Delta}) + (1 - \Pr(\Delta, y_j)) V_{-j}(W_{t+\Delta}) \right) \tag{A3.3}$$

$$W_{t+\Delta} - W_t = \Delta(y_j + rW_t - PC_t) \tag{A3.4}$$

$$W_{t+\Delta} \geq (1-\theta) q h_{t+\Delta}. \tag{A3.5}$$

As the time steps Δ become small, the discount factor $\beta(\Delta)$ and income probability $\Pr(\Delta, y_j)$ can be approximated as $1 - \Delta\rho$ and $1 - \Delta\lambda_j$ respectively, where ρ is the rate of time preference and λ_j is the Poisson intensity parameter associated with draw y_j.[36] Plugging these in the Bellman equation and simplifying, we get:

$$V_j(W_t) = \max_C \ \Delta u(C_t) + (1 - \Delta\rho) \left((1 - \Delta\lambda_j) V_j(W_{t+\Delta}) + \Delta\lambda_j V_{-j}(W_{t+\Delta}) \right). \tag{A3.6}$$

Subtracting $(1 - \Delta\rho) V_j(W_t)$ from both sides and dividing by Δ yields

$$\rho V_j(W_t) = \max_C \ u(C_t) + (1 - \Delta\rho) \left(\frac{V_j(W_{t+\Delta}) - V_j(W_t)}{\Delta} - \lambda_j V_j(W_{t+\Delta}) + \lambda_j V_{-j}(W_{t+\Delta}) \right). \tag{A3.7}$$

Taking the limit $\Delta \to 0$, we have $\lim_{\Delta \to 0} (1 - \Delta\rho) = 1$ and, by using the budget constraint (A3.4), we can express the second limit as

$$\begin{aligned} & \lim_{\Delta \to 0} \frac{V_j(W_{t+\Delta}) - V_j(W_t)}{\Delta} \\ &= \lim_{\Delta \to 0} \frac{V_j(W_t + \Delta(y_j + rW_t - PC_t)) - V_j(W_t)}{\Delta} \\ &= \frac{dV_j(W_t)}{dW} (y_j + rW_t - PC_t) \end{aligned}$$

where the third line makes use of L'Hôpital's rule. Plugging this in (A3.7) above and dropping time subscripts, we get the Hamilton-Jacobi-Bellman equations analogous to (3.8) and (3.10):

$$\rho V_j(W) = \max_C \ u(C) + \frac{dV_j(W)}{dW} (y_j + rW - PC_j) + \lambda_j (V_{-j}(W) - V_j(W)).$$

[36] Recall that the density of a standard Poisson process is given by $\lambda e^{-\lambda t}$, and the probability that an event occurs before t is: $\int_0^t \lambda e^{-\lambda s} ds = [-e^{-\lambda s}]_0^t = 1 - e^{-\lambda t}$. In continuous time, λ is a flow probability.

A3.1.2 Kolmogorov Forward equation

The Kolmogorov Forward equation can be derived in a similar fashion to the HJB equation by referring to the discrete time counterpart in time steps of size Δ. Denote by $G_j(W,t)$ the distribution for households with wealth $W_t \leq W$ and the density as $\partial G_j(W,t)/\partial W = g_j(W,t)$. The fraction of households holding wealth up to W increases over time through dissaving ($S_j(W) < 0$)). For small Δ time steps, the evolution of wealth can be explained by $W_t = W_{t+\Delta} - \Delta S_j(W_{t+\Delta})$.[37] With only one income state, the fraction of households with wealth up to W is:

$$\Pr(W_{t+\Delta} \leq W) = \Pr(W_t \leq W - \Delta S(W_{t+\Delta}))$$

that is, the fraction of people who decumulate wealth enough to hold up to W. When income is stochastic, some households move out of the distribution for the income state j at the rate λ_j, whereas others move into this state at rate λ_{-j}. Therefore, the fraction of households with wealth lower than W evolves (increases) over time by:

$$\begin{aligned}\Pr(W_{t+\Delta} \leq W|_{y_{t+\Delta}=y_j}) = &(1-\Delta\lambda_j)\Pr(W_t \leq W - \Delta S_j(W)|_{y_t=y_j}) \\ &+ \Delta\lambda_{-j}\Pr(W_t \leq W - \Delta S_{-j}(W)|_{y_t=y_{-j}})\end{aligned}$$

$$\Rightarrow \; G_j(W,t+\Delta) = (1-\Delta\lambda_j)G_j(W-\Delta S_j(W),t) + \Delta\lambda_{-j}G_{-j}(W-\Delta S_{-j}(W),t).$$

Subtracting $G_j(W,t)$ from both sides and dividing throughout by Δ we have:

$$\begin{aligned}\frac{G_j(W,t+\Delta)-G_j(W,t)}{\Delta} = &\frac{G_j(W-\Delta S_j(W),t)-G_j(W,t)}{\Delta} \\ &-\lambda_j G_j(W-\Delta S_j(W),t) + \lambda_{-j}G_{-j}(W-\Delta S_{-j}(W),t)\end{aligned}$$

taking the limit $\Delta \to 0$ we get

$$\frac{\partial G_j(W,t)}{\partial t} = -S_j(W,t)\frac{\partial G_j(W,t)}{\partial W} - \lambda_j G_j(W,t) + \lambda_{-j}G_{-j}(W,t) \tag{A3.8}$$

[37] That is, instead of $W_t = W_{t+\Delta} - \Delta S_j(W_t)$, where the last term is saving at time t rather than $t+\Delta$.

where the limit on the right makes use of l'Hôpital's rule:

$$\begin{aligned}
&\lim_{\Delta \to 0} \frac{G_j(W - \Delta S_j(W), t) - G_j(W, t)}{\Delta} \\
&= \lim_{\Delta \to 0} \frac{\partial G_j(W - \Delta S_j(W), t)}{\partial W}(-S_j(W)) \\
&= -S_j(W)\frac{\partial G_j(W, t)}{\partial W}.
\end{aligned}$$

Equation (A3.8) is the law of motion in terms of the wealth distribution. Differentiating it with respect to wealth, and noting the definition for the wealth density above, we get the Kolmogorov Forward equation:

$$\frac{\partial g_j(W,t)}{\partial t} = \frac{\partial\left[-S_j(W,t)g_j(W,t)\right]}{\partial W} - \lambda_j g_j(W,t) + \lambda_{-j} g_{-j}(W,t).$$

In the stationary equilibrium the density is time-invariant and we have

$$0 = -\frac{d}{dW}\left[S_j(W)g_j(W)\right] - \lambda_j g_j(W) + \lambda_{-j} g_{-j}(W)$$

which is the equation shown in the text.

A3.2 Numerical algorithm

I describe the numerical procedure to solve the model in the benchmark calibration above, for the given calibration choice of logarithmic utility ($\sigma = 1$).[38] Algorithm 1 describes the procedure for obtaining the stationary solution which finds the policy functions, cut-off point W^o, conditional distributions $G_j(W)$ and market clearing prices $\{q, p\}$.

Algorithm 1 Solving for market clearing prices $\{q, p\}$

---

1. Discretize wealth W on a grid of I points between the bounds $\underline{W} = 0$ and some upper bound $\overline{W}$.

2. Set the parameter values and convergence tolerance limits for market clearing `tol-MC`.

3. Set a guess for the house price q, and compute the rental rate p using (3.4) and the aggregate price P using (3.15). Set upper and lower values for the guess of q, $\{\underline{q}, \overline{q}\}$, used by the bisection algorithm in the last step.

4. Calculate maximum feasible house ownership associated with the LTV constraint $h(W)^{\text{coll}} = \frac{W}{(1-\theta)q}$ at each point i on the wealth grid $W_{i \in I} \in [\underline{W}, \overline{W}]$.

5. Solve the renter's problem using a *upwind finite difference* scheme to solve the HJB (3.10), which yields $V_j(W)^r$ and the associated policy functions. See Algorithm 2 for further details.

6. Using $V_j(W)^r$ from the previous step, solve the HJBVI (3.11). This yields the value function $V_j(W)^o$, the associated policy functions and the cut-off W^o. See Algorithm 2 for further details.

7. Calculate the distribution $G_j(W)$ by solving the Kolmogorov-Forward equation (3.16), using the saving policy functions derived from step 6. See Algorithm 3 for more details.

8. Check for market clearing as in (3.20) by aggregating over all housing that is either owned or rented. If excess demand is less than or equal to `tol-MC` in absolute terms, stop. Otherwise, update q using a bisection algorithm and return to step 3 until convergence is achieved.

I use $I = 7{,}500$ equally-spaced points on the wealth grid for the benchmark model, and the value of $\overline{W}$ at which saving under the high income state is turns negative is just under 120 times average income $\overline{y}$. The entire stationary wealth density computed by the algorithm and the resulting policy

[38] This choice simplifies some terms such as the boundary condition when wealth approaches zero and ensures that the algorithm is stable and converges to an (approximate) solution.

functions and densities are very smooth at this fine discretization of the wealth state. Algorithm 2 describes the *upwind finite difference* scheme discussed in Achdou et al. (2017) to solve the HJB equation, and the added steps needed to solve the HJBVI.

Algorithm 2 Solving the HJB equation or the HJBVI

---

1. For given parameters and prices, calculate steady state expenditure: $PC_j(W_i)^{ss} = y_j + rW_i$ for each income state y_j and calculate optimal steady state allocations for c^{ss} and s^{ss} as in (3.13) and (3.14).[39] Set a tolerance for the value function iteration `tol-VF`.

2. Use these values to initialise the value function as:

$$V_j(W_i)^0 = \frac{1}{\rho} \log \left(\left(\frac{c^{ss}}{\alpha} \right)^{\alpha} \left(\frac{(1 - \psi \mathbf{1}_{\text{rent}}) s^{ss}}{1 - \alpha} \right)^{1-\alpha} \right).$$

3. Approximate the derivative $dV_j(W)/dW$ using both a forward difference (F) and backward difference (B):

$$V_j'(W_i)^F \equiv \frac{V_j(W_{i+1}) - V_j(W_i)}{\Delta W}$$
$$V_j'(W_i)^B \equiv \frac{V_j(W_i) - V_j(W_{i-1})}{\Delta W}$$

   where ΔW denotes the distance between grid points.

4. Set the boundary condition (3.21) for households on income state y_1 at $W = \underline{W}$: $V_1'(W_1)^B = (y_1)^{-1}$.

5. Calculate $C_j(W)^k$, using (3.12) for each approximation of $V_j'(W_i)^k$, were $k \in \{F, B\}$. Calculate the resulting saving policies $S_j(W_i)^k$ for each k.

6. Choose between using the forward or backward difference on the basis of an *upwind* scheme:

$$V_j'(W_i) = \begin{cases} V_j'(W_i)^F \text{ if } S_j(W_i)^F > 0; & \Rightarrow \mathbf{1}_F = 1 \\ V_j'(W_i)^B \text{ if } S_j(W_i)^B < 0; & \Rightarrow \mathbf{1}_B = 1. \end{cases}$$

   This means that policy functions for total consumption and saving should be based on the forward difference approximation $(\mathbf{1}_F = 1)$ when saving is positive, and on the backward difference approximation $(\mathbf{1}_B = 1)$ when saving is negative.[40] At points where neither inequality

[39] In the renter's problem these are the unconstrained allocation shares α and $1-\alpha$ of total expenditure respectively.

[40] Since the value function is concave, the case where both $S_j(W_i)^F > 0$ and $S_j(W_i)^B < 0$ is ruled out.

is satisfied, a household is at the steady state ($S_j(W_i) = 0 \Rrightarrow \mathbf{1}_{ss} = 1$) and $C_j(W_i)^{ss}$ from step 1 applies.

7. Calculate the total consumption policy as: $C_j(W_i) = C_j(W_i)^F \mathbf{1}_F + C_j(W_i)^B \mathbf{1}_B + C_j(W_i)^{ss} \mathbf{1}_{ss}$, the implied policies $c_j(W_i)$ and $s_j(W_i)$ and the associated utility $u_j(c_j(W_i), s_j(W_i))$.

8. (a) HJB: solve for the value function using the iterative scheme:

$$\begin{aligned}\frac{V_j(W_i)^{n+1} - V_j(W_i)^n}{\Delta} + \rho V_j(W_i)^{n+1} = {} & u\left(c_j(W_i)^n, s_j(W_i)^n\right) \\ & + V_j'(W_i)^{n+1,F} S_j(W_i)^{n,F} \mathbf{1}_F \\ & + V_j'(W_i)^{n+1,B} S_j(W_i)^{n,B} \mathbf{1}_B \\ & + \lambda_j \left(V_{-j}(W_i)^{n+1} - V_j(W_i)^{n+1}\right)\end{aligned}$$

which is implicit in the value function and where n is the iteration counter and Δ is a step size, set to a large number. Stack over j the value functions $V_j(W)^n$, $V_j(W)^{n+1}$ and utility $u_j(c_j(W_i)^n, s_j(W_i)^n)$ into the $jI \times 1$ vectors $\mathbf{V}^n$,$\mathbf{V}^{n+1}$, and $\mathbf{u}^n$ respectively, and collect all other right-hand side elements into the $jI \times jI$ transition matrix $\mathbf{A}^n$ as:

$$\mathbf{A}^n = \begin{bmatrix} \chi_{1,1} & \omega_{1,1} & 0 & \dots & 0 & \lambda_1 & 0 & 0 & \dots & 0 \\ \zeta_{2,1} & \chi_{2,1} & \omega_{2,1} & 0 & \dots & 0 & \lambda_1 & 0 & \dots & 0 \\ 0 & \zeta_{3,1} & \chi_{3,1} & \omega_{3,1} & 0 & \dots & 0 & \lambda_1 & \dots & 0 \\ \vdots & \ddots & \ddots & \ddots & \ddots & \ddots & \ddots & \ddots & \ddots & \vdots \\ 0 & \dots & 0 & \zeta_{I,1} & \chi_{I,1} & 0 & 0 & \dots & 0 & \lambda_1 \\ \lambda_2 & 0 & \dots & 0 & 0 & \chi_{1,2} & \omega_{1,2} & 0 & \dots & 0 \\ 0 & \lambda_2 & 0 & \dots & 0 & \zeta_{2,2} & \chi_{2,2} & \omega_{2,2} & \dots & 0 \\ 0 & 0 & \lambda_2 & 0 & \dots & 0 & \zeta_{3,2} & \chi_{3,2} & \omega_{3,2} & \dots \\ \vdots & \ddots & \ddots & \ddots & \ddots & \ddots & \ddots & \ddots & \ddots & \vdots \\ 0 & \dots & 0 & 0 & \lambda_2 & 0 & \dots & 0 & \zeta_{I,2} & \chi_{I,2} \end{bmatrix}$$

where, given the definitions of the forward and backward difference approximations

$$\begin{aligned}\zeta_{i,j} &= -\frac{S_j(W_i)^{n,B}}{\Delta W} \mathbf{1}_B \\ \chi_{i,j} &= -\frac{S_j(W_i)^{n,F}}{\Delta W} \mathbf{1}_F + \frac{S_j(W_i)^{n,B}}{\Delta W} \mathbf{1}_B - \lambda_j \\ \omega_{i,j} &= \frac{S_j(W_i)^{n,F}}{\Delta W} \mathbf{1}_F.\end{aligned}$$

Note that $\zeta_{i,j} = \omega_{I,j} = 0$. The iterative scheme can then be written in matrix form as:

$$\frac{1}{\Delta}(\mathbf{V}^{n+1} - \mathbf{V}^n) + \rho \mathbf{V}^{n+1} = \mathbf{u}^n + \mathbf{A}^n \mathbf{V}^{n+1}.$$

The new value function iterate $\mathbf{V}^{n+1}$ is obtained as:[41]

$$\mathbf{V}^{n+1} = \left[\left(\frac{1}{\Delta} + \rho \right) \mathbf{I} - \mathbf{A}^n \right]^{-1} \left[\mathbf{u}^n + \frac{1}{\Delta} \mathbf{V}^n \right].$$

If the maximum absolute difference between $\mathbf{V}^n$ and $\mathbf{V}^{n+1}$ is less than `tol-VF`, stop. Otherwise, go to step 3.

(b) HJBVI: recall the problem (3.11). Using the same notation as in 8(a), this can be written as:

$$\min \{ \rho \mathbf{V} - \mathbf{u} - \mathbf{A}\mathbf{V}, \mathbf{V} - \mathbf{V}^r \} = 0$$

where the same matrix defintions apply, and $\mathbf{V}$,$\mathbf{u}$ and $\mathbf{A}$ relate to the owner's problem are obtained in the same way following steps 1-8(a), while $\mathbf{V}^r$ is from the renter's problem obtained following steps 1–8(a). Denote by $\mathbf{B}$ the matrix

$$\mathbf{B} = \left[\left(\frac{1}{\Delta} + \rho \right) \mathbf{I} - \mathbf{A}^n \right]$$

by $\mathbf{z}$ the slack vector

$$\mathbf{z} = \mathbf{V} - \mathbf{V}^r$$

and by $\mathbf{q}$ the matrix:

$$\mathbf{q} = -\mathbf{u} - \frac{1}{\Delta} \mathbf{V} + \mathbf{B} \mathbf{V}^r.$$

Then the problem can be solved as a Linear Complementary Problem:

$$\begin{aligned} \mathbf{z}^T (\mathbf{B}\mathbf{z} + \mathbf{q}) &= 0 \\ \mathbf{z} &\geq 0 \\ \mathbf{B}\mathbf{z} + \mathbf{q} &\geq 0 \end{aligned}$$

and solved using a suitable LCP solver, which yields the value function for owners as the vector $\mathbf{V}$, the associated policy functions and the ownership cutoff which occurs when $\mathbf{V} \neq \mathbf{V}^r$.[42] If the maximum absolute difference between successive iterates of $\mathbf{V}$ is less than `tol-VF`, stop. Otherwise, go to step 3.

As discussed in Achdou et al. (2017), the upwind scheme strategy satisfies the Barles-Souganidis conditions such that the approximation converges to the solution of the HJB (Barles and Souganidis, 1991). In order to satisfy the borrowing constraint, the derivative at the lower end of the state

[41] The A matrix is large but sparse, but the system can still be solved using sparse matrix routines.

[42] I use the LCP solver by Yuval Tassa, available at https://www.mathworks.com/matlabcentral/fileexchange/20952-lcp-mcp-solver-newton-based (accessed 3 December 2019).

space is calculated by setting (3.21) as an equality and applying it when the drift is negative, that is, when agents are approaching the borrowing constraint from above. Therefore, the boundary condition in step 4 only applies to households on the low income state, and relates only to the backward difference. See Achdou et al. (2017) for further details.

Algorithm 3 Solving the Kolmogorov-Forward equation

1. The stationary KF equation (3.16) can be discretized as:

$$0 = -\left[\frac{S_j(W_i)^{n,F} g_j(W_i) - S_j(W_{i-1})^{n,F} g_j(W_{i-1})}{\Delta W}\mathbf{1}_F + \frac{S_j(W_{i+1})^{n,B} g_{i+1,j} - S_j(W_i)^{n,B} g_j(W_i)}{\Delta W}\mathbf{1}_B\right] - g_j(W_i)\lambda_j + g_{-j}(W_i)\lambda_{-j}$$

which makes use of the same upwind scheme as above. Collecting like terms, we have:

$$0 = g_j(W_{i-1})\frac{S_j(W_{i-1})^{n,F}}{\Delta W}\mathbf{1}_F + g_j(W_i)\left(-\frac{S_j(W_i)^{n,F}}{\Delta W}\mathbf{1}_F + \frac{S_j(W_i)^{n,B}}{\Delta W}\mathbf{1}_F - \lambda_j\right) - g_j(W_{i+1})\frac{S_j(W_i)^{n,B}}{\Delta W}\mathbf{1}_B + g_{-j}(W_i)\lambda_{-j}.$$

This can be written in matrix form as:

$$\mathbf{0} = \mathbf{A}^{\mathrm{T}}\mathbf{g}$$

where $\mathbf{A}^{\mathrm{T}}$ is the transpose of $\mathbf{A}$ from the last iteration of Algorithm 2 and

$$\mathbf{g} = [g_1(W_1)\ \dots\ g_1(W_I)\ ,\ g_2(W_1)\ \dots\ g_2(W_I)]^{\mathrm{T}}.$$

This is an eigenvalue problem with the constraint (3.17) that the entire density must integrate to 1. To solve it, create a vector $\widetilde{\mathbf{b}}$ of zeros of length $jI \times 1$ and set an element to a small number, and set all the entries of the corresponding row in matrix $\mathbf{A}^{\mathrm{T}}$ to 0 except for 1 in the diagonal, and denote this matrix as $\widetilde{\mathbf{A}}^{\mathrm{T}}$.[43]

2. Obtain the density vector $\widetilde{\mathbf{g}}$ as:

$$\widetilde{\mathbf{g}} = \left[\widetilde{\mathbf{A}}^{\mathrm{T}}\right]^{-1}\widetilde{\mathbf{b}}.$$

[43] This method, discussed in Achdou et al. (2017), is one way of solving the eigenvalue problem that satisfies (3.17). Without this adjustment, the matrix $\mathbf{A}^{\mathrm{T}}$ is singular and the next steps do not work. Although an eigenvalue routine such as the `eigs` function in Matlab can also be used, it runs into numerical problems when I is higher than about 1,300 in this example.

3. Obtain the normalised stacked density vector $\mathbf{g}$ as:

$$\mathbf{g} = \frac{\widetilde{\mathbf{g}}}{\sum \widetilde{\mathbf{g}} \Delta W}.$$

4. Obtain the discretized conditional distributions $G_j(W)$, $\mathbf{G_1}$ and $\mathbf{G_2}$, as the cumulative sum of the densities weighed by the step size ΔW:

$$\mathbf{G}_{1,i} = \sum_{1}^{I} \mathbf{g} \Delta W$$
$$\mathbf{G}_{2,i} = \sum_{I+1}^{2I} \mathbf{g} \Delta W.$$

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