“Thank me later”
Why is (macro)prudence desirable?*

Graeme Cokayne† Eddie Gerba§ Andreas Kuchler¶
Rasmus Pank Roulund‖

We examine the social desirability of macroprudential measures, particularly those aimed at riskier home buyers. We examine the effectiveness of these measures against social costs, such as reduced access to the housing ladder for poorer households. Our analysis shows that the measures implemented so far have not limited access to credit or the housing markets. They have been effective in limiting the riskiest loans, minimizing negative equity episodes, reducing systemic risks by debilitating the house price-leverage spiral, and limiting the depths of contractions of a range of macro-financial variables. The welfare of households has also improved. Costs from these measures have been limited and have materialized through a rise in the age-income profile of first-time buyers, and somewhat more attenuated booms. Our results point to the conclusion that macroprudence is desirable when insulated from short-term interference and quick gains. The economy becomes more robust and even households in the lowest decile of the wealth distribution benefit from the general equilibrium effects of more stable financial provision.

Keywords: BBM, panel methods, ABM, DSGE, inequality, policy effectiveness
JEL Codes: E58, G51, D31, D62, C63

---

*The views expressed are those of the authors. No responsibility for them should be attributed to DN, the BoE, the ECB, the ESCB or the RBNZ. We are especially indebted to Grzegorz Hajal and two anonymous referees of the JFS for their assistance in substantially improving the paper. We are also grateful to Michael Sigmund and participants in parallel session 3b at the IV Conference on Financial Stability; attendees of the 2021 Eastern Economic Association annual conference; FPC committee members and attendees of the 2021:Q1 Research Discussion Forum; organizers and participants in the 2020 ABM4Policy seminar; David Aikman and 2019 Bank of England-FPC seminar participants; Thomas Sangill; and Elizabeth Tepper for their input and suggestions.

†Royal Bank of New Zealand, Adviser, 2 The Terrace, Wellington 6140, NZ

‡Bank of England, Head of Prudential Policy Research, Threadneedle St, London EC2R 8AH, UK

§Corresponding author: Eddie.Gerba@bankofengland.co.uk

¶Danmarks Nationalbank, Principal Economist, Langelinie Allé 47, 2100 Copenhagen, DK

‖European Central Bank, Financial Stability Expert, Sonnemannstrasse 20, 60314 Frankfurt am Main, DE

1 Introduction

Following the 2008 financial crash, many jurisdictions around the globe adopted a new set of financial measures aimed at system-wide resilience, so-called (macro)prudential policy. In particular, these measures try to correct for negative externalities that financial institutions create when they (myopically) optimize their behaviour. These demand externalities result in social problems such as overindebtedness, mispricing of (tail) risks, and high interconnectedness within the financial system.[1] The economic impact of these social issues could be multiple, including financial instability, severe crises and financial poverty. Borrower-based measures are one set of macroprudential measures that directly tackle the problems of overindebtedness and borrower vulnerability. In most cases, they limit the borrowing capacity of households purchasing homes, or require more or higher quality collateral when applying for a mortgage. Since 2014, Denmark has adopted a number of prudential policies aimed at containing risky lending in the mortgage market and limiting extreme house price surges. These measures were introduced as part of the GFC reform packages and the new financial regulation architecture. They were the outcome of the lessons learned following the housing cycle of 2008–12 (where houses prices dropped 30% on average) and the role risky mortgages plus overpriced collateral played in driving the house prices to a historic peak. The price surge was so extreme that it was 15 index points higher than the OECD average, and more than 10 index points above the UK house price index, typical of a country with an overheated housing (mortgage) market (Figure 1). In the two largest cities, this gap was even more accentuated, and this divergence with respect to the rest of the country continued to grow. By 2019, the price of a single-family house in Copenhagen was as much as 50 index points higher than both the previous peak of 2006 and the average for rest of Denmark (Figure 3).

Yet, because of the extreme wealth distribution of Danish households (see Figure 16), in 2019 politicians raised concerns that these measures may be having profound side effects on poorer households. In particular, because the measures require a certain credit rating at origination, households that, e.g. have lower than average wealth or a more unstable income flow (which may well be those households that need credit the most) may be shut out of the mortgage market. In addition, as house prices increase, the problem is exacerbated, as households increase their demand for mortgage credit while income and non-housing wealth may not have changed. Therefore, the likelihood of rejection when applying for e.g. a mortage increases for e.g. younger first-time home buyers. Thus, it may also become an intergenerational problem if older and richer households (or the children of such households)

1. For a more detailed discussion of the theoretical underpinnings of macroprudential policy, see Aguilar et al. (2020).

have better access to the housing ladder. In other words, although these measures aim to protect the most vulnerable borrowers from taking high-risk loans and prevent them from being pushed into delinquency, they may be creating social exclusion by adversely affecting the young and less wealthy, at least in the short run. Similar concerns have been raised in other parts of Europe and globally.[2] Yet, because of the extreme financial characteristics of Danish households and the relatively early adoption of prudential measures, Denmark can be considered a precursor to what many prudential authorities will face in the future, and therefore an interesting case study.

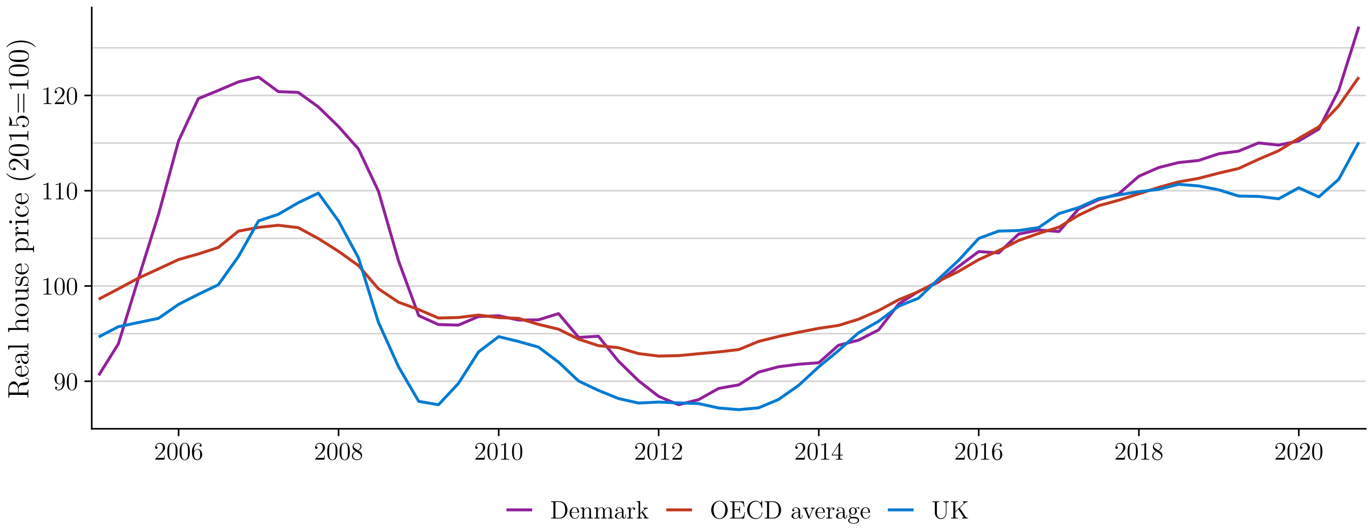


Figure 1: House price indices in Denmark, OECD average and the UK over time. We use the UK for comparison as this is the other European country that experienced high house price and LTV growth, in particular prior to the Global Financial Crisis. Source: OECD.

The average debt-to-income ratio of Danish households is twice that of UK households (Figure 2). Although it has somewhat shrunk since the Global Financial Crisis (GFC), it remains significantly above that of most other advanced economies. Hence, the need to insulate (poorer) households from unexpected shocks to collateral, mortgage rates or house prices is pronounced in the Danish case. Therefore, any investigation needs to be comprehensive and recognize the many channels through which borrower-based measures may affect households, financially, economically and socially. Specifically, the equality and exclusion effects from borrower-based measures need to be evaluated against their effectiveness. That is exactly the purpose of this paper, utilizing the Danish experience as a warning for potential concerns elsewhere, thereby providing early input into this nascent

2. For international examples of these concerns and analytical discussions, see Colciago et al. (2019), Kelly and Mazza (2019), Frost and Stralen (2018).

Yet, there is no single approach or model that can pin down all these effects. There are a number of challenges that make a direct empirical identification impossible. First, the household data are only of annual frequency, which for recent treatments makes it difficult to pin down the exact effects. Second, several other policies were simultaneously or sequentially implemented (unconventional monetary, fiscal and social welfare policies, policies affecting housing supply). Such policies directly impact the welfare distribution of households, making a separation of effects difficult. Third, the sample period contains other distinct but somewhat correlated shocks (e.g. the European banking union, repo market stress, the introduction of the bank leverage ratio and output floor) that may complicate a clean identification. Therefore, we propose a three-stage complementary approach. We first employ an empirical diff-in-diff regression on household-level data to get a rough estimate of the total policy effect on household financial characteristics. To refine these estimates, in the second stage we proceed to examine the impact of tighter LTV constraints in an agent-based model. In particular, we measure their effects on a number of key household indicators and decisions, such as age of first-time buyers, time elapsed to purchase, loan granted at purchase, income of first-time buyers, frequency of negative equity, etc. This framework allows us to pin down the exact policy transmission on the entire distribution of households. Hence, we can explicitly and uniquely quantify the intensive and extensive margins from the LTV measure. From the size of the extensive margin, we can infer whether households are permanently excluded from the housing (and mortgage) market. To put these effects into perspective, we finally examine the general equilibrium effects of the same policies in a DSGE model, primarily focusing on (higher-order) costs and benefits in the short versus long run. The main objective is to pin down the opportunity costs and welfare gains from converging to a more resillient economy. As far as we are aware, this is the first time the welfare effects of macroprudential measures have been examined from a general equilibrium vis-a-vis granular (in)equality perspective. Moreover, we slice the larger problem into various pieces and use the complementary strengths of the various analytical tools to examine each segment separately. Although the theoretical models underpinning the policy evaluation are not novel, the particular counterfactuals conducted and the welfare applications are.

Our results show that (macro)prudence is desirable, even when (unintended) distributional consequences and short-term convergence costs are accounted for in the assessment. A stricter LTV constraint, from 98 to 95%, delays somewhat the age of first-time homebuyers (by two to three years on average) and restricts the riskiest of loans. There is an 11% higher income requirement, on average, to enter the housing market, but we do not find evidence of permanent exclusion. From the broader regulatory perspective, this may even be desirable, as the probability of future sector-wide default is reduced. In addition, when higher-order effects of the LTV and mortgage amortisation measures are considered, the balance is clearly positive. From a policy objective function perspective, these measures have attained their desired outcome by making the Danish economy more robust.[3] Note, however, that the attainment of these objectives may only be visible in the long(er) run, which complicates the discipline, since short-term (convergence) costs from these measures are more readily observable in the short run. Thus, from a dynamic perspective, strict institutional discipline and insulation from short-term interference are essential.

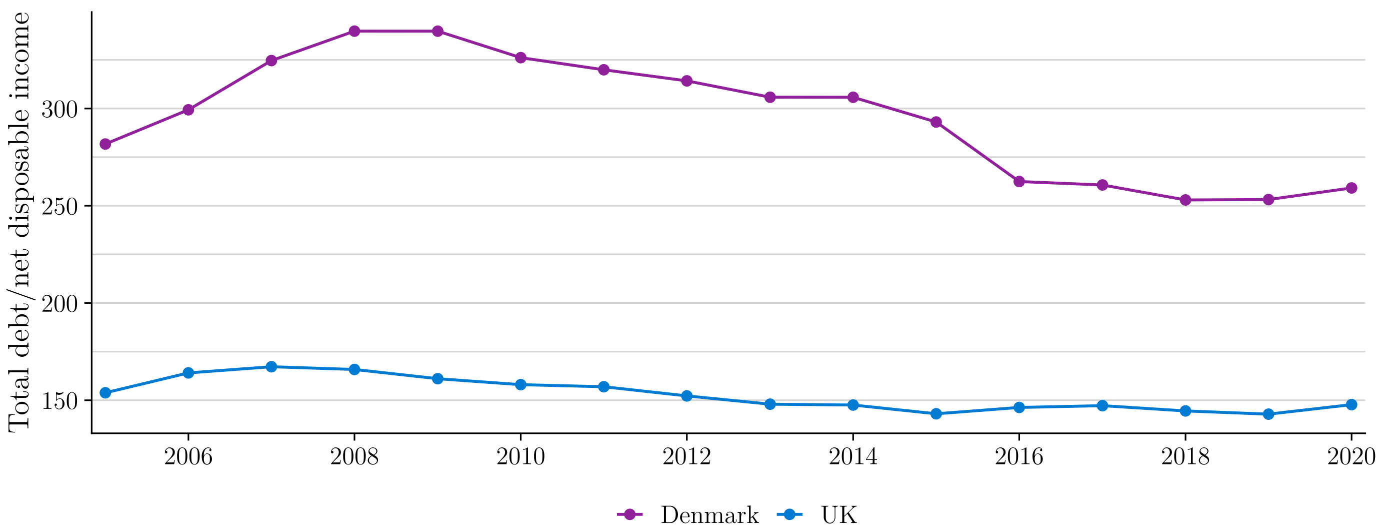


Figure 2: Debt-to-income ratio in Denmark and the UK. We use the UK for comparison as it is the other European country that experienced a high increase (and subsequent correction) in debt prior to (post) the GFC. Source: OECD.

The remainder of the paper is structured as follows. We start with a focused literature review of borrower-based measures. Section 3 describes the Danish context by outlining the borrower-based macroprudential policies that have been implemented since 2014. We also briefly describe the evolution of the Danish housing and credit markets over the relevant horizon. Section 4 examines the first-order effects of these measures in a panel setting using household-level data. We proceed to quantify any (in)equality and distributional effects of the targeted 95% LTV measure with an agent-based model in section 5. The model has been calibrated to Denmark (using the stylized facts outlined in section 3). In section 6, we turn our attention to the wider general equilibrium effects, in particular examining the convergence to a new steady state as a result of these measures. To accomplish this, we use

3. The ultimate objective of Danish macroprudential policy is to raise the economy to a more robust level.

a heterogeneous expectations DSGE model with Knightian uncertainty. Here, our particular interest is to evaluate the effectiveness of achieving higher financial resilience against the convergence costs. First, we evaluate the LTV measure only, but then marginally consider the joint effects of LTV and amortization rules. Finally, in section 7 we synthesize our findings and answer our core question of whether macroprudence is desirable, and under what institutional setup. To maintain the focus on policy evaluation, the core text of the paper centers around policy simulations only. For details on the models, we refer to appendices B and C, or the original papers describing the frameworks in more detail.

2 Literature review

This paper focuses on the benefits and costs of borrower-based macroprudential policies, which macroprudential authorities, typically central banks, have increasingly employed since the Sovereign Debt Crisis of the early 2010s. Macroprudential policies have, among other objectives, been aimed at preventing a build-up of (endogenous) risks in the financial system, which could, if unmitigated, cripple the real economy if/when such risks materialize. A build-up of debt, especially when tied to real estate, has been shown to be particularly hard to recover from if the risks materialize (Jordà et al., 2015). In this analysis, we are particularly interested in borrower-based housing market policies[4] such as loan-to-value (LTV) and debt-to-income (DTI) ratios, which are typically implemented to limit the build-up of debt stock[5].

The earlier focus of the literature on macroprudential policies was on the efficiency of these policies in reaching the stated goals, such as limiting excessive credit growth (e.g. Richter et al., 2019; Cerutti et al., 2017; Kuttner and Shim, 2016; Arregui et al., 2013). This paper contributes to this literature by examining and comparing the efficiency of the borrower-based measures in two different models calibrated to match the same moments of the Danish economy. While the agent-based model focuses on cross-sectional impact, the DSGE model centres around dynamic efficacy.

One way to elicit the costs of macroprudential policies is to measure them in terms of output. For instance, if the DTI is limited, the amount of collateral available to households is reduced, which could limit capital accumulation. Richter et al. (2019) examine the historical costs in terms of output losses associated with more severe macroprudential policies, such as decreasing maximum LTV ratios. They find only moderate costs. Rubio

4. See Piazzesi and Schneider (2016) and Davis and Van Nieuwerburgh (2015) for characterizations of housing economics and the impact of housing on the wider economy.

5. See also Shim et al. (2013) for a comprehensive database of implemented macroprudential polices in different countries.

and Carrasco-Gallego (2014) examine how LTVs impact aggregate welfare in a DSGE model, but without specifying costs. Our DSGE model, since it involves heterogeneous expectations and uncertainty, allows us to quantify the costs from converging to the new policy steady state vis-a-vis the benefits from improved resilience. Furthermore, extreme wealth distribution may in itself create problems for financial stability. In a theoretical model where some agents are more wealthy than others, Kumhof et al. (2015) show how the distribution of wealth can itself cause endogenous financial crises to emerge if less wealthy agents become too leveraged.

A number of empirical papers examine whether recent central bank policies have had distributional consequences.[6] lenza18 examine the impact of the ECB's monetary stimulus programs and find that they have restricted income inequality, as they have helped increase output and thus limited unemployment. On the other hand, casiraghi18 find that the ECB's quantitative easing programs have primarily benefited asset-owning households, which tend to be the more wealthy ones. Importantly, the two papers highlight the fact that recent central bank policies may impact the income and the wealth channels differently. In this paper, we examine both channels through the two models.

Macroprudential policy, such as LTV and DTI restrictions, can have permanent effects on the housing market. Frost and Stralen (2018) examine the distributional impact of macroprudential policies using a panel of countries and find that LTV and DTI restrictions may increase inequality slightly, depending on the measure of inequality, although, as the authors point out, the results only identify correlations. Carpantier et al. (2018) use an overlapping generation model to examine how several factors, including LTV restrictions, affect inequality. We contribute to this literature by examining how large the extensive margin of borrower-based measures has been since the GFC. In addition, our agent-based simulation offers an alternative approach to the structural approach taken by Carpantier et al. Before we proceed to examine specific channels, let us briefly characterize the evolution of the Danish housing market and present some stylized facts that have guided our modeling work.

3 Policy and housing market developments

In the year preceding the 2008 crisis, the Danish housing market experienced a rapid price surge. The national housing price index increased by more than 50% from 2004 to 2006, (see Figure 3). Like in many other Western countries, the booming housing market was

6. colciago19 present an impressive recent survey of the distributional impact of both monetary policy and macroprudential policies.

fueled by heavy credit growth, with double-digit yearly growth rates. During the subsequent bust, house prices and credit growth sharply declined. The macroeconomic costs, in terms of declining economic activity, were high, partly due to highly indebted households. The latter drastically increased their leverage before the crisis but subsequently cut back sharply on consumption, cf. Andersen et al. (2016). The recovery was also asymmetric across urban and rural areas: prices on flats in e.g. Copenhagen regained their pre-crisis peak levels (in nominal terms) in 2015, while single-family homes across Denmark only regained the pre-crisis peak in 2018.

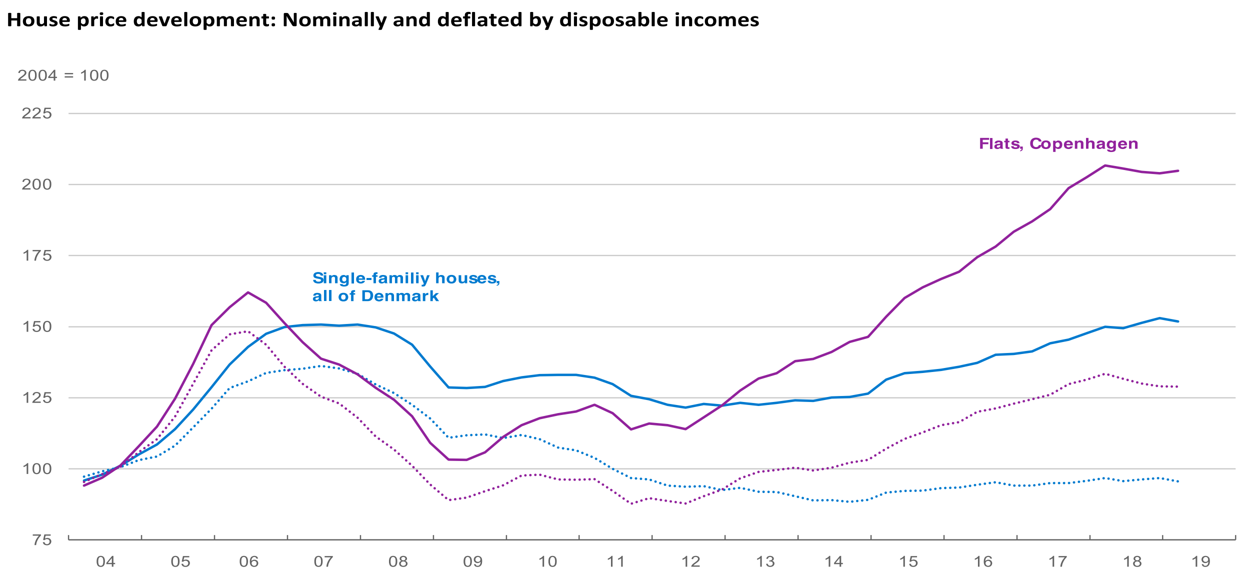


Figure 3: House price growth. Solid lines indicate nominal house prices, while dotted lines indicate house prices deflated by disposable income. Source: Statistics Denmark.

At the same time, Danish homeowners are among the most indebted in the world.[7] The large debt stock may imply that financial stability in the Danish economy is vulnerable to shocks to the housing market. The combination of interest rates at record-low levels and mortgages with (indefinitely) deferred amortization could imply that homeowners are able to leverage more aggressively than previously relative to their incomes. With low interest rates, households may consider high debt to be easy to service, especially if the first ten years of the loan are interest only. However, this could change as interest rates increase to more conventional levels. Moreover, the distribution of DTI across household percentiles is highly skewed (see Figure 4). Although it has dropped somewhat, in particular since 2016, households above the 99th percentile have DTIs corresponding to approximately ten times their income.

7. The high gross debt of Danish households is matched by corresponding assets such as real estate and pension wealth.

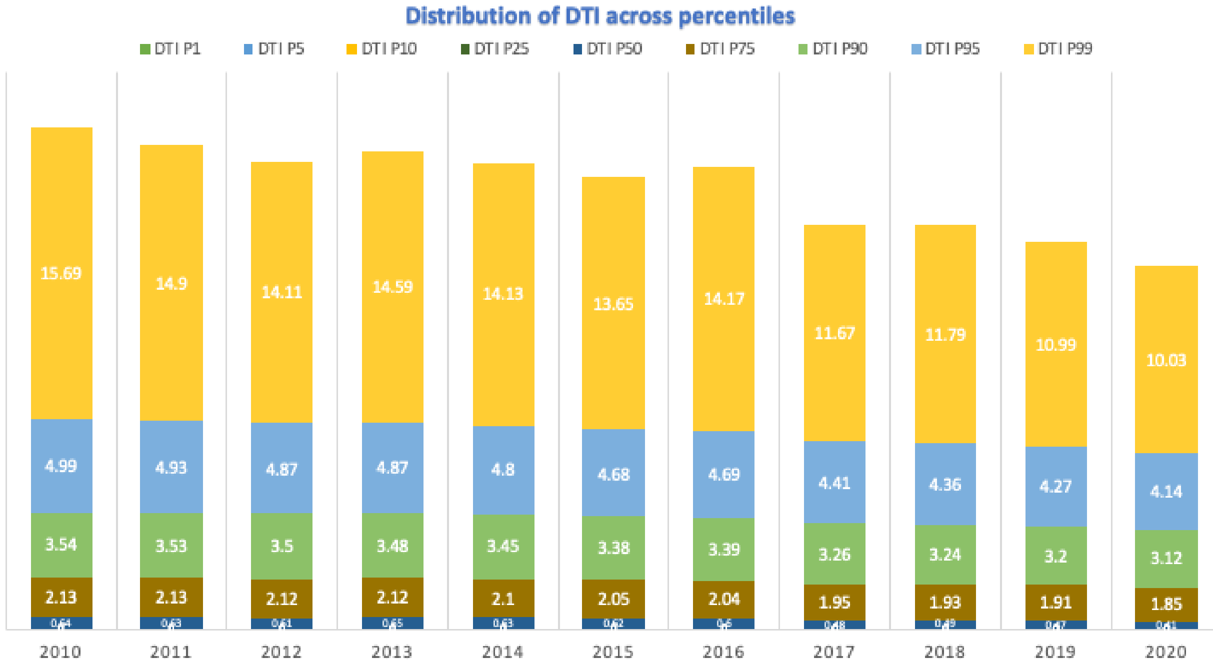


Figure 4: DTI across time for various percentiles of the household distribution. Figures include all households, and the DTI is based on all personal debt. Source: own calculations based on household-level data from Statistics Denmark.

Against this backdrop, Danish authorities have implemented a number of measures aimed at protecting homeowners and the financial sector against negative shocks to equity and house prices, and rising interest rates (Table 1).[8]

The new rules affect individuals' ability to buy or borrow against real estate. However, because of the high share of home ownership and the sharp surge in house prices in Denmark, the rules have often been contested. All the measures target the most risky borrowers and mortgages (see Figure 5). Banks and mortgage credit institutions can issue any type of mortgage to clients with a DTI ratio below 4 and an LTV ratio below 60%, provided that the clients can service a 30-year fixed-rate mortgage with principal repayments, and are deemed creditworthy according to the internal credit policy of the bank. However, the most highly indebted borrowers in Copenhagen and Aarhus must, in general, amortize. The rules allow banks and mortgage credit institutions to issue 30-year fixed-rate mortgages with principal repayments to creditworthy clients even when both the DTI and LTV ratios are high. Of the various requirements, only the 5% minimum downpayment requirement should, as a general rule, be observed (in addition to a standard credit assessment of the borrower

8. The Danish Supervisory Diamond policy stipulates a number of special risk areas, stating limit values which, as a point of departure, the bank should comply with from the end of 2012. These measures include a sum of large exposures limited to less than 100%, lending growth smaller than 20%, a funding ratio smaller than 1.25, concentration on commercial property lower than 25%, and an excess liquidity coverage of above 50%.

Table 1: Policies implemented in Denmark since 2013. The years refer to measures entering into force, except for the Supervisory Diamond policy, which was announced in 2014 and entered into force 2018–20. Source: Bentzen et al. (2020).

Year	Description
2013	Origination requirement that all borrowers should be able to service a 30-year fixed rate mortgage with principal repayments.
2014	Limits on deferred amortisation mortgages, etc. in the Supervisory Diamond for mortgage credit institutions.
2015	5% minimum downpayment requirement.
2016	DTI restrictions on lenders with non-amortized and/or floating interest rate mortages via the Danish Financial Supervisory Authority's so-called growth area guidelines.
2018	Restrictions on available mortage products for borrowers with an LTV above 60% and a DTI above 4.

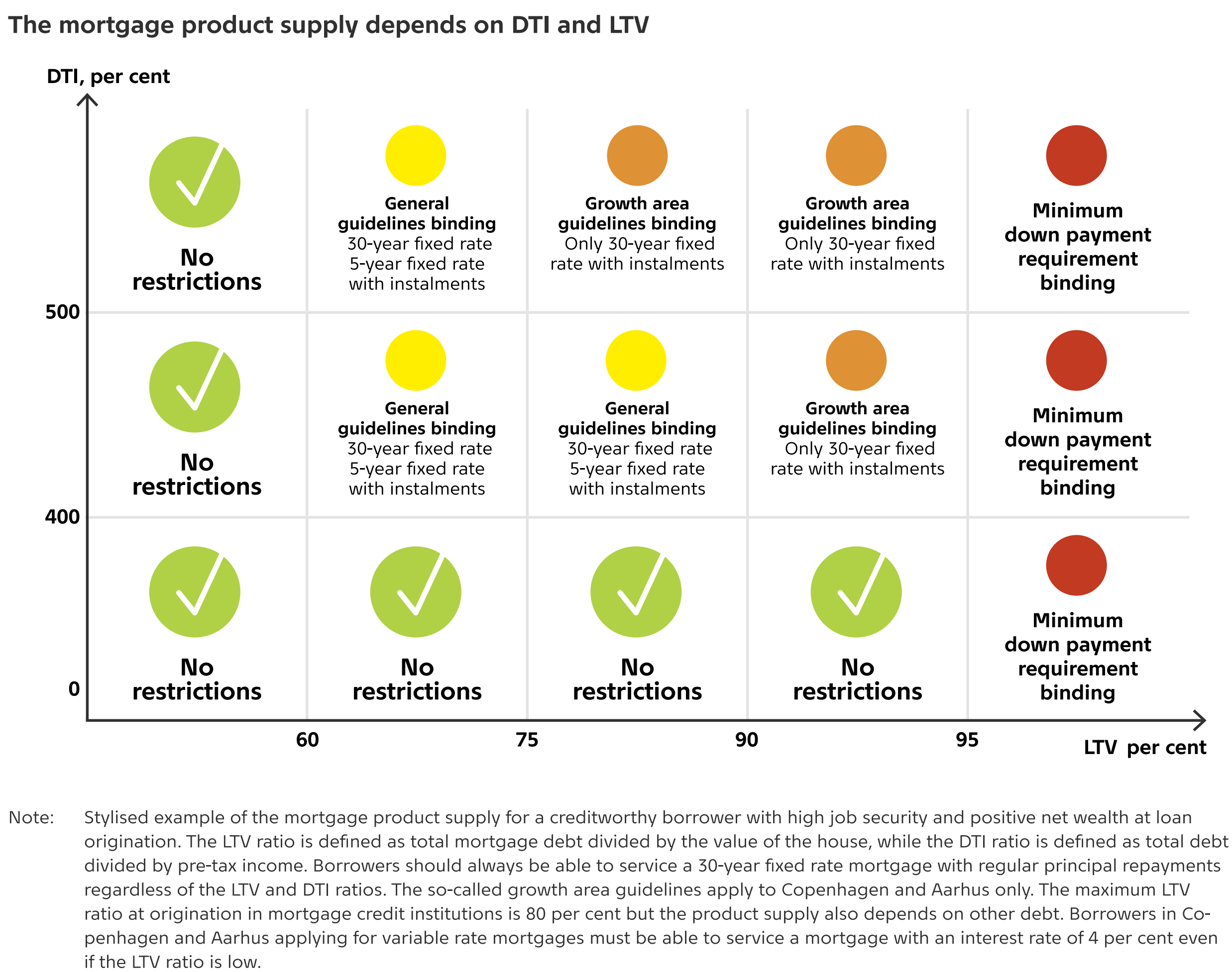


Figure 5: Binding rules. Source: Bentzen et al. (2020).

and the collateral).

Looking at the *true* distribution of LTV across all homeowners in Denmark in (see Figure 6), at the time the measures were announced, they would have affected the <90th percentile of homeowners. By the time the measures became binding, they were binding at the 95th percentile. Thus, although the average LTV across percentiles has gradually decreased over time, the new rules have affected a significant proportion of homeowners. Note that this distribution does not include aspiring first-time buyers, as it only shows the LTV of existing homeowners. Thus, the measures would arguably be binding for a lower percentile (or larger cohort) than the one reported here.

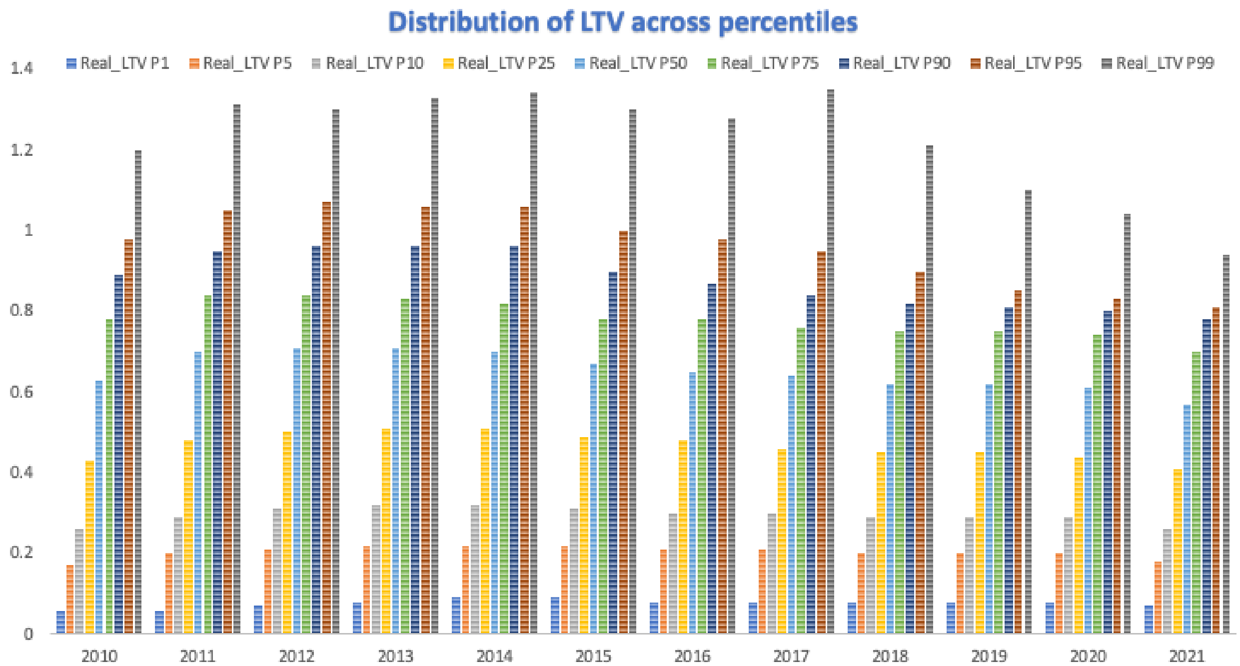


Figure 6: LTV across time for various percentiles of the homeowner distribution. Figures include only homeowners, and the LTV is based only on loans from mortgage banks. Source: own calculations based on household-level data from Statistics Denmark.

The new rules tend to be relatively more binding for young first-time buyers in the larger cities, where house prices are high relative to incomes. Therefore, a mortgage with principal repayment and a 30-year fixed interest rate may be the only choice for many young first-time buyers. Similarly, the new rules could potentially affect older borrowers' ability to remortgage their house above an LTV ratio of 60% if their retirement income is relatively low. Figure 7 shows that mortgage credit institutions have increased the flow of new lending to *all* groups of borrowers during the period from 2010 to 2013. New lending for house purchases has continuously increased since 2010, totaling around EUR 10 billion (DKK 76 billion) for Denmark as a whole. The increase in new lending applies to both first-time and subsequent home buyers. Similarly, the flow of home equity withdrawals was relatively high in 2018, totaling around EUR 15 billion, of which 36% was granted to homeowners above the age of 60. This was 31% more than the amount granted in 2013. In Copenhagen and Aarhus, the picture is broadly the same.

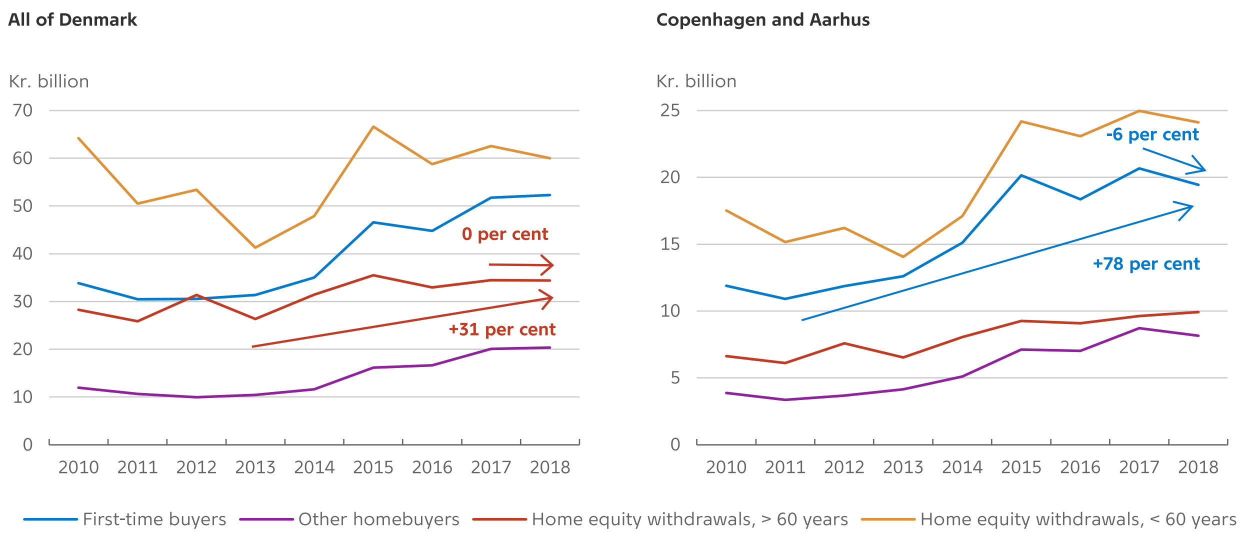


Figure 7: House price growth. The chart shows mortgage credit institutions' flow of new lending to different groups of borrowers. Source: Bentzen et al. (2020).

New mortgages to borrowers with high DTI and LTV ratios have increased over time, albeit with some correction since the new mortgage rules entered into force in 2018.

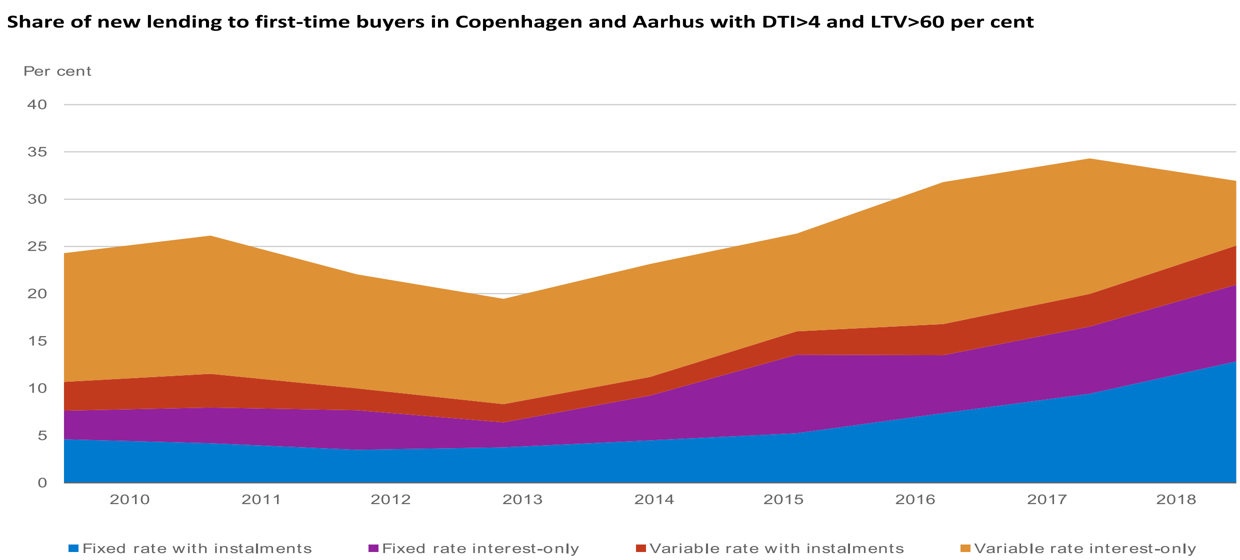


Figure 8: Shares of new lending to first-time buyers in Copenhagen and Aarhus with a DTI above 4 and an LTV above 60%. Source: own calculations based on micro data from Statistics Denmark.

4 How restricted are Danish home buyers? An empirical analysis

In this section we seek to get a broad estimate of the impact of borrower-based prudential measures using disaggregated household-level data for Denmark. The question is whether the non-binding and binding borrower-based measures introduced in 2015 and 2018, respectively, have altered the characteristics of first-time buyers. The complexity is due to other contributing factors also having changed between 2008 and 2018. For instance, house prices rose faster than incomes, especially in the high-growth areas, such as Copenhagen. Meanwhile inflation was persistently low. For this reason, the empirical analysis will only serve as a first check on the effects, providing qualitative input for the models in the subsequent two stages.

In the previous section we provided some indicative evidence that policies have altered the *intensive margin*; that is, tighter borrower-based measures have pushed first-time buyers to choose amortized mortgages[9]. As argued, the policies are intended to manipulate exactly this margin.

However, if the policy results in the inability of the marginal potential home buyer to take up a mortgage, so that she is priced out of the market, it is said that the policy manipulates the *extensive margin*. Note that this does not necessarily diminish overall welfare if, for instance, these households are particularly vulnerable to house price shocks. But, if the distribution of shocks to home values, and therefore the risk associated with the debt, is not well understood, it may not be possible to determine the overall welfare effects. However, empirically, this may be impossible to pin down. By combining empirical and theoretical approaches, this paper is, in part, trying to determine the welfare effects from the extensive margin.

4.1 Data

We use proprietary Danish household data from Statistics Denmark. For each household, we observe a number of financial variables, such as income and net wealth, in addition to municipality, age of the oldest member of the household and other household characteristics. We have yearly observations from 2010 to 2018.

As described previously, our sample captures three distinct phases of borrower-based measures:

- Before 2013, no macroprudential borrower-based measures had been implemented.

9. One caveat is that amortized loans also became cheaper over the period; as such, we cannot say that changes to the loans composition are entirely due to the introduction of borrower-based measures.

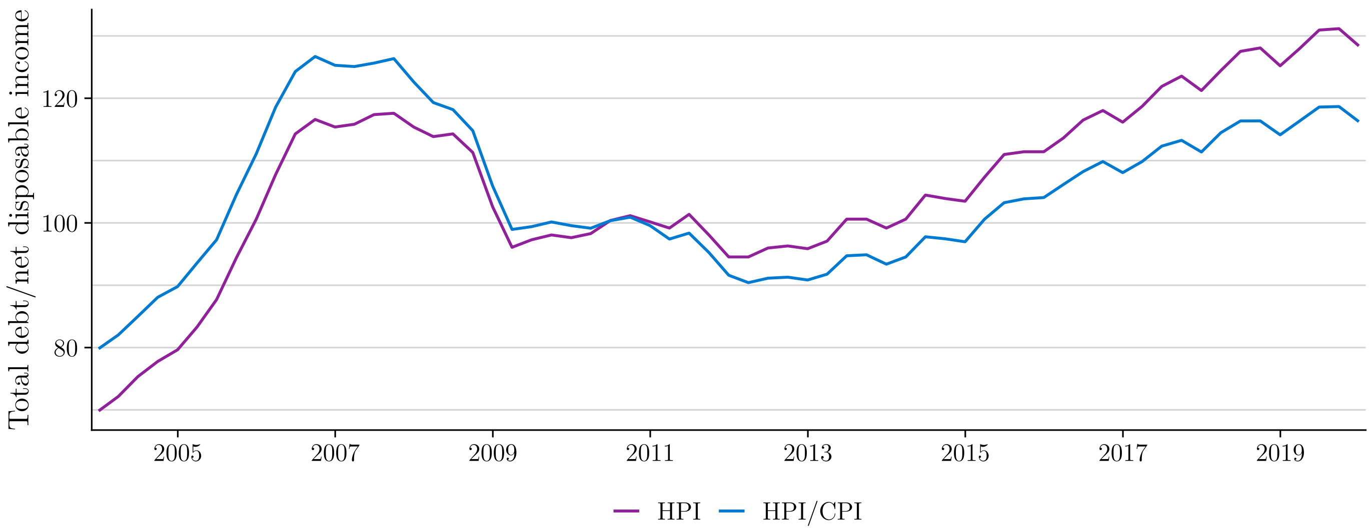


Figure 9: House price indices in nominal terms and nominal deflated by CPI terms. Normalized to 100 in 2010. Source: BIS selected property prices and own calculations.

Table 2: Summary statistics for households purchasing real estate for the first time. The table displays the 5th, 10th and 50th percentiles for age, household income and household net wealth. For the latter two, we show the place relative to all households (unconditional quantiles).

BBM group	N	Age			Income_{t-1}			Net wealth_{t-1}		
		5%	10%	50%	5%	10%	50%	5%	10%	50%
No BBM	84242	23	25	35	0.28	0.42	0.72	0.05	0.08	0.43
Non-Binding BBM	108190	24	25	34	0.24	0.40	0.72	0.06	0.10	0.46
Binding BBM	23452	25	27	34	0.26	0.41	0.71	0.05	0.08	0.45

- In the period between 2013 and 2017, borrower-based measures were formally in place, but were not binding. Rather, they served as guidance to banks. The implementation coincided with the re-emergence of rising nominal and CPI-deflated house prices after the GFC (see Figure 9).
- From 2018, the last observed period, binding borrower-based measures are included.

4.2 Changes in buyer characteristics

As a first pass, we examine whether the characteristics of first-time buyers at the time of their purchase have changed over time, and if this corresponds to the introduction of stricter borrower-based measures. To do so, we calculate the empirical cumulative distribution for all households and determine each household's position within the distribution for income, net wealth, and age.

Table 2 show the 5th, 10th and 50th percentiles for age, household income and net wealth one year before the household purchased its first home. The table shows that while the median household age has not changed with the introduction of borrower-based measures, buyers have become older at the margin, in particular at the 5th percentile. There is no clear sign that the income and wealth characteristics of the households have changed.

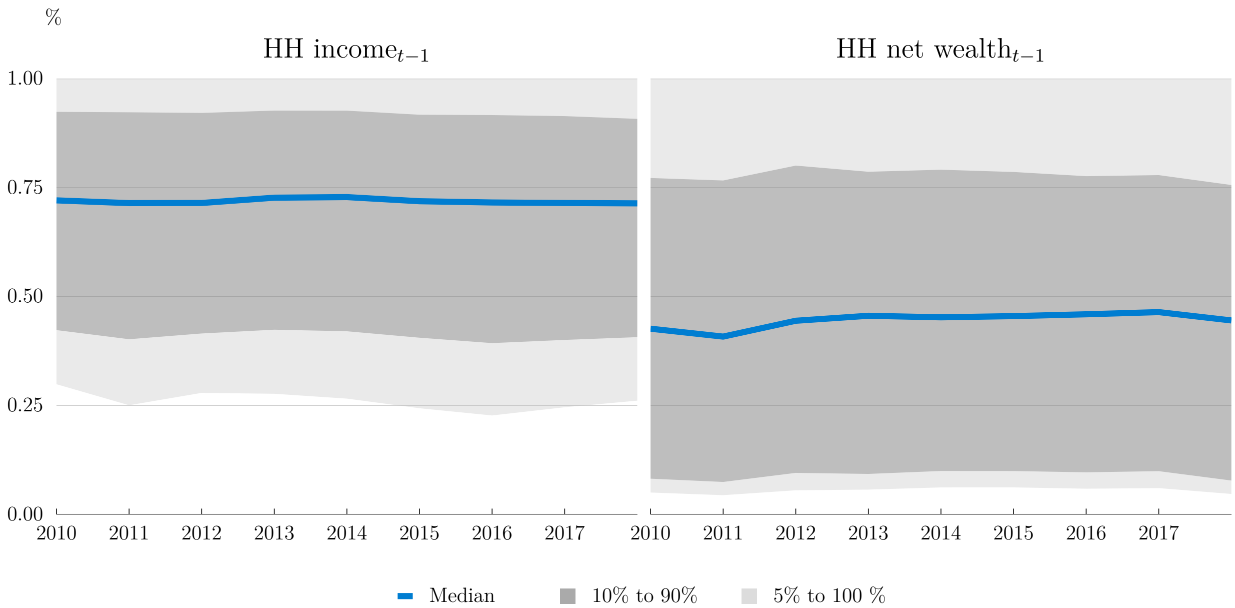


Figure 10: Absolute distributional position for households purchasing real estate for the first time over time. Source: Statistics Denmark and own calculations.

Next, Figure 10 reports the full distribution from Table 2 by depicting households' distributional placement of income and net wealth one year before their first real estate purchase. The figure shows that the *net wealth required to enter the housing market* does not seem to have changed as borrower-based measures have been implemented.

4.3 Estimation

Next, we look for indications of a change in the extensive margin as a result of tighter borrower-based measures. Specifically, we estimate the probability of purchasing a home based on a number of household characteristics. We focus on the pool of households that had not purchased homes before 2010 and consider their decision to enter the housing market. Given the housing supply, households' decisions to purchase real estate are partly determined by their preference for owning real estate, preferred location, prices in that area, income, wealth, and creditworthiness, etc[10].

Thus, we consider the simple linear probability model:[11]

$$y_{ict} = \alpha_i + \beta + \gamma' x_{it} + \beta' z_{it} + \kappa_c + \epsilon_{ict}$$

where y denotes the probability of buying a first home, i denotes households, c denotes geographical areas, and t denotes the time measured in years. We include household characteristics in z_{it} , namely household age (oldest person), household relative income and net wealth, and dummies for their professional status (i.e. whether household members are small business owners, students, unemployed or retired). We also include a number of municipality fixed effects, κ_c. These are used to remove, e.g. the impact of differential housing demand effects.

Our main interest lies in the policy-household interaction described by x_{it}. We interact the policy dummies, corresponding to years where non-binding and binding borrower-based measures are in place, with indicators for households below the median in terms of income and net wealth, as well as age group indicators.

The results are displayed in Table 3. The first column shows first-time home purchase regressed on lagged income and net wealth. As expected, the signs are positive, indicating that households with greater income and/or net wealth are more likely to purchase a home.

In the second column, we include a number of fixed effects to assess whether there are (un)equal effects from borrower-based measures. The coefficients are mainly non-linear time effects. We also include indicators for income and wealth being below the median (in the second column), to explore whether it has become "harder" to enter the housing market for less wealthy households. We interact the dummies with the policy variables indicating that either non-binding or binding borrower-based measures are in place. Similarly, we include age group indicators as well as their interactions with policy variables. The results show the expected patterns regarding income, wealth and age characteristics. The interaction terms between income, wealth, age and policies show that non-binding restrictions do not have much impact in terms of housing market entry. Following the introduction of the binding BBMs, the probability that a household with below-median income or net wealth becomes a homeowner is somewhat reduced. At the same time, however, households in their 30s in particular are generally more likely to enter the housing market. This is consistent with the previous results indicating a smaller delay in entry to the housing market. It also indicates

10. One could formulate a proper random utility decision model to understand household choices; however, this is not the focus of this paper.

11. A more sophisticated approach would be a panel survival analysis examining the state change from being a renter to being a home owner. We do not have the relevant granular data, however, and so leave this for future work.

Table 3: Regression results. The dependent variable is first-time house purchase.

	I	II	III	IV
Income_{it-1}	0.400^{***}			
	(0.000398)			
Net wealth_{it-1}	0.0626^{***}			
	(0.000209)			
Below-median income		-0.116^{***}	-0.114^{***}	-0.113^{***}
		(0.000322)	(0.000322)	(0.000320)
Below-median net wealth		-0.0338^{***}	-0.0342^{***}	-0.0413^{***}
		(0.000302)	(0.000302)	(0.000301)
Age < 30		0.0488^{***}	0.0553^{***}	0.0591^{***}
		(0.000417)	(0.000427)	(0.000424)
Age $30 - 39$		0.0869^{***}	0.0871^{***}	0.0918^{***}
		(0.000436)	(0.000437)	(0.000434)
Age $40 - 49$		0.0340^{***}	0.0342^{***}	0.0354^{***}
		(0.000447)	(0.000448)	(0.000445)
Below-median income $\times$ non-binding BBM_t		0.0199^{***}	0.0197^{***}	0.0194^{***}
		(0.000412)	(0.000411)	(0.000408)
Below-median income $\times$ binding BBM_t		-0.0480^{***}	-0.0480^{***}	-0.0474^{***}
		(0.000582)	(0.000581)	(0.000577)
Below-median net wealth $\times$ non-binding BBM_t		-0.0121^{***}	-0.0122^{***}	-0.0124^{***}
		(0.000386)	(0.000386)	(0.000383)
Below-median net wealth $\times$ binding BBM_t		-0.0617^{***}	-0.0615^{***}	-0.0618^{***}
		(0.000549)	(0.000548)	(0.000544)
Age < 30 $\times$ non-binding BBM_t		-0.00462^{***}	-0.00432^{***}	-0.00498^{***}
		(0.000529)	(0.000529)	(0.000525)
Age < 30 $\times$ binding BBM_t		0.00909^{***}	0.00885^{***}	0.00849^{***}
		(0.000737)	(0.000738)	(0.000732)
Age $30 - 39$ $\times$ non-binding BBM_t		-0.00643^{***}	-0.00651^{***}	-0.00704^{***}
		(0.000554)	(0.000554)	(0.000549)
Age $30 - 39$ $\times$ binding BBM_t		0.0474^{***}	0.0469^{***}	0.0446^{***}
		(0.000767)	(0.000767)	(0.000761)
Age $40 - 49$ $\times$ non-binding BBM_t		-0.00254^{***}	-0.00309^{***}	-0.00296^{***}
		(0.000576)	(0.000576)	(0.000571)
Age $40 - 49$ $\times$ binding BBM_t		0.0298^{***}	0.0288^{***}	0.0284^{***}
		(0.000823)	(0.000823)	(0.000816)
Small business			0.0406^{***}	0.0473^{***}
			(0.000538)	(0.000535)
Retired			-0.00679^{***}	-0.00770^{***}
			(0.000487)	(0.000483)
Student			-0.0243^{***}	-0.0167^{***}
			(0.000252)	(0.000253)
Unemployed			-0.0296^{***}	-0.0252^{***}
			(0.000474)	(0.000471)
Year_i FE	✓	✓	✓	✓
Municipality_c FE				✓
Num. obs.	7,275,685	7,487,690	7,487,334	7,487,334
R^2	0.141	0.096	0.099	0.113

$^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$

Standard errors clustered on households.

that access to the housing market has not generally been distorted for the younger cohorts by the introduction of the binding BBMs, though households with lower income or wealth may have found it somewhat harder to enter the housing market.

We conduct two further refinements. In the third column, indicators for small business owner, retired status, student status and unemployed status are added. In the final column, we add fixed effects for each municipality. These refinements do not alter the conclusions.

The empirical results do not lead us to believe that there are significant (un)equal consequences of binding borrower-based measures (compared with the pre-measure period). However, there are indications that creditworthiness plays a somewhat larger role for the probability of entering the housing market. The results cannot be interpreted causally as other time-varying factors may also play a role. We therefore analyze the question further in the agent-based framework in the second stage. There, we can identify the policy transmission channel for the household characteristics of interest.

5 Do borrower-based measures punish the less wealthy? Insights from an agent-based model

5.1 Model

The merit of using an agent-based model for a policy counterfactual analysis is that one can pin down the direct effects of a policy on households' individual decisions and characteristics. Those individual decisions can in turn be aggregated to obtain coherent macroeconomic statistics, such as house price indices. Meanwhile, one can analyze the effects of macro variables/policies on granular model elements, such as age of first-time buyer or equity holdings across the household distribution. An agent-based model can introduce a greater degree of heterogeneity among the agents than is possible in other theoretical frameworks, such as DSGE models. Therefore, the policy transmission can be traced at a very granular level.

To maintain consistency with the previous empirical analysis, we propose using a model that is specifically geared to Danish households and the Danish housing market, and calibrated to replicate the Danish stylized facts, as discussed in section 3. The model is essentially that of Cokayne (2019) (based on Baptista et al., 2016). In it, households earn an income according to their age and age-dependent income percentile and then make decisions about their housing situation. If they are not currently in accommodation, they decide whether they want to buy or rent a home, and then they bid an amount on the relevant market, based on their income and desired quality of housing. If they own their own home, they decide if they want to sell it, and if they are in rental accommodation, they decide if they wish to leave that rental property. If they are selling their home, they put an offer on the housing market.[12]

Bids and offers are then matched on the housing and rental markets. When households wish to purchase a home they can apply for a loan from the bank. The bank will grant a mortgage to any household that meets *loan-to-value*, *loan-to-income* and *affordability criteria*. These macroprudential criteria are set by the central bank. Figure 11 provides a flowchart of the decision-making process (Cokayne, 2019). The model is calibrated to line up with Danish data both in terms of distributions of inputs (such as incomes) and outcomes (such as the frequency of home sales).

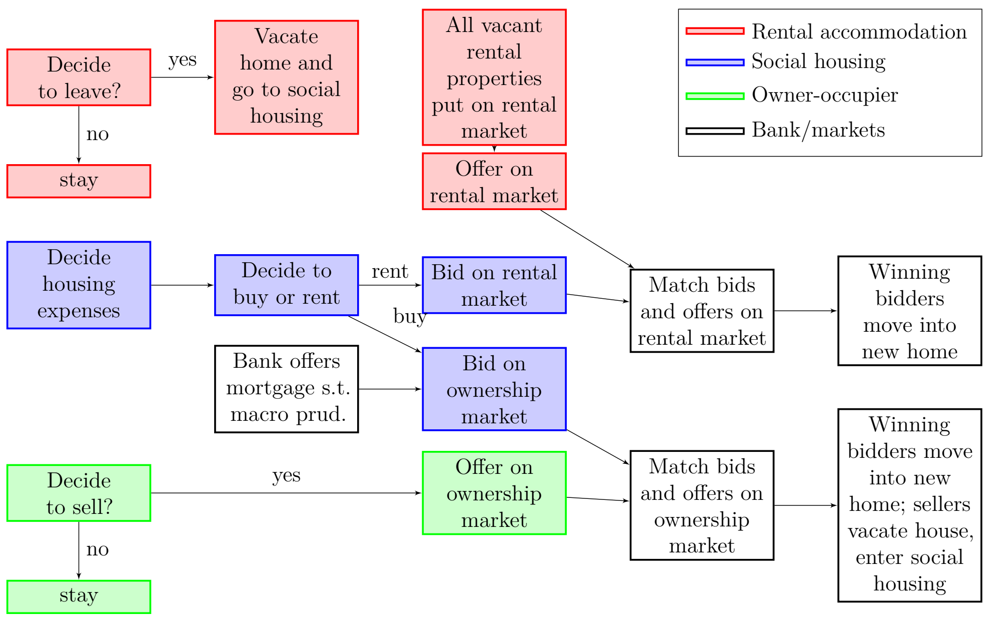


Figure 11: Flowchart of the dynamics of the decision-making process for each household per time step (reproduced from Cokayne, 2019). Households in social housing decide how much they wish to spend on housing, and then decide whether to buy or rent. If they decide to rent, they bid on the rental market. If they decide to buy, they bid on the ownership market subject to the mortgage offered by the bank. Non-controlled rental accommodation (NCRA) tenants decide if they want to leave their home. If they do, they vacate the property and move into social housing. The NCRA owner then puts all vacant NCRA on the rental market. Owner-occupier households decide if they want to sell their home. If they do, they offer it on the ownership market. Bids and offers are then matched on the rental and ownership markets. Winning bidders move into their new homes, sellers on the ownership market vacate their home and move into social housing. Controlled rental accommodation is not featured in this flowchart.

12. Further details on the individual decisions and mechanics can be found in the online appendix.

5.1.1 Calibration

We calibrate the parameters of the model at both the micro and macro levels. We align the parameters with microdata as far as possible. Because agent-based models feature heterogeneous agents it is important to get not only the main moments of the data correct but also the distributions. We therefore align the distributions of the model with distributions from Danish society as closely as possible. For example, the age and income distributions of the model closely reflect those of Danish society in Table 2. Unfortunately, it is not possible to do this for all the model inputs. Therefore, we have also validated the model by considering its output and inspecting the extent to which it aligns with the relevant Danish data (Cokayne, 2019).

5.1.2 Validation

To ensure fit to the Danish housing market, we compute various distributions for the model and compare them with those of Danish data. Post-tax income distributions for various ages in the model align reasonably closely with those of Danish society (see Figure 12).

When comparing the house price index profile of a typical simulation of the model with those of actual Danish society, we can see that they have similar cycles and amplitudes. Figure 13 shows the profile of the Danish house price index from 1971 to 2018, de-trended and seasonally adjusted. The simulated data have been transformed from their original monthly frequency into quarterly data to conform to the frequency of the real data. The baseline model has a standard deviation of 6.43, which is close to the 7.26 standard deviation of the real data. That is a key variable in our evaluation.

We have also considered other statistical moments extracted from the simulated data and compared those with empirical analogues (see Table 4). Most of the empirical variables are available from 1973 to 2018, except for household credit growth, which is only available from 2004 onwards. Analogously, the measures extracted are from the baseline model with a cap on LTV at 98% and an LTI of 6. The model moments are all within the range of the real data, suggesting that the model is fairly accurate in replicating the Danish experience (Cokayne, 2019).

The remainder of the parameters have been calibrated exactly as in Cokayne (2019), so we refer to Appendix A in the latter for a full list and motivation.

5.2 Results

We ran two sets of simulations, one for the pre-LTV restriction phase (98% LTV) and one for the post-LTV restriction phase (95% LTV restriction). Each simulation consists of

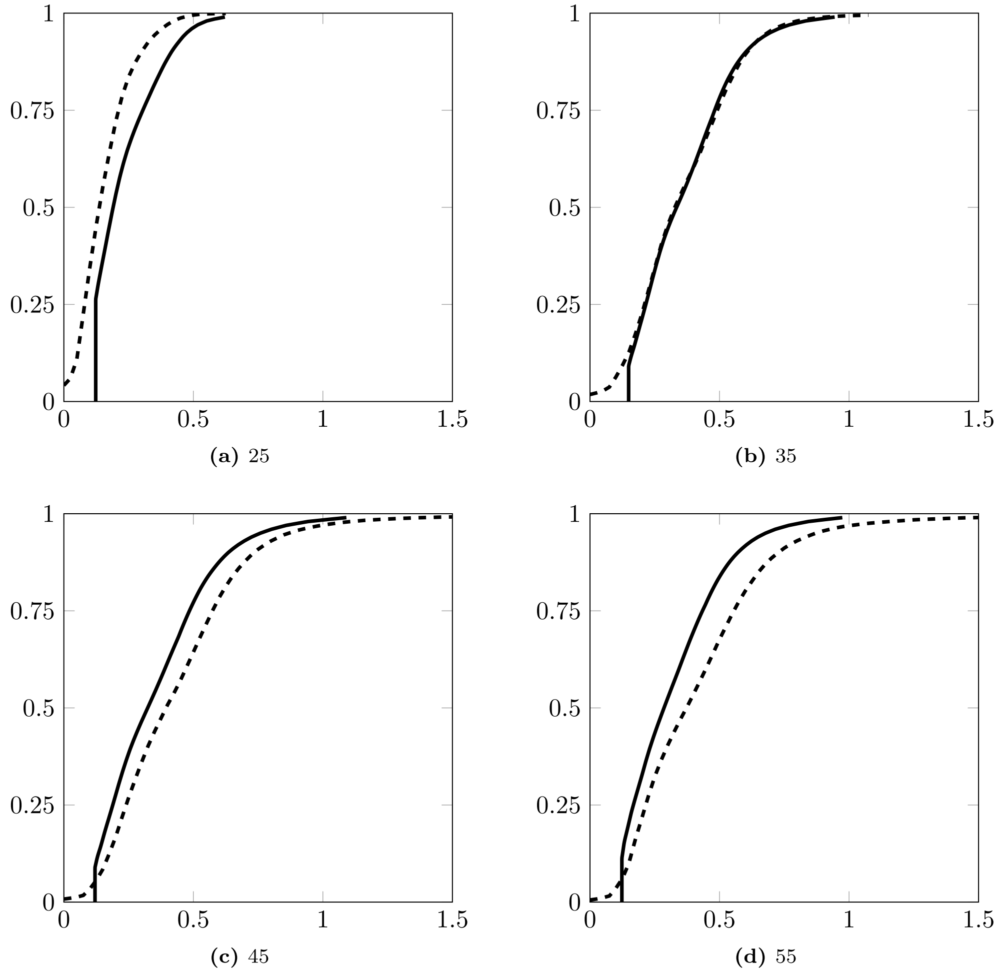


Figure 12: Cumulative distributions of post-tax income (in million DKK) in the model (dotted lines) and the data for Denmark (solid lines) for the ages 25, 35, 45 and 55. Source: Cokayne (2019).

40 runs of 1000 periods.

In the absence of a central bank restriction, banks are likely to have their own internal restrictions, which is what the 98% LTV ratio represents. The tightening to 95% captures the LTV policy implemented in 2018 by the macroprudential authority, as shown in Figure 1. In practice, loans with an LTV greater than 95% are not allowed. Loans are allowed at other LTV levels, though other conditions might be placed on those loans if the DTI is above 4 (see section 3 for further discussion). We will consider the distributional effects across a range of variables, including house prices, income, age, home equity, and actual LTV. However, before doing so, let us first briefly comment on the important issue of debt overhang.

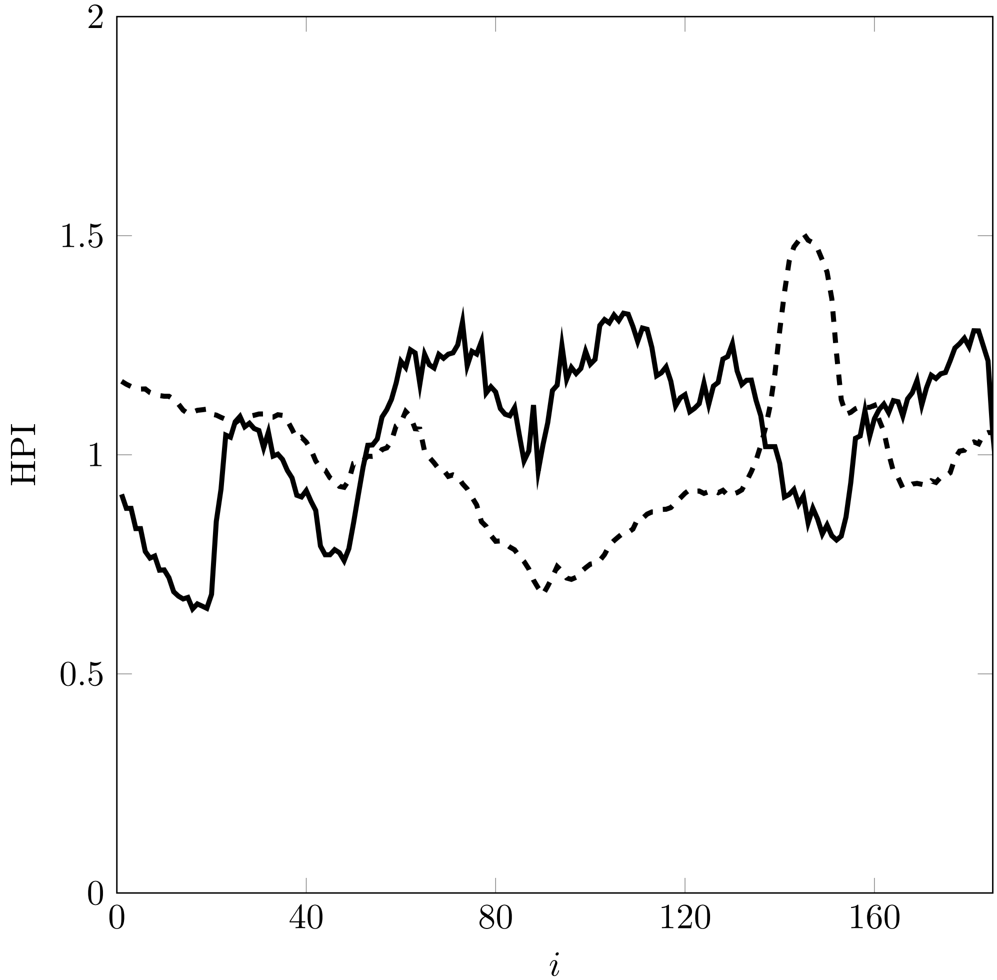


Figure 13: Results from an average simulation (solid lines) of the house price index for 200 quarters versus the actual (dotted lines) Danish house price index, seasonally adjusted and de-trended. Source: Cokayne (2019).

5.2.1 Debt overhang

The model is a steady state model so there are no cycles in income and/or unemployment. This means that there is no debt overhang (i.e. a negative feedback loop) mechanism affecting business cycles. However, debt overhang is one of the principal causes of the downside risk in house price cycles. In order to accommodate a mechanism for debt overhang we would have to introduce assumptions related to the following: (i) the extent to which falls in house prices lead to falls in consumption; and (ii) the extent to which falls in consumption lead to falls in income and/or employment. Moreover, these assumptions would need to include further granular assumptions about how these relations affect households in different parts of the income distribution.

Introducing the multiplicative effects of these assumptions would create too much

Table 4: Comparison of various indicators of the Danish housing market with those from the simulated model. Date range for values: LTV: 1973 Q1 to 2018 Q2; household credit growth: Jan 2004 to Dec 2018; debt to income: 1973 Q1 to 2018 Q2; house price growth: 1973 Q4 to 2018 Q3.

Indicator	Danish data Minimum	Danish data Mean	Danish data Maximum	ABM simulations Mean
LTV ratio	24.8%	40.7%	57.4%	26.5%
Household credit growth	0.2%	4.9%	15.5%	3.5%
DTI ratio	117.1%	198.1%	326.3%	199.8%
House price growth	-15.3%	6%	27.5%	0.8%

arbitrary variability in the results. Instead, we opt to leave the model without debt overhang, and accept that the results are likely to be conservative in terms of how households are affected by falls in house prices. Therefore, our ABM estimates should be interpreted as a lower-bound policy effect. On the other hand, the DSGE model used in the third phase models this leverage stock effect endogenously, enabling us to quantify explicitly the effects of debt overhang on house price swings, consumption distribution and overall welfare.

5.2.2 Reduced house price cycles

As reported in Cokayne (2019), one of the major benefits from tightening borrower-based macroprudential measures is a reduction in the volatility of house prices, specifically the standard deviation of the house price index (Figure 17)[13]. This is achieved by reducing the peaks in house price cycles. Tightening the LTV restriction limits the amount that (at least some) households are able to borrow to spend a home. The amount that households can subsequently bid on a home is also restricted, so the final house price surge is restricted during booms. Yet, because there is no debt overhang in the model, the troughs of the house price index tend to be at around the same level regardless of the cycle's peak. This means that the results here might be considered somewhat conservative, as the model misses any extra volatility in prices that might come from added losses through debt overhang.

Next, we wish to understand which households have the most to lose from a constrained house price peak, and if there are any policy benefits.

13. Polices targeting LTV ratios typically aim to reduce overall house price growth, dampening the peak-to-trough ratio of the house price cycle. However, we measure the effect of the LTV policy on the standard deviation of the house price index, rather than house price growth, as we believe that the peak in the house price index is more relevant for effects, such as negative equity after the peak. Nonetheless, the results are fairly similar regardless of which measure is used.

5.2.3 Higher income required to enter the market

The policy tightening is modelled as an increase in the level of deposits required to secure a mortgage. As this requires households to save a larger sum of money, given the value of the home they wish to purchase (which is time-varying), it is reasonable to speculate that the policy should bind more on younger and poorer households.

Yet simulations show that the *average* age of first-time buyers does not increase. However, the income that is required for households to enter the market *does* increase, by 11% on average. When the required LTV ratio was at 98%, the average age of the first-time buyer was 39.9 years and their average monthly income DKK 33,277. Under the tighter policy, the average age of the first-time buyer is 39.2 years and the average income DKK 36,819. While the average age of the first-time buyer is fairly similar, the distribution of age appears to be somewhat more narrow under the tighter policy (Figure 18). This suggests that the policy is binding on households at both younger and older ages. More specifically, we might say that, in general, under the tighter policy, *households are less likely to enter the housing market for the first time at an age under 30 or over 50 compared with the less restrictive policy.* This delay in the first purchase of a home accounts for the increase in the average income of first-time buyers under the tighter policy.

If we additionally consider the within-age cohort income percentile, we can see a shift towards the higher (income) percentiles under the tighter policy. As Figure 19 shows, under *either* policy setting it is rare for first-time buyers to be below the 30th percentile for their age. Households in these percentiles presumably are unable to save enough to acquire the deposit required under either macroprudential stance. Above this level, however, we see a shift in the distribution. Under the looser policy setting, there is a fairly even distribution across income percentiles above the 30th percentile. In contrast, under the tighter policy, the distribution of income shifts towards the higher-income percentiles. This further suggests that the tighter policy is more binding on households in the lower portion of the income distribution, most likely because they are less able to save sufficiently for the now increased deposit.

So, while this is clear evidence of an intensive margin, it also appears to be initial indicative evidence of a sizeable extensive margin. Let us decouple this effect further.

5.2.4 No change in the share of households who never buy a house over their life-cycle

While households will generally have a higher income when they enter the housing market, our results show that the overall share of the population that enters the market at all does not change under the tighter policy stance (see Figure 20). The share of households that never buy a home remains constant at around 65% in both policy scenarios. Coupled with the previous results, this suggests that although the overall rate of home ownership remains constant, under a tighter policy there is a small shift in the distribution of home owners towards "richer" households.

5.2.5 Lower rates of negative home equity

Since the introduction of a tighter LTV requires households to hold a higher income at purchase, this appears to benefit households through a reduction in house price cycles. In particular, the share of households with negative equity is significantly reduced. Following model assumptions, it is only households owning their first home that ever experience negative equity. When the mandated LTV ratio is 98%, the average share of first-time buyers that have negative equity in their home at any given time is 6.4%. Under the tighter policy, this average share drops to 5.1%. Moreover, the average peak share of first-time owners with negative equity drops from 23.0 to 20.3%. By forcing households to save a larger share of the value in their home before purchase, the tighter policy makes it less likely that households will end up with negative equity if house prices fall.

5.2.6 Distributions of LTVs

This reduction in negative equity can also be seen in the distributions of *individual de facto* LTV ratios across households. When households take out a mortgage, their LTV ratio must be below that set by the central bank. However, once they have purchased their house, if the house price falls, their LTV ratio might rise above that set by the central bank. This effect can be especially pronounced if they purchased their house at the peak of the market, since the price correction in bust may be larger. Under the tighter regime, there are lower peaks in house prices and so the effect is more muted. As shown in Figure 21, among households with LTV ratios above 100% (which represent those with a mortgage greater than the value of their home), the probability of being overexposed is lower under the tighter regime.

5.2.7 Home equity distributions

This difference is even more evident under the distribution of home equity. Figure 22 reports the distributions of first-time home owners' home equity. Each data point is a household's home equity in one period. The main driver of households' home equity is the house price. The higher the house price, the higher the home equity will be. Because the tighter policy reduces the peaks in house prices, occurrences of large home equity are also reduced. However, the tighter policy also reduces the occurrences of negative home equity.

This is because the seeds of negative home equity are planted during the peaks in house prices, when households take out large loans to purchase a home.[14] So, the higher the peak, the more likely it is that home owners will experience larger negative equity in a bust. This contributes to higher household vulnerability and a higher probability of future default.

Overall, the ABM evidence suggests that a tighter LTV constraint of 95% will delay entry at the margin and require an 11% higher income, on average, to enter the housing market. But it does not support the claim of a sizable extensive margin. The share of households that never purchase a home remains the same under both policy scenarios. Yet, the borrower-based measure brings a number of benefits. The policy not only reduces the occurrence of negative home equity but also reduces the severity of negative home equity once it occurs. This reduces household life-cycle vulnerability, especially for the lower percentiles. Coupled with smoother house price cycles, we should expect a lower probability of sector-wide default. However, to test that more formally in a dynamic setting, we would need to turn to a DSGE framework. That is our aim in the third phase, but before we proceed, we wish to discuss the broader welfare gain implication from the LTV cap we have just examined.

5.2.8 Welfare analysis

The agent-based model does not have an explicit utility function for households. Therefore, we cannot compare the scenarios using a measured change in utility. Nonetheless, we can infer some implicit utility effects. In general, we can assume a utility function with diminishing marginal utility in wealth, and that people tend to be risk averse. Therefore, households would prefer smaller variations in house price growth rates as long as the mean growth is unchanged. Therefore, the tighter restrictions on LTV ratios, which result in a narrower distribution of wealth, would have a greater utility for households than the more lax policy.

Furthermore, with explicit loss aversion, households' utility would be more negatively affected by a fall into negative equity than positively affected by a similar gain in wealth. This means that households would derive greater utility from a lower frequency and severity of negative home equity than otherwise.

The model also includes an assessed cost of renting versus owning a home, a type of "psychological cost of renting". This implies a greater utility from owning a home than renting. Therefore, to the extent that a tighter policy delays entry into the housing market for first-home buyers, it would represent a temporal reduction in utility while the latter

14. Because the horizon of mortgage repayment is long, when house prices fall, a significant share of households may end up with equity below zero.

are excluded from the housing market. However, because this only affects households at the margin, and the delay is only temporal, the welfare loss is expected to be very small. Although this is not a formal and complete welfare comparison, from our ABM analysis we might tentatively conclude that the tighter policy regime has a higher utility associated with it, without generating social exclusion and a sizable extensive margin.

This paves the way for the third and final step in our analysis. The DSGE framework we propose includes agent heterogeneity and uncertainty regarding true risk. This will allow us to compare the policy-induced steady state versus the alternative, as well as costs associated with the convergence to it. We can therefore measure first and higher-order effects from macroprudential policy, in a fully dynamic setting. That should enable us to say something more formally about long-run welfare outcomes for the economy as a whole.

6 How large are the convergence costs and benefits from these policies? A DSGE perspective

So far, we have examined the direct policy impact on cohorts of Danish households, focusing on the (un)equal effects across the distribution and the impact on (intensive and extensive) margins. However, we still need to complement the evaluation in a number of directions, examining (1) the general equilibrium (or higher-order) effects, (2) the effectiveness (of the policies) in attaining their objectives, and (3) the convergence dynamics to an economy where the policy is fully embedded. A DSGE model is capable of accommodating such components. In the following, we use a financial frictions model where all agents engage in the housing market but a share of them need to borrow to climb the housing ladder (reflecting the heavy distinction between renters and owner-occupiers in Denmark, captured by Figure 16). Borrowing is done against non-negative collateral, but lenders are uncertain about the risk distribution in the housing sector. We run a number of comprehensive policy counterfactuals with various types of borrower-based measures (based on the Danish policies) against a no-policy benchmark and pin down the general equilibrium effects. We also consider the costs along the convergence path. Moreover, because of the uncertainty aspect in housing (e.g. the large adjustments or corrections of Danish house prices, cf. Figure 1), we can additionally consider how policy interacts with or affects the tails of distributions in credit, house prices and consumption. We also conduct a formal welfare analysis and explore the optimal LTV ratio policy for Denmark. Finally, we consider the institutional implications from our analysis.

Note that the analysis in this third step is complementary to the previous steps as we aim to put the existing results into a broader (dynamic) context and gain a better understanding of the desirability of these measures from a long-run, economy-wide perspective. Our DSGE model can encapsulate extreme house price swings, household leverage and debt overhang, and the Danish mortgage market conditions we described earlier. Moreover, the model is calibrated to match Denmark to the extent possible.

6.1 Brief model outline

We use the model of Gerba and Żochowski (2017)[15]. The backbone of the model is a standard financial DSGE extended to include informational frictions (uncertainty) and heterogeneous expectations (through learning). Financial (or credit) frictions are caused by the limited borrowing capacity of impatient households who use housing collateral. Informational frictions emerge because agents have limited capacity to estimate the expected house price and the accumulated value of risk on their balance sheet as a result of their indebtedness. As a result, they face limitations in determining the expected household-level LTV ratio (or leverage). Instead, they must infer it using two alternative forecast rules. Agents evaluate the performance of each rule using an objective function and rationally choose the rule that performs best. In that sense, agents are intrinsically rational and gradually learn from the past. This learning process gives rise to heterogeneous expectations and allows for switching between rules in an endogenous and rational manner. Furthermore, these features make it possible to endogenize the cyclical evolution of many housing market and financial stability indicators that we are interested in for our policy evaluation. As a consequence, the model is highly non-linear and convergence is gradual.

Figure 14 provides a schematic overview of the model. Our economy is populated by three agents: households, financial intermediaries and the government. We divide households into two categories: patient and impatient households, with the discount factor, β, of patient households higher than that of the impatient. This forces the latter to complement their internal funds with loans from the credit market. While patient households both produce and consume land, impatient ones only consume it. Therefore, we explicitly model the adjustments in two markets: one for credit and one for housing (or land: both terms will be used interchangeably).

What differentiates this model from most other financial friction frameworks is that it incorporates uncertainty explicitly. Uncertainty is modelled in the sense that agents are (intrinsically) rational insofar as they efficiently optimize over time, but do so under incomplete information regarding two variables in the model: the LTV ratio, and the price of asset/collateral. The former is exogenous while the latter is endogenous but dependent

15. For further details on the micro-foundations and the market-clearing mechanisms, see the online appendix or Gerba and Żochowski (2017).

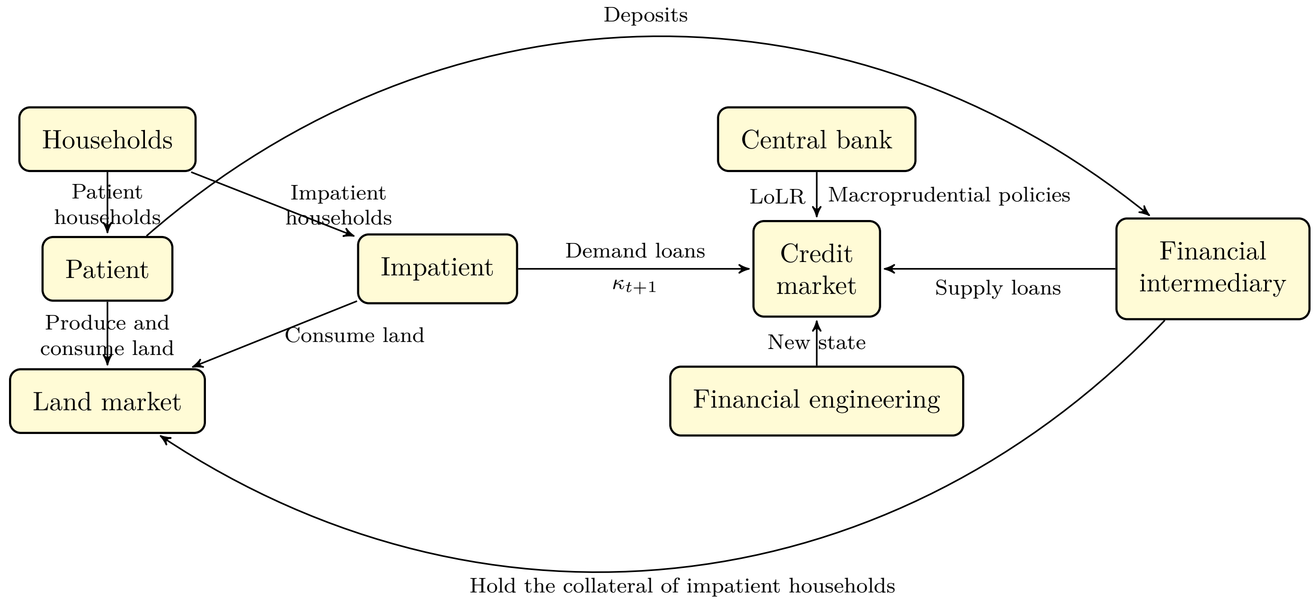


Figure 14: Schematic overview of the DSGE model.

on the realization of the first. Agents engage in adaptive learning and learn about the "true" leverage and asset price only after observing a sufficiently long set of realizations of both variables. Note that the learning convergence is slow since households only learn from their practical experiences.

6.2 Danish simulations

The model has been calibrated, where possible, to the Danish data. Those parameters are also consistent with those of the ABM, in order to maintain consistency between the two frameworks. That includes parameters related to the share of impatient households (72%), consumption (67%), land (4%), bank equity-to-GDP (23.45%) ratios and the LTV floor (24.8%). The share of impatient households captures the high proportion of borrowers in the Danish population (see Figure 6). The low land-to-GDP ratio reflects the limited land that is available in Denmark, in particular for residential construction purposes, and therefore a limited housing supply. Last, the high bank equity-to-GDP ratio represents the high profitability of the concentrated Danish banking sector, as also modelled in the ABM. Table 8 shows empirical autocorrelation and correlations for some key variables in the model for empirical Danish data. In general, the calibration matches these moments decently (see Table 6). Other parameters are deep and therefore do not have a direct empirical counterpart. Only econometric estimations would make it possible to extract those and that is beyond the scope of the paper. The parameters are thus calibrated as in Gerba and Żochowski (2017). For a more thorough discussion of the rest of the parameters and values, see the online appendix and Table 5.

For policy counterfactuals, we proceed with multiple calibrations, one for each scenario. In the benchmark-unconstrained scenario, the cap on the LTV ratio, $\bar{\kappa}$, is set to 98%. In the first policy scenario, we tighten the cap to 95%. In the second scenario we tighten it much more to 24.8%, representing the historical de facto LTV floor for the riskiest of loans in Denmark in the period 1973Q1–2018Q2. We only use this as a hypothetical test scenario to quantify the general equilibrium effects if all loans were constrained by this rule. Finally, we include the amortization rules that were introduced on top of the LTV ratio cap. To capture this, we model the LTV policy as an AR(1) process where deviations from the LTV rule are constrained by amortization requirements. The AR coefficient is calibrated to 0.8, implying that, on average, 80% of loans are additionally required to adhere to the amortization requirements. Note that this does not mean that all 80% of the stock of loans will be bound by this rule. But it represents the share of loans which might be constrained. The remaining 20% of loans are issued to wealthy households who are not bound by the amortization requirements. In order to avoid determinism on the loans that are required to adhere to these rules, we add a white noise shock to this rule, which randomizes the loans that will have to adhere to the requirement.

Furthermore, we wish to examine whether the relationship between the LTV constraint and the mitigation of systemic risks is linear, or whether there is an optimal interior point at which systemic risks are asymptotically eliminated but without a policy-induced credit contraction. For this part, we examine the impact on policy target variables (or response function) when the model gradually moves from a steady state with a 95% LTV cap to a cap of 24.8%.

We simulate the model for 2000 quarters, or 500 years under each policy scenario. Note that the calibration of all parameters except the LTV policy rule remains the same across scenarios. The same ceteris paribus principle extends to the initialization of each scenario.

6.3 Policy assessment

For the sake of focus, we will just discuss parts where there are impact differences between the various policy scenarios.[16] For rapid inspection, we report the final median outcome and distributions in the same graphs for each variable. Policies are introduced at the beginning of each new simulation chain, as part of the model optimization/convergence

16. For other results not reported here, please contact the authors.

algorithm, and we report the final results. This is standard for policy counterfactuals in the DSGE literature. An alternative approach would be to introduce policy in the midst of a simulation chain and compare the outcomes, akin to a difference-in-difference approach as in our ABM model. However, for convergence and general equilibrium analysis, this is not appropriate, and our discussion here will complement what we discussed in the ABM and empirical sections. We examine the effects of the various policies on model variables in a number of ways. We start by examining the (long-run) distributions of consumption and land price (two key model variables) after simulating 2000 quarters across the various policy scenarios (Figure 23). This allows us to examine the cross-quantile impact of those. However this is static. To complement, we also look at the endogenous cyclical evolution of financial variables, including credit, the interest rate on credit and bank equity across the different scenarios (Figure 24). These are therefore swings that endogenously result in the model under the various conditional scenarios of LTV policies. Here, we focus on the volatility. Finally, the information is collected (and expanded for all variables) in tables 6 and 7, where we calculate the various moments across the different scenarios. This is thus a numerical summary of the variables depicted in figures 23 and 24, and includes many more. So, for instance, the autocorrelation of land price is smaller when a LTV policy is in place, which means that the policy has succeeded in reducing the otherwise high persistence in the housing (land) market.

6.3.1 How effective are the Danish borrower-based measures?

An LTV cap of 95% (scenario 1) can *simultaneously* reduce systemic risks and improve the welfare of the average household. On the one hand, it significantly reduces the probability of large land price falls by restricting the volume of credit accessible to the riskiest of borrowers, thereby reducing their risk profile. On the other hand, the credit cycle is smoothed since the additional credit that would be granted in the absence of this policy is now removed, while the repayment rate of credit is smoothed over time as shown in the upper graph in Figure 24. This in turn facilitates households' intertemporal planning, which has a high weight in life-cycle consumer models. Both effects increase the welfare of households, which, in the absence of other agents, increases the welfare of the economy.

To shed some light on the quantitative effects from policy, we proceed by looking at some target variables in the model. For instance, a tightening in LTV requirements from 98% to 95% reduces the intrinsic probability of default of a household (at any point in time) by 50% (see Table 7). Moreover, severe deteriorations in credit conditions, as measured by severe troughs or left tails in credit distributions, are completely eliminated (Figure 23). In the short run, in the cyclical frequency, this means that land price growth is moderated, which also keeps household leverage in check (middle graph in Figure 24)[17]. At the same time, the subsequent trough in land prices is reduced by up to 20%, as shown in the lower histogram in Figure 23.

In the long run, which we capture by calculating relevant statistical moments based on the full run of simulations of 2000 quarters, we show that land price cycles are curbed. Land price surges are, on average, 25% smaller over the long run compared with an economy where borrower-based measures have not been implemented (comparing columns 2 and 3 in Table 7). The consequence is a more predictable housing market and, at least in theory, more affordable houses. That is particularly visible for important aggregates such as output, consumption and credit. Furthermore, the introduction of the 95% LTV policy reduces long-run volatility in most model variables to around a half, as shown in columns 2 and 3 in Table 7. Another benefit is a reduced disparity in wealth, considering that wealthier households own disproportionately more of the total housing wealth. The volatility of leverage is also reduced by a factor of three, while extreme deteriorations in leverage are removed. At the same time, comparing columns 6 and 7 and 10 and 11 in Table 7 shows that leverage is controlled and moderated. The skewness of the 95% LTV scenario is significantly more negative than with no policy, at the same time as kurtosis is smaller in the first case. Therefore, the number of outliers is reduced, while all the mass is on the positive tail.

Banks become safer since they absorb much less credit risks on their books. This is due to two effects: *the direct effect* from lower default probabilities on their loan books, and *the indirect effect* from less frequent reversals in the price of collateral resulting in more solvent and creditworthy households over their lifetime. The total impact on bank equity is also sizeable. Even during periods of low growth and sustained downturns, the aggregate equity of a bank does not shrink by more than 20%, shown in the lower graph in Figure 24. In other words, banks become more resilient, even during times of economic recession. Overall, the probability of a systemic crisis is reduced.

Average (median) consumption in the long run is almost 3% (2.7%) higher (upper graph in Figure 23), while its variation is reduced by almost a half (see standard deviations in Table 6). Moreover, autocorrelations of consumption, credit, land price and bank equity is also lower, as are their cross-correlations in Table 6. This is indicative evidence that the doom loop in downturns between house prices, debt, and default risk is weakened. In other

17. In this framework, *short run* refers to the dynamics of the model variables while we simulate the model's path. Note that because this is a model with uncertainty and learning, convergence to steady state is not immediately achieved. Thus, we contrast the evolution of the variables of interest during a period less than 200 quarters, conditional on the various policy scenarios. In contrast, *long run* refers to the model variables after the full simulation run of 2000 quarters. In this case, the model variables/patterns we compare across the various scenarios are akin to the (very) long run, where the model has converged or is at least close to converging.

words, the debt overhang problem is diminished.

Turning to scenario 3, we find that the long-run outcomes from the more complex LTV rule do not differ much compared with scenario 1. (Auto)correlation matrices between the two policy scenarios are broadly the same (Table 6), in terms of both signs and magnitudes. The only correlations where the magnitude is larger for the complex rule are those between leverage and credit, leverage and land prices, and leverage and consumption. Although low in the complex rule as well, they are somewhat higher than in scenario 1. This implies that the restriction on leverage is not as rigid in this scenario since either of the two policies can be binding at a particular time (LTV or amortization), which delays learning in this model, and at margin could allow credit to boom somewhat more than with only a simple rule. That is why we observe a somewhat stronger loop between land price, credit, leverage and consumption than in scenario 1. The statistical moments are almost identical in both policy scenarios. This means that the tails are equally small and the cycles equally smooth across both scenarios.

So where do (some of) the costs from these policies come from in this model? Overall, because credit volumes in expansions are attenuated, the business cycle booms are more moderate. Moreover, the lower autocorrelation and cross-correlations mean that the economic spillovers from housing market expansions are less persistent, and possibly less sentiment-driven. Therefore, the gains in terms of stability and consumption are traded for more moderate economic expansions and less *optimism*. A formal welfare analysis would put these numbers into perspective. We will discuss this next.

6.3.2 What about welfare gains from these policies?

In standard rational expectations (RE) DSGE models, one evaluates the policy welfare effects by calculating the conditional gains using a second order approximation of households' welfare. However, in our model, RE is substituted with heterogeneous beliefs, which means that the policy maker does not know how to weight these numerous beliefs into a general welfare function. Hence, imperfect information also impacts households' welfare.[18]

To overcome this problem, we instead value the long-run welfare using a utility (or consumption equivalence) measure of an economy with and without the policy. Knowing the parameters in the utility function, and the median consumption of households in an economy with and without the LTV cap, we can calculate the long-run utility gains that an average household will make when the rule is imposed. Moreover, we can test the gains from having a simple LTV cap versus the complex LTV rule that includes an amortisation

18. There are attempts, such as Brunnermeier et al. (2014), to define belief-neutral welfare functions in models with distorted (or imperfect) beliefs. However, more work is necessary before a robust method can be obtained for loss function derivations.

requirement of 80%.[19] Since household utility only depends on consumption, the gains will be expressed in consumption equivalence terms.

We find that the welfare gains from having a policy in place are clearly higher than if no policy was in place. For a simple cap on household LTV, the gain is 1.1%. This means that, on average, a household will consume 1.1% more when a central bank imposes a cap compared with an economy without it. Decomposing this gain, we find that 1% out of the 1.1% derives from an increase in the level of consumption, while 0.1% comes from a reduction in variability (or volatility) of consumption over the cycle.

For the complex rule, the gain is higher, at 2.1%. The additional gain from the complex LTV policy comes from the added credit expansion at the margin, with a boost in aggregate demand (through land production).[20]

6.3.3 What role does the house price play in the welfare gains?

The main reason for the higher level of long-run consumption in scenarios 1 and 3 is a combination of smoother repayment rates and smoother land prices. Judging from the lower graph in Figure 23, severe land price drops are less likely with the 95% LTV cap. At the same time, the magnitude of each drop is also reduced. For households, this has two implications. First, the consumption path is smoothed because negative surprises in land production are minimized. Second, due to budget constraints, this means that land price, q_t, is more stable over time, which allows for higher consumption. This has an even greater effect on the risk-averse households (depositors), who are more sensitive to land price fluctuations.

Second, the loan interest rate charged by banks, R_t^b, is directly affected by the cyclical movements in the land price. If that becomes smoother, the repayment cost is also smoothed. This means that, in addition to the previous channel, consumption is further increased because households can better estimate future repayment costs. Combined, these two channels significantly increase the consumption level in the *long run*.

Yet *during the convergence path*, the consumption level may even be lower due to the foregone booms. By shedding light on these dynamic trade-offs, we provide an argument for why this policy needs to be delegated to a disciplined independent authority that can look beyond short-run rewards from either sharp house price surges or underpriced repayment rates, and focus on the long run.

19. Note that since model variables have asymmetric distributions in the benchmark model, the median is more representative of the center of the distribution than the mean. That is why we use the median consumption in our calculations.

20. The leverage remains, which means that the credit expansion is driven by an expansion in fundamentals, and hence the somewhat weaker loop between land price, credit, leverage and consumption compared with scenario 1, discussed above.

6.3.4 How linear is the link between LTV stringency and mitigation of systemic risk?

Considering these welfare improvements, we will now explore whether there is a linear or monotonic desirability for having a stricter LTV cap. The answer seems to be that there is not: borrower-based measures can be damaging for the economy if they become too stringent, according to this model. As scenario 2 shows, while a very conservative LTV limit of 24.8% eliminates the credit risk in the economy, it even restricts those households that could have handled the risk. In other words, it is so restrictive that even households with a solid repayment status are denied mortgage access. The effect is policy-induced austerity and contraction. This can be seen by comparing the left tails of the ergodic distributions of leverage and consumption (Figure 23). In particular, the left tail of the distributions of the 24.8% leverage cap is fatter than those of the 95% leverage cap. This means that sustainable expansion can be achieved by applying more lenient credit checks and extending credit.

Therefore, good financial policies must strike a balance between risk mitigation and granting economic agents, here households, opportunities to climb the housing ladder.

7 Is (macro)prudence desirable?

To capture the full-scale impact of borrower-based policy, short-run vs long-run aggregate effects need to be balanced on top of any distributional consequences those policies may generate. Yet, these policies are very novel in advanced economies, including Denmark, which makes it difficult to conduct causal inference based on empirical data alone. In addition, although the objectives of these policies are clear and their target is to directly reduce risks in the most vulnerable segment of the housing (or financial) market, the trade-offs involved are not well understood. In particular, it is not clear whether these policies may have unintended effects (first- or higher-order), or further repercussions for other policies. One such concern is whether borrower-based measures like those implemented in Denmark are harming those same households they are aimed at shielding. Magnitudes of intensive and extensive margins have not been pinned down so far, nor has it been understood if either of the two effects dominates. Moreover, it is not clear whether subsequent changes in the characteristics of first-time buyers are temporary or permanent.

To conduct an evaluation along these lines, two tasks need to be performed simultaneously. First, (direct and indirect) effects of the policies across the wealth and income distributions need to be measured. Second, these effects need to be judged against a performance criterion, revealing how successful those same policies are in attaining their intended objectives. But a number of complications arise. These policies have been gradually implemented, delaying their full impact or potentially generating (endogenous) behavioral alterations. Moreover, other shocks have been present and other policies have been simultaneously undertaken, which have a direct or indirect impact on the relevant groups of households, complicating the specific policy transmission identification. Furthermore, these borrower-based measures may have an amplifying effect on other policies focusing on inequality and social insurance, which may prove difficult to disentangle. Taking all these factors into account, we have opted for a multi-stage, pluri-methodological approach. We rely on the merits of each framework to examine a fraction of the complex problem, and then link it back to answer the broader question. We also connect the insights from each stage to fine-tune the analysis of the next. All models have been geared and calibrated, as much as possible, to the Danish experience in order to derive meaningful estimates, able to be contrasted across models. Moreover, this ensures the coherency of the story.

Our results indicate that the Danish borrower-based measures have been successful in improving the resilience of the Danish housing market and mortgage market, without generating social exclusion. Although there is evidence of a sizeable intensive margin, the size of the extensive margin is minimal. In particular, the main distributional impacts are the somewhat delayed entry at the margin and the 11% higher income requirement, on average, needed to enter the housing market. Yet, the borrower-based measures bring a number of benefits, even to the households of the lower percentiles of the wealth distribution. The policy reduces both the occurrence of negative home equity and the severity of that negative equity when it occurs. This reduces the life-cycle vulnerability of households, especially in the lower percentiles of the wealth distribution. Coupled with smoother house price cycles, we should expect a lower probability of sector-wide default. In the aggregate and over time, the benefits are even more evident. An LTV cap of 95% can *simultaneously* reduce systemic risks and improve the welfare of the average household. If applied in combination with an amortization requirement (as in the Danish case), the restriction on leverage is not as rigid and at the margin could allow credit to boom somewhat more than with a simple rule only. Overall, consumption is higher and less volatile with both policies in place, with an economy-wide welfare gain of up to 2.1% in steady state consumption equivalence terms. There are also costs, in the form of milder business cycle booms and weaker economic spillovers from housing market expansions. Yet the clear gains in the form of higher system-wide resilience and lower probability of financial meltdowns mean they protect those that are most vulnerable and those that have most to lose in such a setting.

But maybe the biggest contribution of our work on dynamic trade-offs lies in providing an argument for why this policy needs to be delegated to an independent authority that can look beyond the short-run gains from sharp house price surges or underpriced repayment rates. While the answer regarding the social desirability of (macro)prudential policy is affirmative in our paper, the joint considerations of social desirability and optimal design of policy require much deeper reflection in the prudential space. This paper will hopefully contribute to a new avenue for the literature on the optimal institutional design of macroprudential policy.

References

Aguilar, Pablo, Stephan Fahr, Eddie Gerba, and Samuel Hurtado. 2020. *Quest for Robust Optimal Macroprudential Policy.* Dynare working paper. CEPREMAP.

Andersen, Asger Lau, Charlotte Duus, and Thais Lærkholm Jensen. 2016. "Household debt and spending during the financial crisis: Evidence from Danish micro data." *European Economic Review* 89:96–115.

Andersen, Marc Lund. 2022. *Grundpriser for enfamiliehuse 1996-2019 - med fokus på huse købt til nedrivning.* Analyse. Boligøkonomisk Videncenter.

Arregui, Nicolas, Jaromír Beneš, Ivo Krznar, Srobona Mitra, and Andre Oliveira Santos. 2013. *Evaluating the Net Benefits of Macroprudential Policy: A Cookbook.* IMF Working paper 167. International Monetary Fund.

Baptista, Rafa, J Doyne Farmer, Marc Hinterschweiger, Katie Low, Daniel Tang, and Arzu Uluc. 2016. *Macroprudential policy in an agent-based model of the UK housing market.* Staff Working Paper 619. Bank of England.

Bentzen, Christian Sinding, Graeme Stuart Cokayne, Eddie Edin Gerba, and Rasmus Pank Roulund. 2020. *Stricter lending requirements have made homeowners more robust.* Analysis 1. Danmarks Nationalbank.

Brunnermeier, Markus K., Alp Simsek, and Wei Xiong. 2014. "A Welfare Criterion For Models With Distorted Beliefs*." *The Quarterly Journal of Economics* 129 (4): 1753–1797.

Carpantier, Jean-Francois, Javier Olivera, and Philippe Van Kerm. 2018. "Macroprudential policy and household wealth inequality." *Journal of International Money and Finance* 85:262–277.

Cerutti, Eugenio, Stijn Claessens, and Luc Laeven. 2017. "The use and effectiveness of macroprudential policies: New evidence." *Journal of Financial Stability* 28:203–224.

Cokayne, Graeme. 2019. *The Effects of Macroprudential Policies on House Price Cycles In an Agent-Based Model of the Danish Housing Market.* Working Paper 138. Danmarks Nationalbank.

Colciago, Andrea, Anna Samarina, and Jakob Haan. 2019. "Central bank policies and income and wealth inequality: a survey." *Journal of Economic Surveys* 33 (4): 1199–1231.

Davis, Morris A., and Stijn Van Nieuwerburgh. 2015. "Housing, Finance, and the Macroeconomy." Chap. 12 in *Handbook of Regional and Urban Economics,* edited by Gilles Duranton, J. Vernon Henderson, and William C. Strange.

Frost, Jon, and René van Stralen. 2018. "Macrodprudential policy and income inequality." *Journal of International Money and Finance* 85:278–290.

Gerba, Eddie, and Dawid Żochowski. 2017. *Knightian uncertainty and credit cycles.* Working Paper 2068. European Central Bank.

Jordà, Òscar, Moritz Schularick, and Alan M. Taylor. 2015. "Leveraged bubbles." *Journal of Monetary Economics* 76:S1–S20.

Kelly, Robert, and Elena Mazza. 2019. *A Measure of Bindingness in the Irish Mortgage Market.* Financial Stability Notes 12. Central Bank of Ireland.

Kumhof, Michael, Romain Rancière, and Pablo Winant. 2015. "Inequality, Leverage, and Crises." *American Economic Review* 105 (3): 1217–1245.

Kuttner, Kenneth N., and Ilhyock Shim. 2016. "Can non-interest rate policies stabilize housing markets? Evidence from a panel of 57 economies." *Journal of Financial Stability* 26:31–44.

Piazzesi, M., and M. Schneider. 2016. "Housing and Macroeconomics." *Handbook of Macroeconomics,* 1547–1640.

Richter, Björn, Moritz Schularick, and Ilhyock Shim. 2019. "The costs of macroprudential policy." *Journal of International Economics* 118:263–282.

Rubio, Margarita, and José A. Carrasco-Gallego. 2014. "Macroprudential and monetary policies: Implications for financial stability and welfare." *Journal of Banking & Finance* 49:326–336.

Shim, Ilhyock, Bilyana Bogdanova, Jimmy Shek, and Agne Subelyte. 2013. *Database for policy actions on housing markets.* BIS Quarterly Review. Bank for International Settlements.

A Additional figures of empirical data

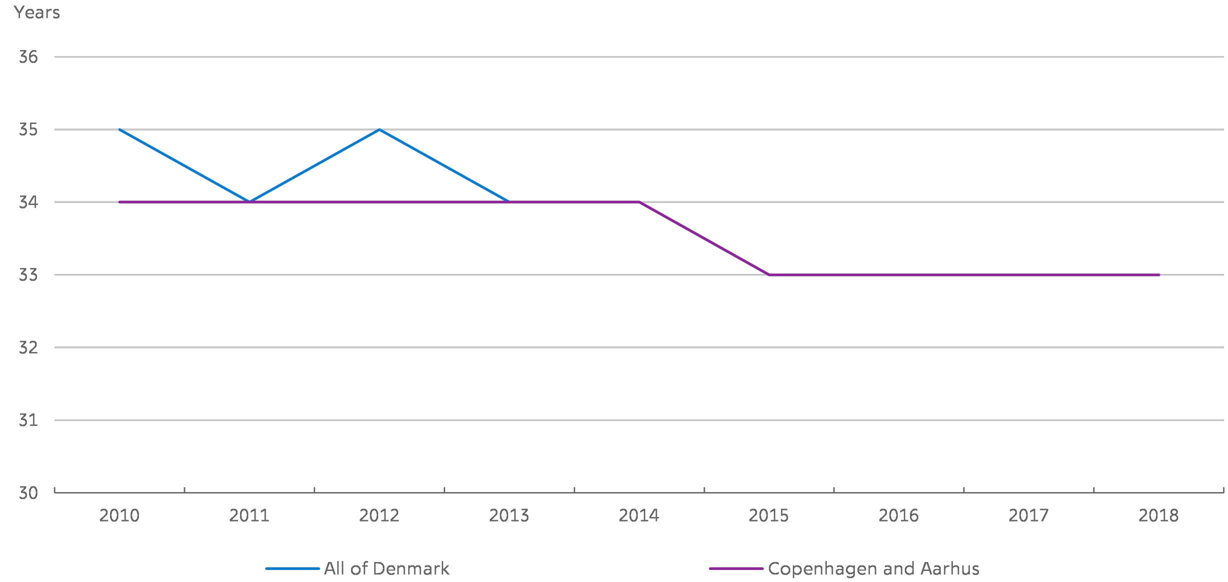


Figure 15: Median age of first-time buyers. Source: Own calculations based on micro data from Statistics Denmark.

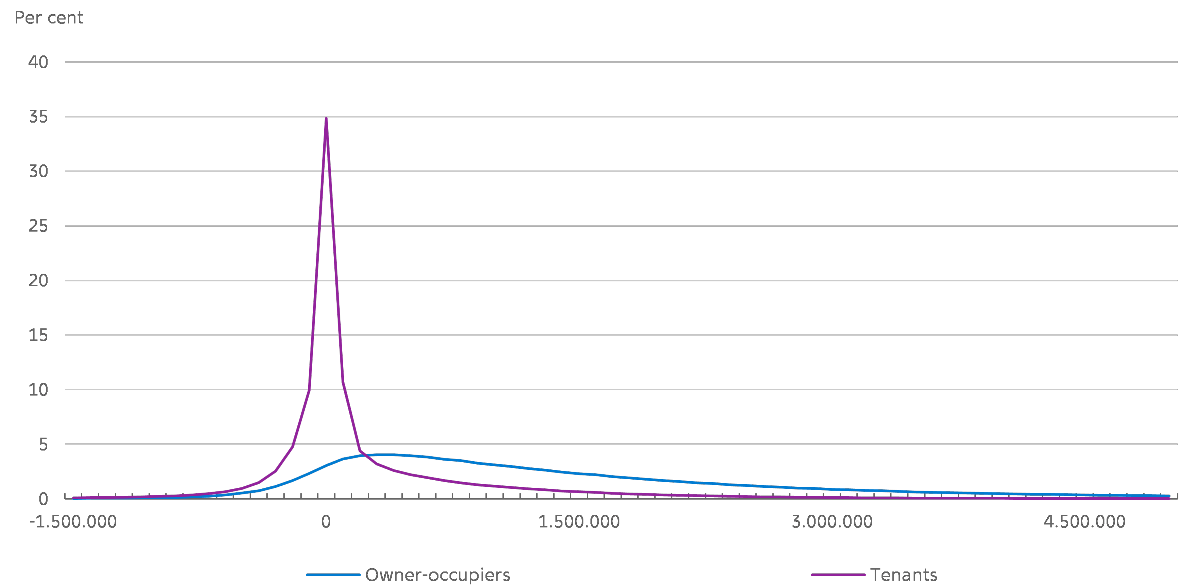


Figure 16: Wealth distribution in Denmark in 2017. Source: Own calculations based on micro data from Statistics Denmark.

B Additional figures for the Agent Based Model

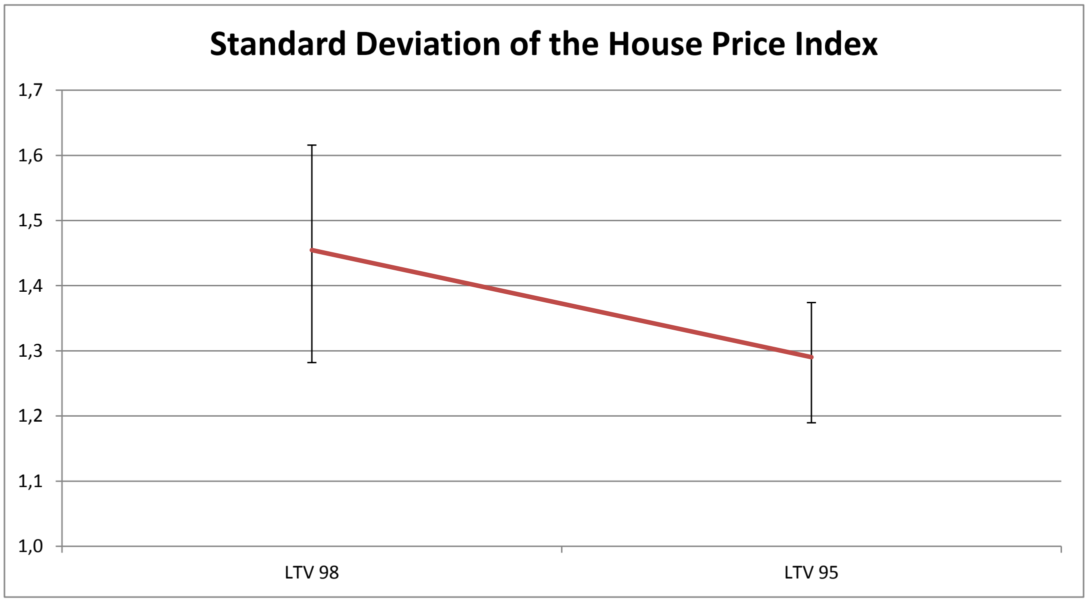


Figure 17: Standard deviations of the house price index under two different macroprudential policies. Namely, one that requires a 98% LTV and one that requires a 95% LTV at mortgage origination. Source: Own calculations.

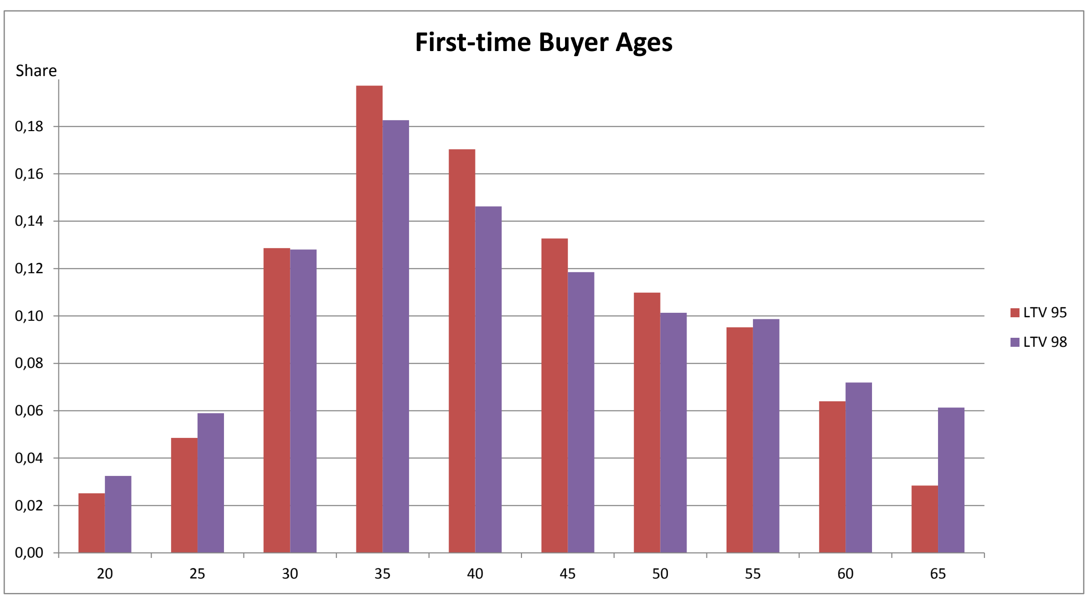


Figure 18: Distributions of the age of first-time buyers under two different macroprudential policy settings. Namely, one that requires a 98% LTV and one that requires a 95% LTV at mortgage origination. Source: Own calculations.

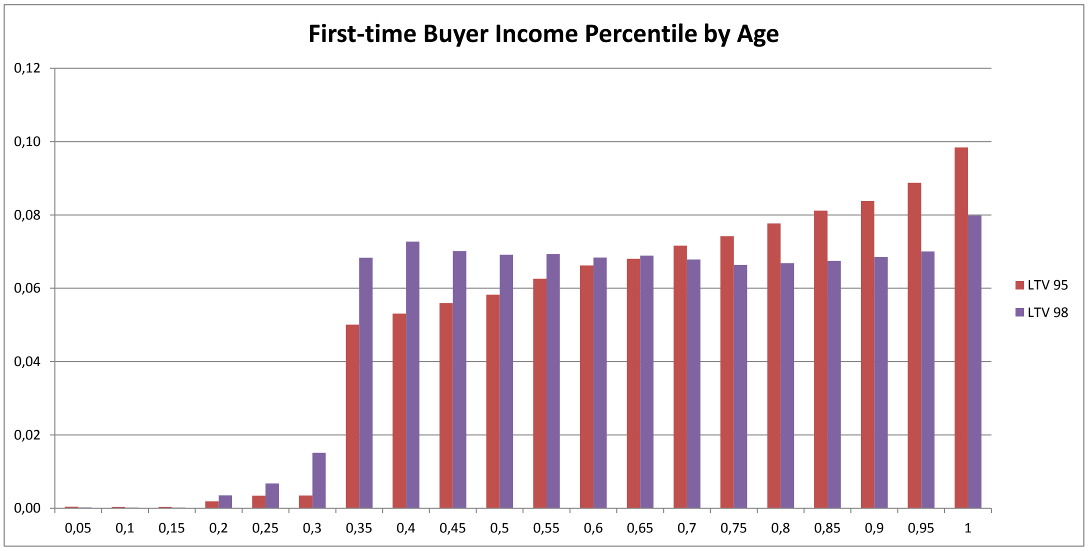


Figure 19: Distributions of the income percentile by age of first-time buyers under two different macroprudential policy settings. Namely, one that requires a 98% LTV and one that requires a 95% LTV at mortgage origination. Source: Own calculations.

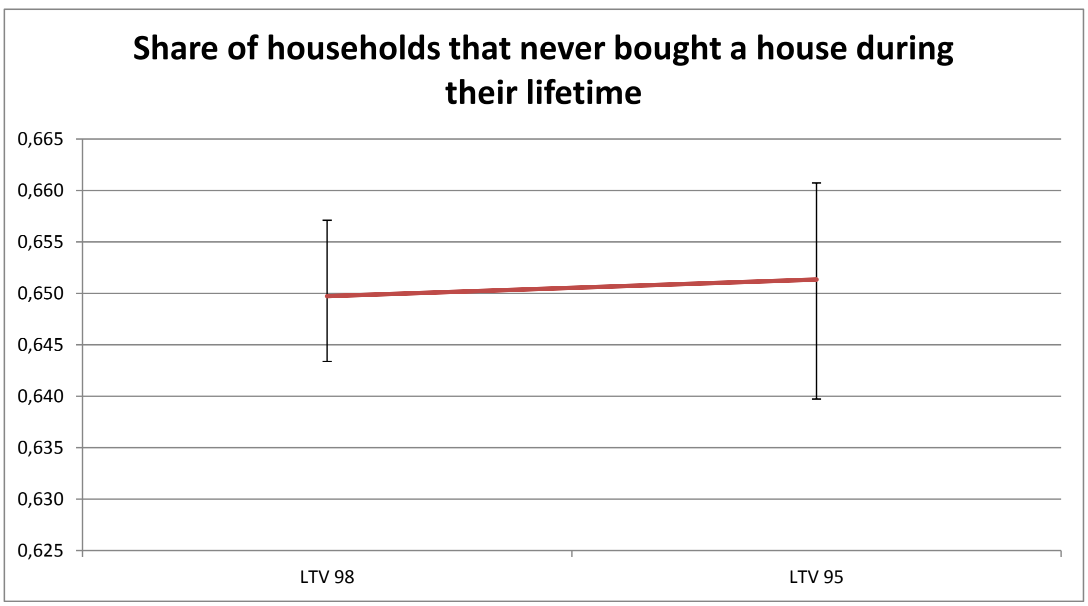


Figure 20: The share of households that never bought a house during their lifetime under two different macroprudential policy settings. Namely, one that requires a 98% LTV and one that requires a 95% LTV at mortgage origination. Source: Own calculations.

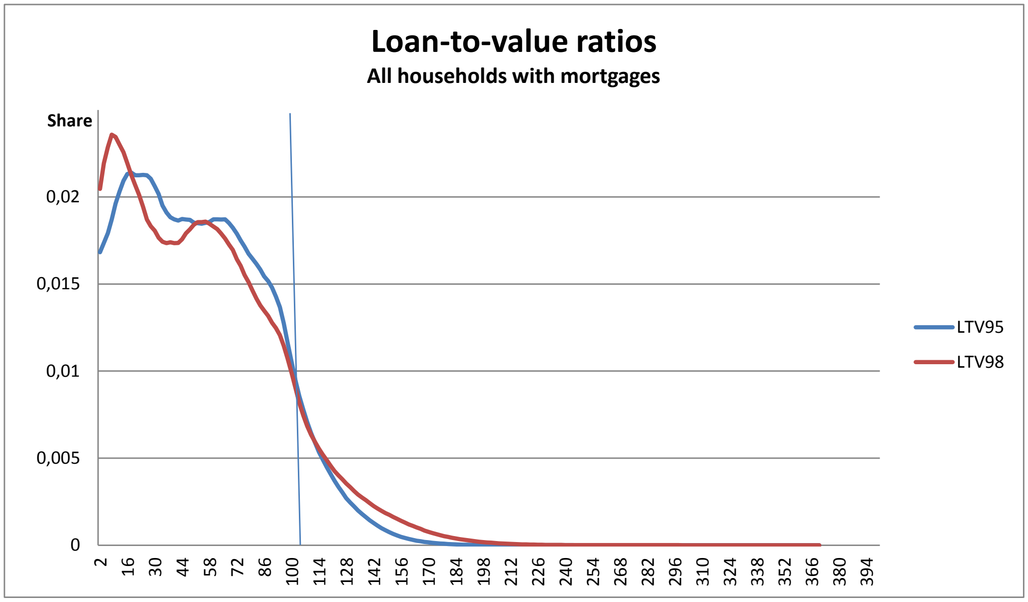


Figure 21: Distributions of loan to value ratios among households with mortgages under two macroprudential policy regimes. Namely, one that requires a 98% LTV and one that requires a 95% LTV at mortgage origination. Source: Own calculations.

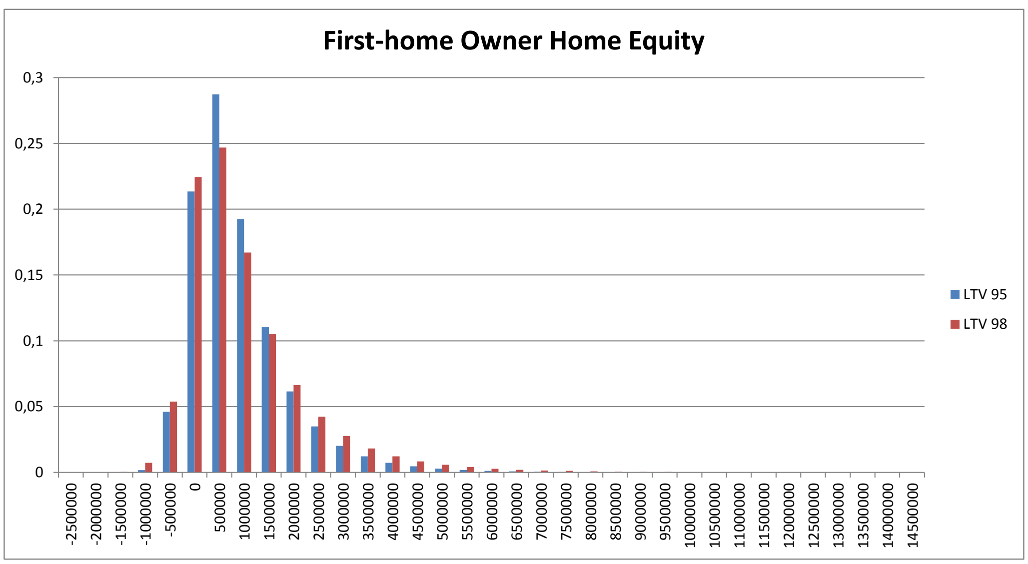


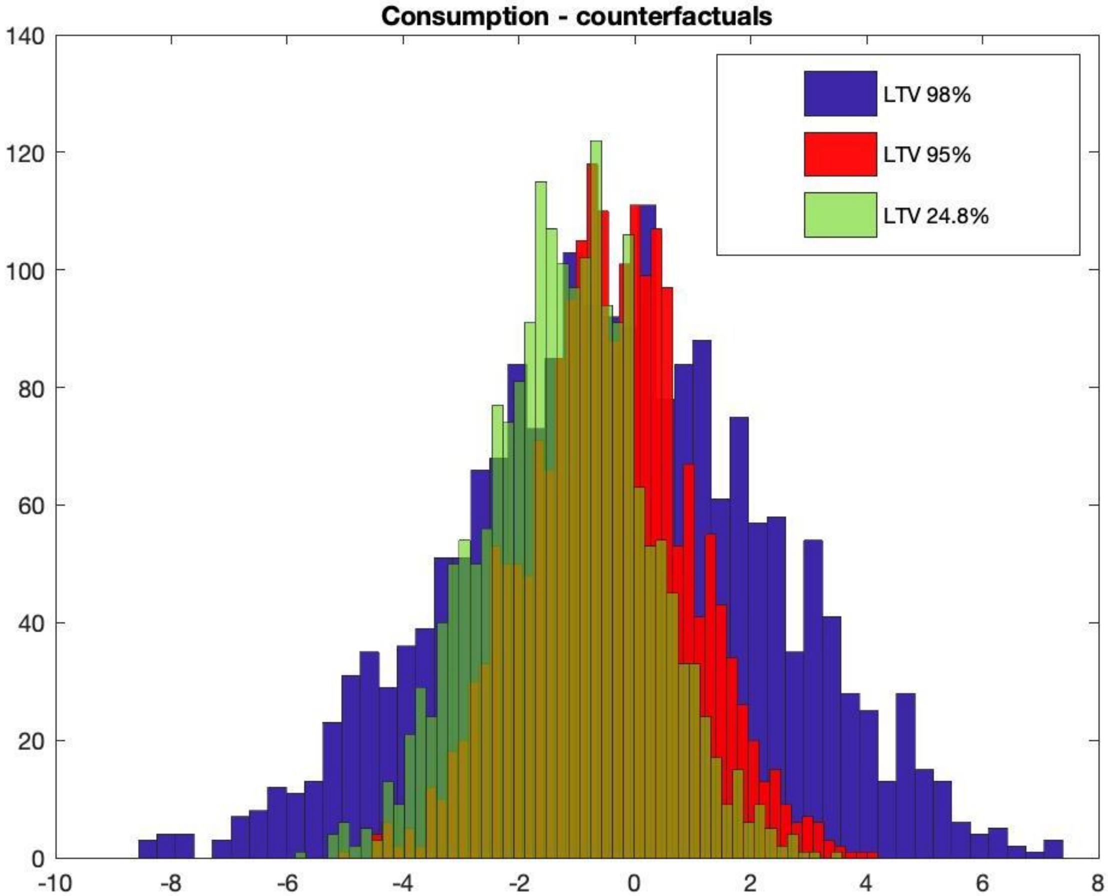
Figure 22: Distributions of the home equity of first-time owners under two macroprudential policy regimes. Namely, one that requires a 98% LTV and one that requires a 95% LTV at mortgage origination. Each data point represents one household's net home equity in a period. Source: Own calculations.

C Additional figures and tables for DSGE model

Table 5: Parameters in the model and their descriptions

Parameter	Description	Value
Calibrated		Calibration
σ	Constant risk aversion parameter in CRRA utility function	2
ω	Share of impatient households int he economy	0.72
β^P	Discount factor of patient households	0.9943
β^I	Discount factor of impatient households	0.975
ω^b	Share of bank profits in bank equity accumulation	1
δ^k	Cost for managing banks' capital position	0.1049
Adj^b	Adjustment cost for changing the deposit rate	0
ν^b	Target capital-to-asset ratio	0.09
κ^{Eb}	Cost of deviating from target capital-to-asset ratio	11.49
α	Factor share of land in production	0.025
l	Aggregate land supply	1
μ^{fx}	(Fixed) Langrangian multiplier of the credit constraint	0.3
$\bar{c}$	Consumption-GDP ratio	0.67
$\bar{l}$	Land-GDP ratio	0.04
$\bar{c}$	Bank equity-GDP ratio	0.2345
γ^r	Interest rate smoothing parameter	0.77
γ^π	Response to inflation in the Taylor rule	2.01
γ^y	Response to output in the Taylor rule	0.35
$\bar{\kappa}$	Cap on household LTV-ratio	2
ρ^κ	Response of LTV to credit growth	0.75
α_0^f	Initial fraction of fundamentalists	0.5
α_0^e	Initial fraction of extrapolators	0.5
γ	Switching parameter in MSFE	1
κ^*	SS LTV-ratio	0.93
q^*	SS land price	1
ν	Weight of forecasted land price in the land price function	0.7
$\tilde{c}$	SS consumption parameter in CRRA geometric series	0.125
ϵ^z	Standard deviation of the TFP shock	1
ϵ^{Eb}	Standard deviation of the capital quality shock	1
ψ	Standard deviation of the income quality shock	1
ϵ^r	Standard deviation of the monetary policy shock	1
ρ_z	AR parameter in the TFP shock process	0.9
ρ_{Eb}	AR parameter in the capital quality shock process	0
ρ_ψ	AR parameter in the income shock process	0
ρ_r	AR parameter in the monetary policy shock process	0.9

Figure 23: Ergodic distribution of consumption (above) and housing (below) across scenarios. Source: Own calculations.



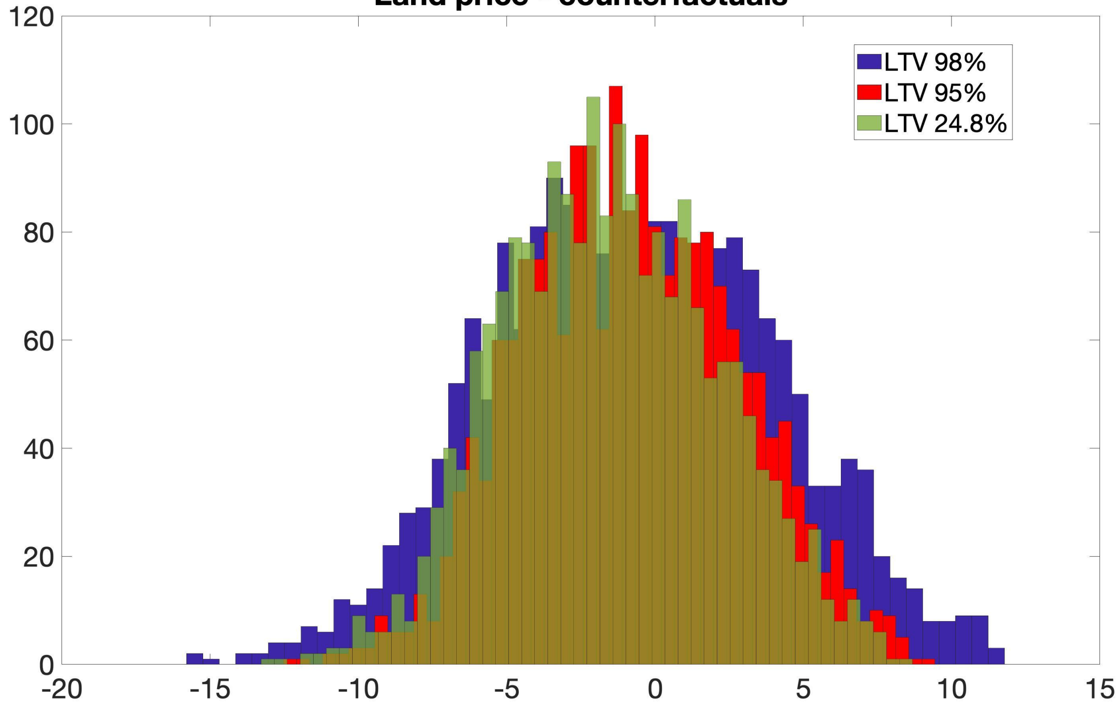


Table 6: Counterfactual analysis with Knightian uncertainty and credit cycles – model correlations and autocorrelations

Definitions	No policy	95% LTV	95% LTV complex	24.8% LTV
Autocorrelation – land price	0.94	0.90	0.91	0.90
Autocorrelation – consumption	0.87	0.69	0.70	0.70
Autocorrelation – bank equity	0.91	0.76	0.81	0.76
Autocorrelation – leverage	0.99	0.99	0.99	0.99
Autocorrelation – policy rate	0.88	0.88	0.88	0.88
Autocorrelation – credit	0.91	0.76	0.81	0.76
Autocorrelation – lending rate	0.91	0.76	0.81	0.76
Correlation (cons	0.78	0.65	0.67	0.64
Correlation (cons	0.87	0.55	0.61	0.54
Correlation (cons	−0.87	−0.55	−0.61	−0.54
Correlation (land price	0.95	0.90	0.90	0.90
Correlation (cons	−0.88	−0.007	−0.23	−0.02
Correlation (land price	−0.93	−0.004	−0.33	−0.01
Correlation (credit	−0.97	−0.006	−0.57	−0.02
Correlation (output	0.42	0.34	0.32	0.34
Correlation (land price	−0.95	−0.90	0.90	−0.90
Correlation (credit, lending rate)	−1.00	−1.00	−1.00	−1.00

Table 7: Counterfactual analysis with Knightian uncertainty and credit cycles – model statistics

	Standard deviation				Skewness				Kurtosis			
LTV: Variables	NP	95%	95% complex	24.8%	NP	95%	95% complex	24.8%	NP	95%	95% complex	24.8%
Output	1.81	0.94	1.02	0.95	0.17	0.035	0.13	0.05	2.89	2.99	3.04	2.96
Credit	1.41	0.79	0.84	0.79	−0.08	−0.02	−0.05	0.01	2.66	2.64	2.69	2.72
Credit/Output	0.78	0.84	0.82	0.83	−2.125	−0.57	−0.39	0.2	0.92	0.88	0.89	0.92
Sentiments	0.45	0.42	0.42	0.40	0.24	0.35	0.36	0.66	1.24	1.42	1.41	1/75
Sentiments/output	0.25	0.45	0.41	0.42	1.41	10	2.77	13.2	0.43	0.48	0.46	0.59
Lending rate	1.41	0.79	0.84	0.79	0.08	0.02	0.06	−0.01	2.66	2.64	2.69	2.72
Lending rate/output	0.78	0.84	0.82	0.83	0.47	0.57	0.46	−0.2	0.92	0.88	0.89	0.92
Policy rate	2.17	2.17	2.17	2.17	0.24	0.24	0.24	0.24	3.11	3.11	3.11	3.11
Policy rate/output	1.20	2.30	2.13	2.28	1.41	6.86	1.85	4.8	1.08	1.05	1.02	1.05
Bank equity	0.19	0.11	0.12	0.11	−0.08	−0.02	−0.05	0.01	2.66	2.64	2.69	2.72
Bank equity/output	0.11	0.12	0.12	0.12	−2.125	−0.57	−0.39	0.2	0.92	0.88	0.89	0.92
Consumption	2.70	1.40	1.52	1.40	−0.07	−0.015	−0.11	−0.03	2.84	2.99	3.01	2.96
Consumption/output	1.50	1.49	1.49	1.47	−0.41	−0.43	−0.85	−0.6	0.98	1	0.99	1
Leverage	5.77	0.02	1.57	0.09	0.12	−44.68	−0.10	−44.69	2.79	2	2.98	0
Leverage/output	3.19	0.02	1.54	0.10	0.71	1276.6	−0.77	−893.8	0.97	0.67	0.98	0
Land price	4.79	3.64	3.71	3.63	0.005	0.05	0.008	0.07	2.63	2.63	2.63	2.66
Land price/output	2.65	3.87	3.64	3.82	0.03	1.43	0.06	1.4	0.91	0.88	0.87	0.90

NP: No policy

Table 8: Additional empirical moments for DSGE calibration

Definitions	Empirical moments	No policy	95% LTV	Source and notes
Autocorrelation – land price	0.93	0.95	0.90	Andersen (2022), general land price index, deflated. 1996–2019 deflated.
Autocorrelation – consumption	0.87	0.87	0.69	Penn. World Table 10.0, real household consumption. 1996–2019.
Autocorrelation – leverage	0.97	0.99	0.99	OECD Household debt. 1996–2019
Autocorrelation – policy rate	0.91	0.88	0.88	BIS Central bank policy rates. 1996–2019.
Autocorrelation – credit	0.90	0.91	0.76	BIS Credit to the non-financial sector, deflated. 1996–2019.
Autocorrelation – lending rate	0.92	0.91	0.76	Danmarks Nationalbank, Realized mortage rates including fees. 2003–2019
Correlation (cons, credit)	0.95	0.87	0.55	
Correlation (cons, lending rate)	−0.58	−0.87	−0.55	
Correlation (output, policy rate)	0.23	0.42	0.34	
Correlation (land price, lending rate)	−0.80	−0.95	−0.90	
Correlation (credit, lending rate)	−0.75	−1.00	−1.00	

Figure 24: Interest rate (above), credit (middle) and bank capital (below) across scenarios. Source: Own calculations.