The Amortization Elasticity of Mortgage Demand*

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Abstract

We study the causal impact of amortization payments on household borrowing. We argue that forced amortization payments are costly in standard economic models and therefore affect credit demand. Exploiting notches in the Swedish amortization requirement, a macroprudential policy, we find that new borrowers reduce their loan-to-value ratios by 4-5 percent in response to a 1 percentage point higher amortization rate. We show that the effect is driven by lower borrowing and that a large share of borrowers lower amortization payments to avoid violating payment-to-income constraints. Our results are relevant for macroprudential policy and for understanding borrowers' mortgage choice.

JEL Classification: G51, G21, E21, E6

Keywords: Amortization payments; Mortgage borrowing; Macroprudential policy; Bunching

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1 Introduction

Mortgage loans are typically the largest household liability (Badarinza *et al.*, 2016). Signing up for a mortgage loan commits the borrower to a long period of mortgage payments, which in most countries are composed of both interest and amortization payments. The amortization payments are designed to build up home equity by paying down the loan over time, and are typically seen as a form of savings. Importantly, however, borrowers often have limited choice over the minimum amounts that they have to amortize, and these forced payments can easily comprise a substantial portion of total mortgage payments. For instance, amortization payments are 55 percent of mortgage payments in the first year for a 30-year annuity loan with an interest rate of 2 percent, and this share grows over time.

Many standard models in finance and economics imply that forced amortization payments are not simply a form of saving, but can also represents a cost to borrowers. As one of several examples that we discuss, forcing a young household with growing income to amortize may cause a sub-optimally high saving rate, a utility cost in any standard consumption model (Cocco, 2013). Alternatively, a borrower may wish to save in risky assets instead of amortizing because of the higher expected return, or may wish to invest in a diversified portfolio to reduce risks. Forcing this borrower to amortize instead would reduce expected returns, lower diversification and worsen liquidity.[1] These models all imply that amortization payments can be costly, and therefore should affect affect borrowing decisions in a manner similar to interest rates.

Estimating the causal impact of amortization payments on borrowing is challenging, however, due to a lack of plausible exogenous variation in amortization rates. Borrowers could select into different mortgage products (Garmaise, 2013), or borrowers could choose an interest-only mortgage to capitalize on house price expectations (Barlevy & Fisher, 2020). We overcome the empirical challenge by documenting considerable bunching in response to non-linear jumps in amortization payments. We study a macroprudential policy introduced in Sweden in 2016,

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[1] The literature on the determinants of mortgage borrowing is vast. See for example Bhutta & Keys (2016), DeFusco & Paciorek (2017), Fuster & Zafar (2020), Bhutta & Ringo (2020), Di Maggio *et al.* (2017), Andersen *et al.* (2020), Gomes *et al.* (2021) and citations within. Several recent studies have examined the role of interest-only mortgages for house price growth (Andersen *et al.*, 2019; Bäckman & Lutz, 2020b; Dokko *et al.*, 2019; Karpestam & Johansson, 2019), and for savings and consumption decisions (Cocco, 2013; Bäckman & Khorunzhina, 2019; Bernstein & Koudijs, 2021; Kuchler, 2015; Larsen *et al.*, 2018; De Stefani & Moertel, 2020), but none provide a credible estimate of how much amortization payments affect borrowing. Hull (2017) construct a theoretical model that shows that amortization requirements are ineffective at reducing debt levels, but does not provide empirical estimates. Moreover, Ganong & Noel (2020) find that mortgage maturity extensions that increase liquidity have large effects on default and consumption, an effect that is largely driven by lower amortization payments.

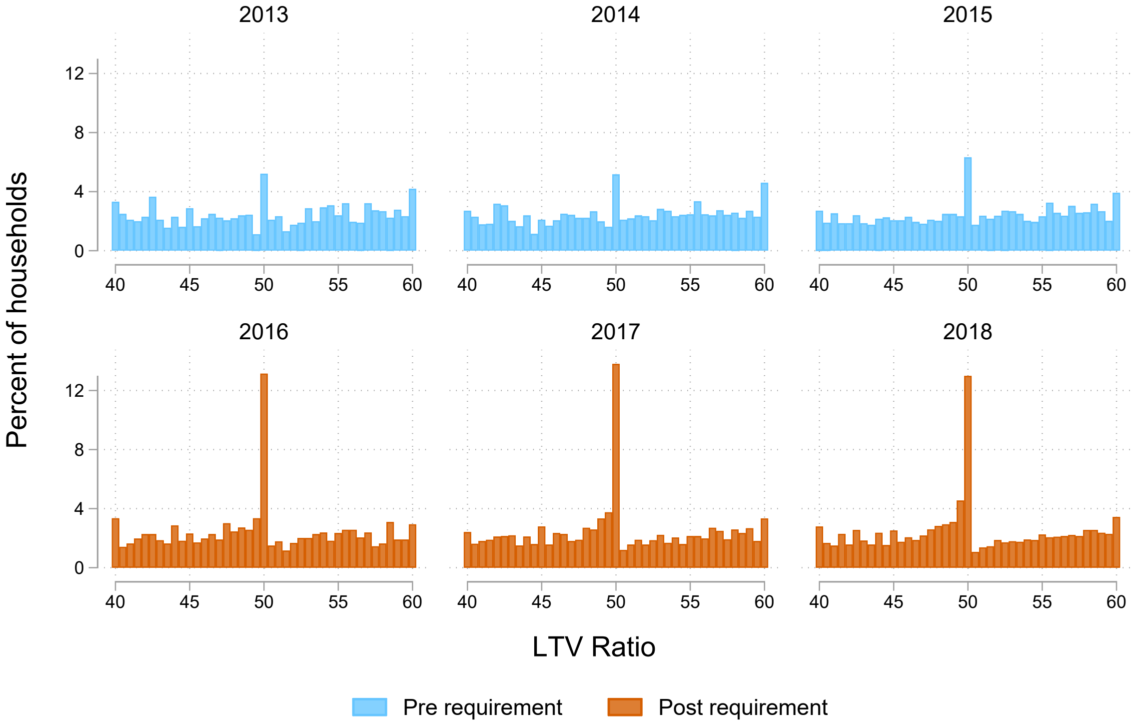

Figure 1. LTV distributions around the lower amortization requirement threshold

Notes: The figure plots the percent of borrowers per loan-to-value bin for each year. We use data from the Mortgage Survey by the Swedish Financial Supervisory Authority. The dataset contains information about all new mortgage loans issued during a two week window in the fall for each year. Loan-to-value ratios are calculated using consolidated household mortgage debt levels divided by the value of the collateral. Collateral values are supplied by the banks, and are based on either the transaction price or the banks' internal valuation models. Pre requirement years are in the top row, and post requirement years featuring a 1% higher amortization rate for LTV above 50 are in the bottom row.

the amortization requirement, which features two notches where payments on new mortgages exhibit a discontinuous jump at specified loan-to-value (LTV) thresholds. Due to the policy, the minimum amortization rate for new mortgages jumps from zero to one percent of the entire mortgage at an LTV ratio of 50 percent, and from one to two percent at an LTV ratio of 70 percent. Existing mortgages are not affected by the requirement. Since Swedish mortgages feature linear repayment schedules and are not annuity contracts, the increase in total mortgage payments at the threshold is fully due to higher amortization payments, not interest expenses. The bunching methodology was developed in public finance (Saez, 2010; Chetty *et al.*, 2011; Kleven & Waseem, 2013; Kleven, 2016), and has recently been used in the context of mortgage markets by DeFusco & Paciorek (2017) and Best *et al.* (2020). Intuitively, if amortization payments are costly, the policy would induce some borrowers to choose lower LTV ratios in order to avoid higher payments.

The identification strategy and main results are easily illustrated in Figure 1. Focusing on the lower of the two thresholds, the figure plots the percent of new borrowers in specific LTV bins in the pre- and post-requirement years. Prior to the introduction of the requirement in 2016, there is a small spike at the LTV ratio of 50 percent.[2] Once the requirement is introduced, the spike is 2.5 times as large as in the previous years, while fewer households choose LTV ratios just above 50 percent, indicating that a large number of new borrowers choose lower LTV ratios to avoid mandatory amortization payments.

As our empirical strategy, we formally estimate the amount of bunching using pre-requirement years to form counterfactuals. Our preferred specification indicates that 7.5 percent of borrowers place themselves at the lower 50 percent LTV threshold because of the higher amortization payments. Borrowers reduce their LTV ratios by 5 percent in response to the requirement. The corresponding number for the upper LTV threshold at 70 percent is 12.9 percent of borrowers and a 4 percent reduction in LTV. These estimates translates into a reduction in LTV of 0.15 to 0.25 percent for a 1 percentage point higher marginal amortization rate. While the elasticity itself is modest, the aggregate effect of changing amortization payments can be substantial. Moving from an annuity schedule to an interest-only mortgage with an interest rate of 3 percent reduces first-year mortgage expenses by 40 percent, implying an increase in borrowing of between 6 and 10 percent using the above elasticity.

The identifying assumption is that previous years provide a valid counterfactual for the LTV distribution that would occur in the absence of the requirement. We first follow DeFusco *et al.* (2020) and show that bunching for each pre-requirement year can be well approximated by using other pre-requirement years to form the counterfactual distribution in placebo tests. We also verify that our results are robust to using the standard approach of fitting a flexible polynomial to the observed distribution to estimate the counterfactual distribution (Chetty *et al.*, 2011; Kleven & Waseem, 2013). Our results are in general more conservative compared to the standard parametric approach.[3] Second, we also verify that there was no change other

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[2] In our view, the most likely explanation for the small spike at the notch is a preference for round numbers, which can also be observed at LTV ratios of 60 and 40 percent. While the spike could be related to other factors, we find no evidence consistent with an increase in costs around the threshold. In addition, as we use previous years to estimate the counterfactual distribution, any round-number bunching or spike at this threshold that is constant over time would be differenced out.

[3] Before 2016 the Swedish Bankers' Association recommended that households amortize on the part of the mortgage with an LTV ratio above 70 percent. While this was only a recommendation and represents an increase in the marginal amortization rate in the pre-requirement period, as opposed to an increase in the average amortization rate in the post-requirement period, we note that this represents a potential source of downward bias. If households were already choosing an LTV ratio of 70 percent because of the recommendation, our pre-reform distribution will already reflect this, which will lower the estimated effect at the upper threshold. For the upper threshold, therefore, the estimate is conservative. At the lower threshold, there is no such confounder, as

than the requirement that causes households to bunch at the threshold in the post-requirement period. We consider several factors unrelated to the requirement that could potentially affect the LTV distribution but conclude that none can explain our results. Most importantly, we find flat interest rates around the notches for all years in our sample, evidence inconsistent with jumps in the mortgage rate at the amortization requirement thresholds.

What is the mechanism behind the change in LTV ratios? Is the reduction in LTV due to a smaller loan, L, or a higher valuation, V? We argue that because of institutional design, banks do not have an opportunity to manipulate property valuation. Moreover, we find similar levels of bunching when we examine loans made to new home buyers, who presumably are not going to pay more for a house to avoid making amortization payments. We therefore conclude that the margin of adjustment is the loan itself. The question then becomes why households adjust their loans to conform to the requirement. We show that about 26 percent of borrowers who bunch face binding credit constraints due to the discretionary income limit imposed by Swedish banks. Moreover, 60 percent of borrowers would experience a drop in their discretionary income by at least 30 percent. These numbers suggest that a majority of new borrowers at the threshold deliberately choose a lower LTV ratio to free up monthly cash flow, either because they are forced by the bank or because higher amortization payments would entail too great a reduction in their disposable income. Similar discretionary limits are also imposed in the United States (Dodd-Frank's Ability-to-Repay requirement) and elsewhere, implying a generalizable finding: amortization payments affect payment-to-income constraints. While amortization payments have recently been included in several theoretical models that incorporate realistic features of the mortgage contract (Greenwald, 2017; Kaplan *et al.*, 2020; Gorea & Midrigan, 2017), their role in relaxing credit constraints has generally been under-studied. An exception is Bhutta & Ringo (2020), who study how relaxed payment constraints affect home buying. Moreover, these results suggest that imposing payment-to-income constraints, like many countries have done in recent years (Alam *et al.*, 2019), may cause borrowers to reduce debt repayments. Bernstein & Koudijs (2021) show that amortization payments are crucial for building wealth, implying that imposing payment constraints could impede wealth accumulation if households reduce amortization payments to comply.

The bunching estimate identifies a local average treatment effect around the notches. Impor-

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this threshold appeared as a surprise.

tantly, however, none of the explanations for why amortization payments are costly is specific to a Swedish context or to the area around the thresholds, suggesting that our results generalize to other parts of the distribution and to other countries. In addition, the aggregate trend in credit growth strongly suggests that the effect we identify is global. The amortization requirement coincided with a sharp reduction in the growth rate of house prices and credit that is difficult to explain otherwise. For example, the interest rate is flat between mid-2015 and 2020. The aggregate-level evidence thus suggests that the effect that we identify is not simply a local effect around the threshold, but that it applies throughout the distribution.

In conclusion, our main contribution is to provide credible and novel evidence that amortization payments affect household borrowing. In the words of Gomes *et al.* (2021), we contribute by providing novel evidence on the true constraints for households when it comes to the complex world of mortgage choice. Borrowers act as if amortization payments are costly, and they are willing to trade off larger loans for lower payments. Our results are relevant for understanding the role played by mortgage innovation in the financial crisis. Lower amortization payments were a common feature of mortgage product innovations during the run-up to the Great Recession in the United States and elsewhere. Interest-only mortgages, option ARMs, and balloon mortgages all feature lower amortization payments in the first years after origination, and Justiniano *et al.* (2021) report that the take-up of such products increased from 3 percent of origination in 2000 to 44 percent of origination in 2005. Scanlon *et al.* (2008) report that a large number of countries introduced interest-only mortgages between 1995 and 2005.[4] Moreover, these products disappeared in 2008 in the United States (Amromin *et al.*, 2018). While the decline in the real interest rate is not sufficient to explain the run-up in mortgage debt and house prices (Glaeser *et al.*, 2012), our results suggest that the increased availability and subsequent disappearance of non-traditional mortgages with lower amortization payments can make up at least a part of the unexplained movements in household debt and house prices.

Moreover, the results are particularly important in today's low interest rate environment, as amortization payments account for a larger share of total payments when interest rates are low (see Table C1). Looking forward, policymakers looking into adjusting amortization rates should be aware that such a reform could have large consequences for credit growth. This channel comes

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[4] Both Barlevy & Fisher (2020) and Amromin *et al.* (2018) report that just under 30 percent of mortgage origination in 2005 and 2006 in the United States consisted of products with lower amortization payments. Between 1995 and 2005, Scanlon *et al.* (2008) document that Australia, Denmark, Finland, Greece, Korea, and Portugal introduced IO mortgages or similar products, out of the 12 countries that the authors provide data for.

in addition to the direct cash-flow effects studied in Campbell *et al.* (2020), who analyze a model where the option to stop amortization payments in a recession helps stabilize consumption and reduces the interest rate. Our results therefore also contribute to the expanding literature on the effect of macroprudential policies (e.g. Cerutti *et al.*, 2017; Bernstein & Koudijs, 2021; Laufer & Tzur-Ilan, 2019; Van Bekkum *et al.*, 2019; Peydró *et al.*, 2020).[5]

The rest of the paper is organized as follows. Section 2 provides background on the Swedish mortgage market and the amortization requirement, and discusses our data. Section 3 presents several arguments for why amortization payments affect household borrowing along with a simple theoretical framework to provide intuition for our empirical strategy laid out in Section 4. Section 5 provides the main results and discusses mechanisms, and 6 assesses several threats to identification. Finally, Section 7 discusses how housing markets reacted to the policy and Section 8 concludes.

2 The Amortization Requirement

The Swedish housing and credit markets experienced rapid growth in the early parts of the 2010s. House prices increased by 31 percent between 2011 and 2015, and the credit growth rate increased from around 5 percent in 2012 to over 8 percent in 2015. Concerned with financial and macroeconomic stability, the Swedish Financial Supervisory Authority (*Finansinspektionen*) introduced new regulation with the goal to reduce debt levels. The purpose was to limit macroeconomic risks posed by high household debt levels. Households with higher LTV ratios were considered a higher risk and consequently had to reduce their debt level more rapidly. The Financial Supervisory Authority (FSA) and the Central Bank (Riksbank) had previously discussed amortization requirements (see e.g. Riksbank, 2012). Even though the Swedish Bankers Association (SBA) had issued recommendations on amortization rates to its members, the Financial Supervisory Authority announced that they would propose new regulation about amortization payments in November 2014. The amortization requirement was finally proposed in

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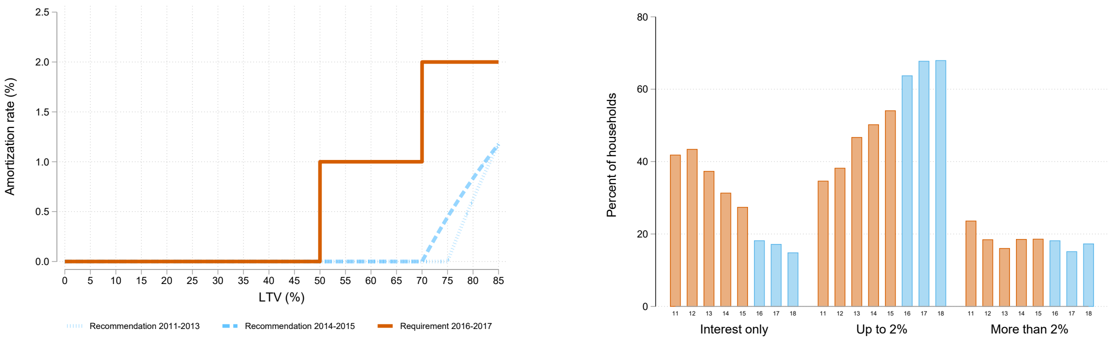
[5] There are several studies on the effect of the Swedish amortization requirement, in addition to the international literature on macroprudential policy. Andersson & Aranki (2017) use a difference-in-difference strategy to show that the amortization requirement reduced household borrowing. Andersson & Aranki (2019) analyze the additional amortization requirement introduced in 2018 that mandated that mortgages with a debt-to-income ratio above 4.5 had to be amortized by an additional percentage point. The authors show that households are borrowing on average 8.5 per cent less than they otherwise would have done and that they are also buying less expensive homes.



a) Required Amortization Rates

b) Actual Amortization Rates by Year

Figure 2. Actual and Required Amortization Rates for new mortgages

Notes: Panel a) plots required or recommended amortization rates by LTV ratios for different periods. The blue lines plot the non-binding recommendations from the Swedish Bankers' Association. Panel b) plots the percentage of new borrowers who amortize a certain percentage for each year.

December 2015, and the law went into effect in June 2016.[6]

The Swedish amortization requirement mandates that all new mortgages issued after June 1st, 2016, with LTV ratios above 50 percent have to be amortized. New mortgages with LTV ratios below 50 percent are exempt. The requirement, along with the previous recommendations from the SBA, is summarized in panel a) of Figure 2. Before 2016, the SBA recommended that highly levered loans be amortized starting from LTV ratios of 75 percent (2011-2013, blue line) and 70 percent (2014-2015, red line), respectively. Compared to the requirement that was introduced in 2016, the recommended rates were lower and implied an increase in the *marginal* amortization rate. The implemented amortization requirement instead mandates that new borrowers must amortize at least 1 percent per year on any mortgage where the initial LTV ratio exceeds 50 percent, and at least 2 percent per year on any mortgage where the LTV ratio exceeds 70 percent. Since continuous re-valuation of property values could have pro-cyclical effects, the law mandates that the valuation can only be made every 5 years. Moreover, any re-valuation has to be based on changes to the property value that are due to renovation or rebuilding of the property, not due to house price changes. A borrower can be granted an exception to the requirement due to extenuating circumstances, such as unemployment, illness, or a death in the family. These exceptions have to occur after the origination of the loan.[7]

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[6] An additional amortization requirement was introduced on March 1, 2018, and mandates that any mortgage where the debt-to-income ratio is above 4.5 has to be amortized by an additional percentage point.

[7] Due to the spread of the Corona-virus in 2020, the FSA allowed exceptions to the requirement for all borrowers until June 2021. See `https://www.fi.se/en/published/press-releases/2020/banks-may-grant-all-mortgagors-amortisation-exemption/`. For an analysis of the exemption, see Andersson & Aranki (2021).

2.1 Data

We use data from the Mortgage Survey (Bolåneundersökningen) from 2011 until 2018. The FSA collects this data directly from the eight largest Swedish banks as part of its micro- and macroprudential mandate. The dataset contains information on all new mortgages issued by these banks during a certain number of days between August and October. The FSA varies the exact dates and announces the dates afterward to surprise banks and prevent them from applying different credit standards during these survey dates.[8] The survey includes household-level data on (gross and disposable) incomes, total debt divided into secured and unsecured loans, and certain household characteristics, as well as loan-level data on loan size, the interest rate, monthly amortization payments, and value of the collateral. The data also includes the bank's calculation of discretionary income, evaluated at a stressed interest rate. Collateral values are usually based on banks' internal valuation models, which use previous transaction prices and local hedonic price indices. For new mortgages to new home buyers, the transaction price is typically used. Less than 2 percent of new mortgages are collateralized by more than a single property. We use the total mortgage debt divided by collateral value to calculate LTV ratios. We are unable to link our mortgage data to other register data as households are reported anonymously. Table C2 in Appendix C provides summary statistics.

2.2 Amortization rates

The requirement had a large impact on amortization rates for new borrowers. Panel b) in Figure 2 plots how the share of new borrowers that amortize at a certain rate changes over time. The share of new borrowers with an interest-only mortgage drops from approximately 40 percent in 2011 and 2012 to less than 20 percent in 2016 and 2017. Concurrently, the share of new borrowers who amortize up to 2 percent increased from 15 percent in 2011 to 50 percent in 2017. This jump in payments is consistent with the amortization requirement affecting amortization rates.

Figure 3 illustrates how amortization rates vary by LTV ratio, before and after the requirement. Interestingly, the amortization rate exhibits a sharp decline just below the threshold in years where the requirement was in place, consistent with borrowers placing themselves at the thresh-

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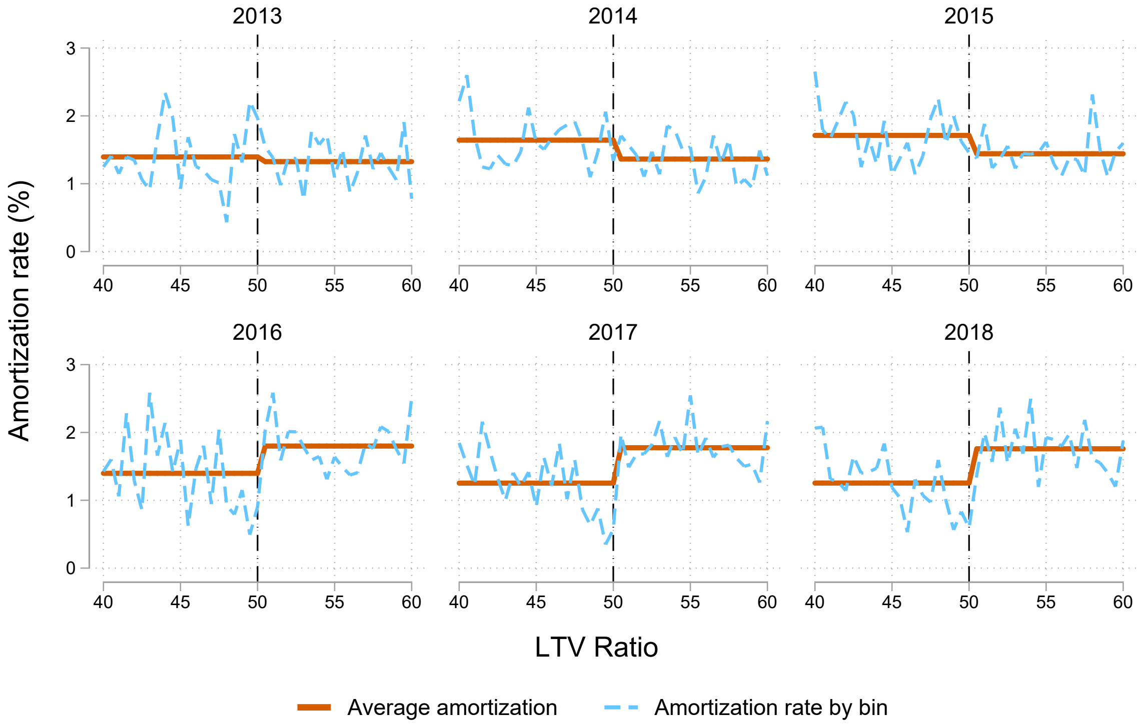
[8] The number of days and exact dates vary per year. Typically, banks report all issued mortgage loans for 5 days in late August and another 5 days in early October. To the extent the chosen days are representative for the rest of the year, the sample is representative of the flow of new mortgage loans.

a) Lower Threshold



b) Upper threshold

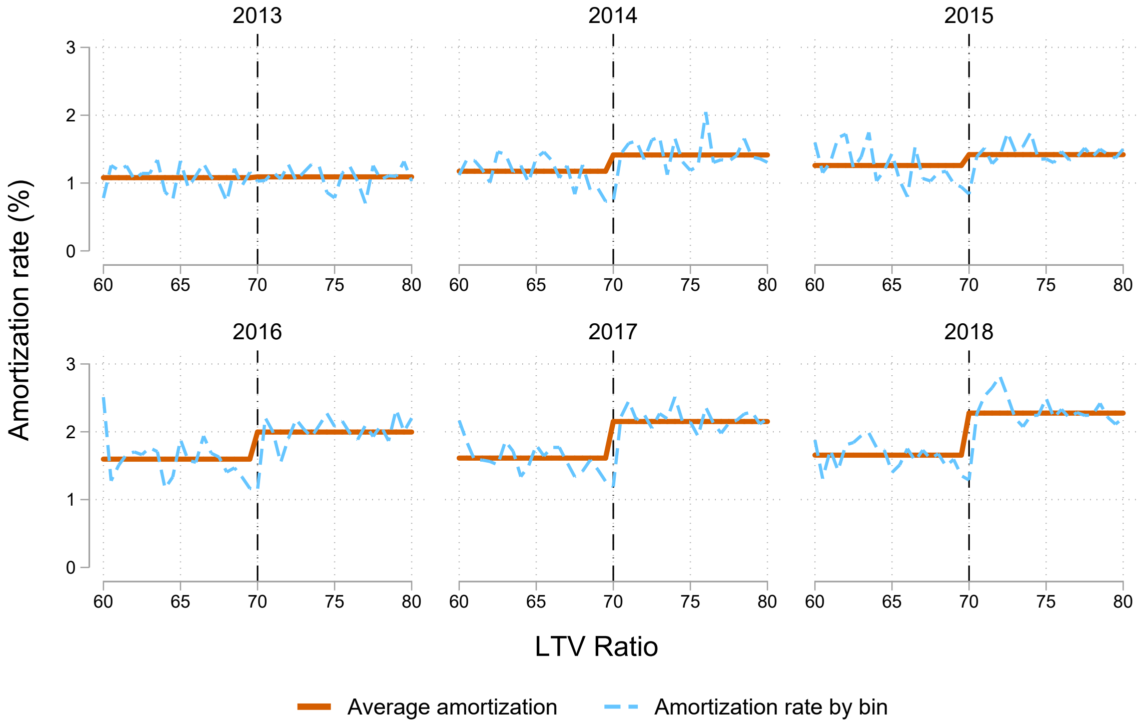


Figure 3. Amortization rate by year and LTV ratio for both thresholds

Notes: The figure plots the average amortization rate by LTV bin (blue dashed line) and the average amortization rate (orange solid line) above or below the LTV threshold marked by the black dashed line. Panel a) plots these around the lower threshold, and panel b) around the upper threshold.

old to avoid making amortization payments. There is no such effect for the lower threshold in pre-requirement years.

2.3 Swedish mortgages

The Swedish mortgage market system works as follows (see e.g. Riksbank, 2014). Banks provide mortgage credit to borrowers directly, subject to a credit assessment. Mortgage debt is full recourse, with unlimited liability of the borrowers and lifetime wage garnishing to compensate lenders in case of default. All Swedish mortgages are subject to a maximum loan-to-value ratio of 85 percent as of 2010, and interest payments are deductible against capital gains and labor income. Mortgage rates are set by the banks. Several Swedish banks use (or have used) a system where the portion of the mortgage with an LTV ratio above 75 percent has a higher interest rate (a so-called "top loan").[9]

Importantly, Swedish mortgages are *not* annuity contracts. Instead, total mortgage payments consist of the sum of interest payments and amortization payments. Total interest payments are simply the interest rate on the mortgage times the outstanding mortgage debt. Similarly, total amortization payments are the amortization rate times the mortgage debt *at origination* (i.e. the loan is repaid linearly over time). This implies that the increase in total mortgage payments at the threshold is fully due to higher amortization payments.

Swedish banks are required to assess the borrower's financial status, including their ability to pay borrowing expenses. This is enforced through a *discretionary income limit*, which requires the household to have enough disposable income to afford consumption and housing expenses (including amortization payments). This limit, which is functionally equivalent to a payment-to-income constraint, is calculated using a stressed interest rate to ensure that borrowers' finances are resilient to higher interest rates. When applying for a mortgage, Swedish borrowers first seek a "borrowing pledge" from their preferred bank. On the pledge, the bank states the maximum amount that they are willing to lend to the borrower, given for example household income and household size. Importantly, this pledge is given *before* the borrower makes a housing purchase. As we discuss later, this makes manipulation of the LTV ratio from the bank unlikely.

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[9] Top loans refer to the slice of the mortgage loan not eligible for funding with covered bonds. Covered bond regulation in Sweden puts a maximum LTV ratio of 75 percent for residential real estate.

3 Previous literature and theoretical background

In this section, we present several arguments for why amortization payments affect household borrowing and present a simple theoretical framework to provide intuition for our empirical strategy. The arguments are mainly derived from standard models in economics and finance and provide rational explanations for why households may prefer lower amortization payments if given the choice. Our theoretical framework incorporates a consumption smoothing argument, but we note that this framework excludes many of the reasons why households may wish to avoid making amortization payments. Instead of providing a unified theoretical framework that incorporates all the below arguments, we simply note that amortization payments are costly for several reasons.

First, forced amortization payments may lead to sub-optimal saving rates. In life-cycle consumption models, the optimal savings rate depends on the relationship between current and future income. Since amortization payments are a form of savings, certain borrowers may wish to avoid payments entirely and instead consume. Forced amortization payments induce a cost on households whose optimal savings are below required amortization payments (Piskorski & Tchistyi, 2010). This applies in particular to older households who intend to live off their savings, as their current income is lower than their permanent income, and to younger households with rising incomes. Consistent with this theory, Cocco (2013) finds that young borrowers with rising income profiles are more likely to choose mortgages with smaller repayment, and Bäckman & Lutz (2020a) report that a large fraction of borrowers above the retirement age in Denmark use an interest-only mortgage. Essentially, not all households want to save, and by placing themselves at the threshold borrowers can achieve a lower savings rate and higher consumption.

Second, even if households want to save, they do not necessarily wish to save by paying down the mortgage. A borrower may wish to save in risky assets because of the higher expected return or may wish to invest in a diversified portfolio to reduce risks. The return on amortization payments is equal to the mortgage rate, and saving by paying down the mortgage concentrates savings in less diversified and more illiquid housing assets, compared to for example stock holdings. By reducing amortization payments, the borrower may be able to improve portfolio returns, increase diversification and improve liquidity.

Third, banks in Sweden evaluate a borrower's ability to repay based on a discretionary income limit, where the borrower has to have sufficient income to meet expenses. The calculation is done to ensure that after-tax household income is sufficient to cover subsistence consumption, borrowing payments, and housing expenses. Importantly, borrowing payments comprise both interest and amortization payments. In practice, this calculation functions like a payment-to-income constraint (Grodecka, 2020). Borrowers facing binding constraints may be unable to borrow more because of the discontinuous jump in mortgage payments above the LTV threshold (Bäckman & Lutz, 2020b).

Fourth, households might suffer from temptation, and therefore want to save in illiquid assets, for example by paying down their mortgage. Attanasio *et al.* (2020) present a two-asset model with temptation preferences that generates a demand for illiquidity (see also Schlafmann, 2020). Mandatory amortization payments serve as a form of commitment and thus increase household savings. If households could choose their amortization payment, however, they may reasonably disagree with the amount of commitment implied by the amortization requirement. As a consequence, some households may reduce their borrowing to attain a lower level of commitment. Households with higher temptation needs can always amortize more than the requirement stipulates. Consistent with this theory, Figure 2 show that the share of households amortizing more than 2 percent a year is not affected by the requirement.

Fifth, households may not realize that amortization payments are savings and may instead consider them a cost, similar to interest payments. Selecting an LTV ratio to minimize amortization payments is then a rational response, even though it comes from a misunderstanding of amortization payments. Survey results reported in SBAB (2018) indicate that more than half of Swedish households does not consider amortization payments to be savings: 44 percent stated that amortization payments were savings, 38 percent stated that they were a cost, and 18 percent did not know what amortization payments were (SBAB, 2018). The survey was conducted on a representative sample of the Swedish population but did not distinguish between borrowers and non-borrowers. Older Swedes were more likely to see amortization payments as savings (45 percent for 36-55 years old versus 40 percent for 23-35 years old). Full results from the survey are reported in Table C3.

Sixth, households may want to maintain a high debt level to receive higher mortgage interest deductions to reduce the tax burden. Finally, interest-only mortgages are beneficial for borrowers who wish to speculate on rising house prices (Barlevy & Fisher, 2020). By maintaining high debt levels, a borrower who does not amortize keeps the default option high. In a Swedish context, this channel is likely limited, as enforced full recourse mortgages remove the option of strategic default. This feature of the Swedish mortgage market also changes the calculation on the mortgage supply side, as banks do not have to estimate the probability of strategic default and loss-given-default in the same manner as they would in the United States.[10] An interest-only mortgage may even be preferred by Swedish banks, as this maintains high debt levels and thus high interest income for a longer period while keeping costs for mortgage origination low.

An amortization requirement can also lead to *higher* LTV ratios (Svensson, 2016). An unconstrained borrower can simply borrow more than necessary, invest excess borrowing in a savings account, and make amortization payments from the savings account. In this setting, a borrower's net debt (debt minus savings) is the same regardless of the amortization requirement, yet LTV ratios will be higher. We shall return to this below, where we show that the implied distribution of LTV ratios in that model will be different from the empirical distribution that we observe in the data.

3.1 Simple theoretical framework

In this section we present a short discussion of the shape of the distribution of LTV values under a linear amortization schedule and a notched amortization schedule. A simple three-period model of mortgage choice that forms the basis for the below discussion can be found in Appendix A. In this stylized model, households just above the threshold optimally choose to borrow less under a notched amortization schedule. LTV ratios therefore decrease, as households reduce their borrowing to achieve lower payments.

Figure 4 plots simulated LTV distributions when households face a linear amortization schedule (left panel) or a notched schedule (right panel). Under the linear schedule, the amortization rate is constant, and the resulting LTV distribution $g_{linear}(LTV)$ is uniform[11]. In the notched schedule, the amortization rate increases by $\Delta\alpha$ whenever the household's LTV ratio exceeds the threshold at $\overline{LTV}$. As a result, a fraction of households that would have located to the right

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[10] Note that this implies that a borrower in the US may value an interest-only mortgage *more*, as some states allow the option to default.

[11] Figure 4 is generated assuming uniformly distributed initial wealth levels across households.

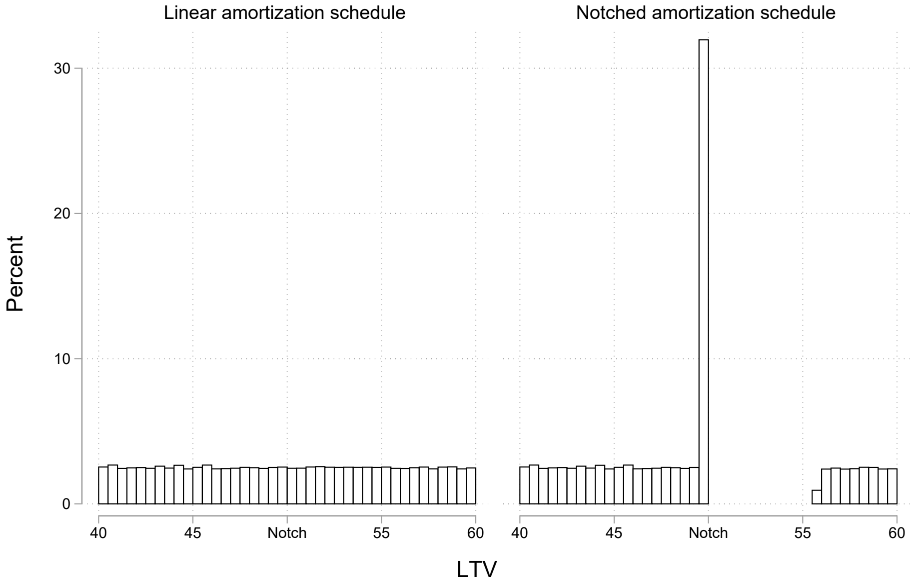

Figure 4. LTV distribution from the model

Notes: The figure plots the LTV distribution using simulated data from a simple three-period model of mortgage choice. In the left panel, households with uniformly distributed wealth levels face a linear amortization schedule. In the right panel, the same households face a notched amortization schedule, where the amortization rate jumps when LTV exceeds the notch at 50. See Appendix A for details.

of the threshold $\overline{LTV}$ in the linear case, will now find it optimal to borrow less in period 1. For households close enough to the threshold, borrowing exactly $\overline{LTV}$ is optimal. These households are willing to invest a larger share of their initial wealth into housing to avoid paying higher rates of amortization.

Comparing the left and right panels in Figure 4, the right panel is characterized by a spike at the threshold, and a missing mass to the right of the threshold, whilst being identical to the left of the notch. We can calculate the number of households bunching at the threshold as:

$$B = \int_{\overline{LTV}}^{\overline{LTV}+\Delta LTV} g_{linear}(LTV)dLTV \approx g_{linear}(\overline{LTV})\Delta LTV \tag{1}$$

where the approximation assumes a constant density at the notch. Equation (1) implicitly defines ΔLTV for the *marginal buncher*: the household located furthest away from the threshold in the linear case that still chooses to bunch at the threshold with the notched schedule. The marginal buncher would have borrowed $\overline{LTV} + \Delta LTV$ with a linear amortization schedule, but is indifferent between borrowing $\overline{LTV}$ and the best interior point beyond the threshold. The marginal buncher, therefore, tells us how much initial wealth households are willing to invest in housing to avoid an increase in the amortization rate given by $\Delta\alpha$.

From our data, we can estimate both $\widehat{B}$ and $\widehat{g_{linear}}$, and hence we can solve for ΔLTV :

$$\Delta\widehat{LTV} = \frac{\widehat{B}}{\widehat{g_{linear}}(\overline{LTV})} \tag{2}$$

The above equation shows the intuition behind our identification strategy. With an estimate of both the amount of bunching $\widehat{B}$ and the counterfactual density around the notch $\widehat{g_{linear}}(\overline{LTV})$, we can calculate the behavioral response $\Delta\widehat{LTV}$, the reduction in LTV ratios induced by the amortization requirement. The reduction in LTV ratios that we estimate then corresponds to the intensive margin response around the notch.

In the stylized theoretical model, ΔLTV identifies the most extreme bunching household, i.e. the household with the lowest wealth that still bunches at the threshold. In practice, there are likely differences between these households that our simple model does not capture. Suppose, for example, that we introduce another source of heterogeneity, denoted by z, which captures differences in incomes, discount rates, housing preferences, utility functions, or some other variable. Equation (1) would then generalize to

$$B = \int_z \int_{\overline{LTV}}^{\overline{LTV}+\Delta LTV_z} g_{linear}(LTV, z) dLTV dz \approx g_{linear}(\overline{LTV}) E(\Delta LTV_z)$$

The bunching estimate is now approximately proportional to the *average* behavioral response $E(\Delta LTV_z)$ among bunching households for a given level of z. We can therefore still back out an estimate of the average reduction in LTV ratios, $E(\Delta LTV_z)$.

In an alternative framework, Svensson (2016) shows that higher amortization payments would instead increase borrowing. In this model, households would borrow more in response to higher amortization payments, invest the additional borrowing in a savings account and make amortization payments out of this savings account. The result would be an increase in debt and LTV ratios, with unchanged consumption. In Appendix A, we show that in Svensson's model, a notched amortization schedule would lead to an LTV distribution that features no bunching at the threshold. While the lack of bunching is in contrast to the empirical distribution, we cannot rule out that some households indeed lever up, and behave according to that model.

4 Empirical Strategy

We now describe our approach to estimating the counterfactual distribution and the amount of bunching induced by the amortization requirement. Our empirical strategy hinges on the estimation of the counterfactual LTV distribution that would have occurred in the absence of the amortization requirement. We exploit the availability of repeated cross-sections to estimate the counterfactual distribution. In other words, we compute a *difference-in-bunching* estimate, where the distribution observed in the years before the requirement will serve as the counterfactual distribution in the post-requirement years. Our identifying assumption is that for each bin, the *fraction* of loans in the post-reform period would have been equal to the fraction of loans in the pre-reform period in the absence of the policy: no other change or policy caused the distribution of LTV ratios to shift between the pre- and post-reform periods. We verify that this assumption is plausible in Section 6.

We note that this is a different assumption than in the empirical bunching literature, where it is more common to assume that the counterfactual distribution is smooth in the absence of the policy change (see e.g. Kleven & Waseem, 2013). The advantage of our approach is that the spikes at LTV ratios of 50 and 70 percent observed before the introduction of the amortization requirement are accounted for. These spikes are presumably due to round-number bunching (Kleven, 2016; Best *et al.*, 2020) or the SBA's recommendation (see Figure 2). Since the spike at 50 is larger than the spikes at other potential round numbers in pre-requirement years, it is more conservative to use the difference-in-bunching approach. For completeness, we do provide results using the standard polynomial approach below, and show that our results are indeed conservative.[12]

We group borrowers into LTV bins with a width of half a percentage point. The goal is to estimate the counterfactual fraction of borrowers in each LTV bin j in the post-requirement period had the amortization requirement not been introduced, denoted $\hat{n}_j^{post}$. We calculate the fraction of borrowers in each LTV bin instead of using the count of borrowers since we have different sample sizes for each year. Since the sample size reflects the number of days the mortgage survey collects data for, the count is uninformative. And as we are using the previous years to form the counterfactual distribution, using the count instead may result in level differences solely due to differences in sample size. We have verified that using the fraction

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[12] Appendix B provides details on the flexible polynomial approach we use.

instead of the count does not affect our empirical estimates.

We measure the amount of bunching $\widehat{B}$ as the difference between the observed and counterfactual bin fractions in the region at and to the left of the threshold located at R:

$$\widehat{B} = \sum_{j=L}^{R} (n_j^{post} - \hat{n}_j^{post}) \tag{3}$$

The amount of bunching is equal to the fraction of additional borrowers who place themselves at the threshold, beyond what the counterfactual distribution based on previous years would predict. We also report the excess mass at the threshold relative to the counterfactual distribution:

$$\widehat{b} = \sum_{j=L}^{R} (n_j^{post} - \hat{n}_j^{post}) / \sum_{j=L}^{R} \hat{n}_j^{post} \tag{4}$$

Similarly but to the right of the threshold, the amount of missing mass is equal to:

$$\widehat{M} = \sum_{j>R}^{U} (n_j^{post} - \hat{n}_j^{post}) \tag{5}$$

The missing mass is equal to the difference between the observed and counterfactual distribution in the region to the right of the threshold. Note that borrowers making up the missing mass could either shift towards the threshold (intensive margin) or exit the market completely (extensive margin). If all borrowers in the region defining the missing mass bunch at the threshold, the intensive margin effect is equal to the amount of bunching. If some borrowers drop out of the market because of the requirement, this is equivalent to stating that not all borrowers shift towards the threshold. In our setting, there can be intensive margin responses for households located to the right of the notch that do not bunch, which makes estimating the extensive margin difficult. For example, a household might choose an LTV ratio of 55 percent, whereas it (counter-factually) would have chosen an LTV of 60 percent had there been no notch. These households fill up the missing mass to the right of the notch.

We use the bunching estimate $\widehat{B}$ to calculate the behavioral response to the requirement, ΔLTV, using equation (2). The equation states that the response to the requirement by the marginal borrower, ΔLTV, is equal to the amount of bunching $\widehat{B}$ divided by the counterfactual density around the notch:

$$\Delta \widehat{LTV} = \frac{\widehat{B}}{\widehat{g_{linear}}(\overline{LTV})}$$

We calculate bootstrapped standard errors for all parameters by drawing random samples with replacement from the full sample of borrowers. We then re-calculate the LTV distribution and re-estimate the parameters at each iteration.

We use the estimated change in LTV from the reform to estimate the amortization elasticity of mortgage demand, described in detail in the next section. This estimate captures the intensive margin response to the amortization requirement – the response of borrowers who still choose to borrow after the requirement was implemented. We believe that this margin is sufficient to demonstrate our main idea: amortization payments are costly and affect credit demand. Identifying the extensive margin response to the reform convincingly, as in for example DeFusco *et al.* (2020), would require strong assumptions over the distribution to the right of the threshold and would require extrapolation from the threshold up until the maximum borrowing limit of 85 percent. DeFusco *et al.* (2020) estimate a convincing counterfactual distribution above their threshold from the conforming loan market. As the Swedish amortization requirement affected 90% of the new mortgage flow, we lack such a counterfactual, and instead focus on the intensive margin response.

5 Main results

This section presents the main results of the analysis. We begin by analyzing the impact of the amortization requirement on borrowing at the lower and upper thresholds, located at LTV ratios of 50 and 70 percent, respectively. We then compute elasticities and examine who seeks to avoid amortization payments.

5.1 Bunching at the lower threshold

The main result for the lower threshold is presented in Figure 5. The figure plots the observed distribution of loans by LTV ratio and the counterfactual distribution estimated from the bunching procedure around the notch at LTV ratios of 50. The estimation procedure uses LTV ratios up to 65 percent to avoid the upper threshold affecting the results. The vertical axis shows the percent of loans in each bin, where each bin is 0.5 percentage points wide. We choose $L = 48.5$ and $U = 51.5$ as our main specification (see equations (3) and (5)). Our estimates of ΔLTV, B, and M are robust to changing these limits of the excluded area in either direction. The orange solid line plots the empirical distribution, i.e. the distribution in 2016-2018, and

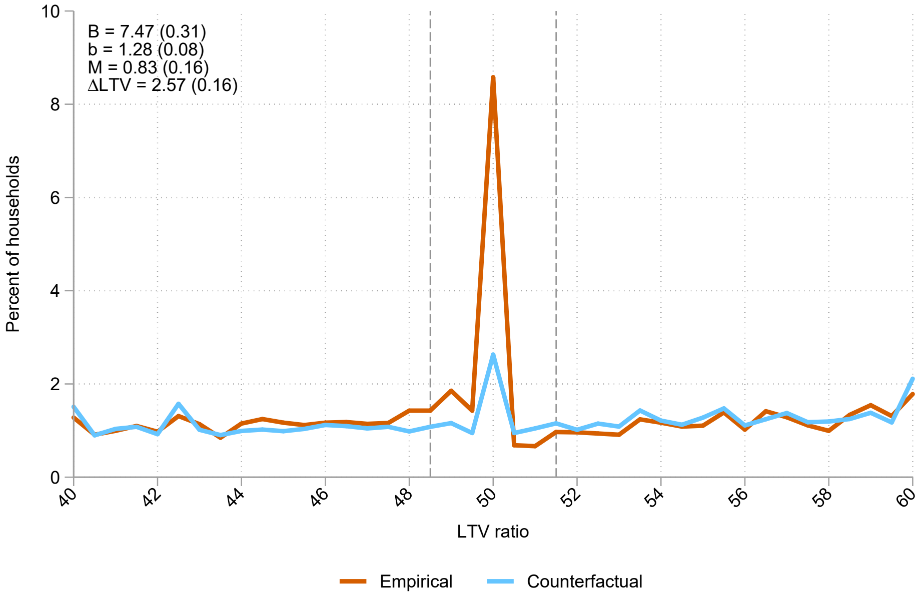

Figure 5. Bunching at LTV=50

Notes: The figure plots the empirical and counterfactual density of mortgage loans by LTV ratio. The estimation is carried out using all loans with LTV ratios between 20 and 65 percent, but only shows the distribution between 40 and 60. The orange line plots the empirical density, where each dot represents the percent of mortgages within each 0.5 percent LTV bin. The blue line plots the counterfactual density estimated using the procedure described in Section 4. The figure reports the estimated percent of loans that bunch at the threshold (B), the excess mass at the threshold (b), the missing mass (M), and the behavioral response by borrowers (ΔLTV). The calculation of these numbers is described in Section 4. Standard errors are calculated using a bootstrap procedure and are shown in parentheses.

the solid blue line plots the counterfactual distribution.

There are several key results in the figure. First, the counterfactual distribution fits the empirical distribution well up to an LTV ratio of 47.5 percent and again starting from an LTV ratio of 52 percent. The difference between the two distributions comes in the area where we expect that the amortization requirement has an impact, namely around the threshold. Second, there is a considerable amount of bunching at the threshold. The bin precisely at the threshold contains approximately 9 percent of borrowers, compared to around 3 percent in the same bin in the counterfactual density. We find 7.47 percent ($\widehat{B} = 7.47$, standard error 0.31) more borrowers with LTV ratios between 48.5 and 50 percent in the post-requirement years compared to the pre-requirement years, an increase by a factor 1.28 ($\widehat{b} = 1.28$, standard error 0.08). Dividing this bunching estimate by the counterfactual distribution, we find that the marginal buncher reduces its LTV ratio by 2.57 percentage points ($\Delta\widehat{LTV} = 2.57$, standard error 0.16) in response to the requirement. Relative to the notch, this yields an approximately 5 percent decrease in borrowing. Third, there is little missing mass to the right of the requirement. We find 0.83 percent ($\widehat{M} = 0.83$, standard error 0.16) less borrowers to the right of the notch in the post-requirement years compared to the pre-requirement years. This estimate of missing mass would suggest a large extensive margin response, that is, borrowers exiting the market altogether because of the notch in amortization rates. However, as discussed previously, there can be intensive margin responses for households located to the right of the notch that do not bunch, which makes estimating the extensive margin difficult.

Interestingly, there is considerable bunching even at relatively low LTV ratios. These borrowers have access to considerable amounts of home equity, making it difficult to argue that they are facing collateral constraints related to their LTV ratio. However, they can still face credit constraints related to payments due to the discretionary income limit applied in Sweden. Bäckman & Khorunzhina (2019) show that payment constraints are more likely to bind if house value to income ratios are high, as this implies that mortgage payments are a larger share of income for a given LTV ratio.

5.2 Bunching at the upper threshold

Next, we turn to the upper threshold. Recall that there are several potential confounding effects relevant to this threshold. First, some new borrowers may already choose an LTV ratio of 70 percent in the pre-requirement years, because of a previous, albeit less strict, recommendation that households amortize on the portion of the mortgage in excess of a 70 percent LTV ratio. This presents a potential source of downwards bias in our estimates, as borrowers may bunch even in the pre-requirement period. Second, several banks offer mortgages with a higher marginal interest rate on the part of the mortgage with an LTV above 75 percent (a so-called "top loan"). This incentive was phased out over time as banks abolished the top-loan system, but did provide an incentive to bunch at a nearby threshold in the years before the requirement. This implies that the marginal interest rate changes above LTV ratios of 75 percent, and that a borrower may want to reduce their borrowing to avoid this higher interest rate. This threshold is clearly noticeable in the counterfactual distribution in Figure 6. Figure D3 in Appendix D shows, however, that the interest rate differential between the top and bottom loan only comes into effect at the 75 percent threshold.

The results for the amortization threshold at LTV ratios of 70 percent are presented in Figure 6. Similar to Figure 5, the figure plots the observed distribution using data from the post-requirement years, and the counterfactual distribution estimated using pre-requirement data.

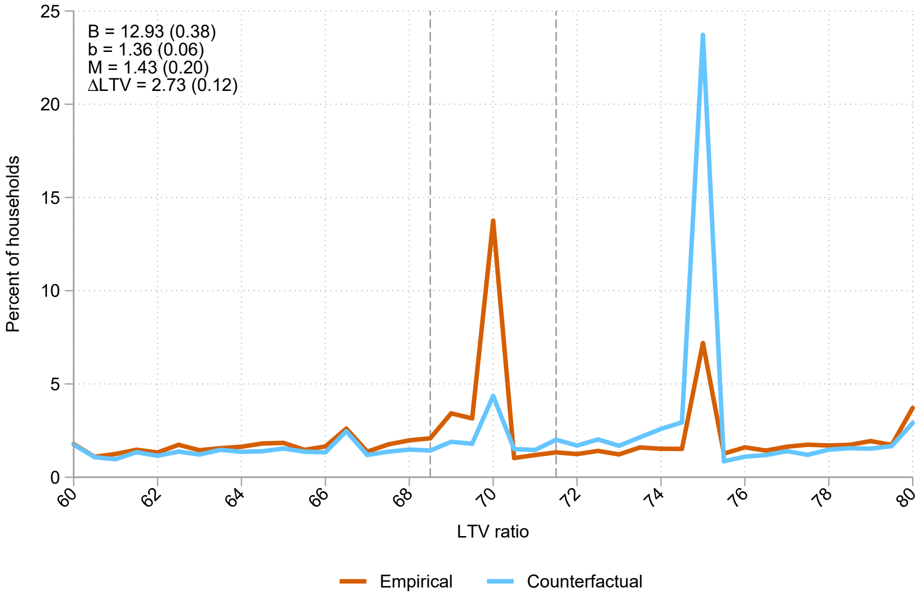

Figure 6. Bunching at LTV=70

Notes: The figure plots the empirical and counterfactual density of mortgage loans by LTV ratio. The estimation is carried out using all loans with LTV ratios between 55 and 80 percent, but only shows the distribution between 60 and 80. The orange line plots the empirical density, where each dot represents the percent of mortgages within each 0.5 percent LTV bin. The blue line plots the counterfactual density estimated using the procedure described in Section 4. The figure reports the estimated percent of households that bunch at the threshold (B), the excess mass at the threshold (b), the missing mass (M), and the behavioral response by borrowers (ΔLTV). The calculation of these numbers is described in Section 4. Standard errors are calculated using a bootstrap procedure and are shown in parentheses.

The estimation procedure uses data from borrowers with LTV ratios between 55 and 80 percent to avoid the lower threshold and the maximum LTV ratio at 85 percent affecting the results. There are two peaks at LTV ratios of 70 and 75 percent in Figure 6. For the black line, the empirical distribution in the post-requirement period, the peak is larger at the upper amortization requirement threshold. Conversely, for the pre-requirement period, the peak at LTV ratios of 75 percent is considerably larger than the peak at LTV ratios of 70 percent. For lower LTV ratios, the empirical and counterfactual densities are almost identical, showing that the procedure is well able to approximate the distribution. The bunching statistic $\widehat{B}$ shows that 12.93 percent of borrowers decide to bunch (standard error 0.38), an increase by a factor $\widehat{b} = 1.36$. Dividing the bunching statistic by the counterfactual distribution at the threshold, we find that the marginal buncher reduces its LTV ratio by 2.73 percentage points (standard error 0.12) due to the amortization requirement. This is marginally higher than the reduction in LTV ratios of 2.57 percent at the lower threshold. Finally, we find 1.43 percent ($\widehat{M} = 1.43$, standard error 0.2) less borrowers to the right of the notch in the post-requirement years compared to the pre-requirement years.

The estimates from the bunching estimates and associated standard errors for the lower and upper threshold are summarized in Table 1.

Table 1. Summary of main estimates

	Lower threshold (Notch at LTV=50)	Upper threshold (Notch at LTV=70)
Bunching	7.47	12.93
	(0.31)	(0.38)
Missing mass	-0.83	-1.43
	(0.16)	(0.20)
Δ LTV	2.57	2.73
	(0.16)	(0.12)

Notes: The table summarizes the main bunching estimates. *Bunching* is the percent of households bunching, calculated using equation (3). *Excess mass* scales the estimate of bunching by the counterfactual distribution, calculated using equation (4). Δ LTV is the estimate of the behavioral response, or the change in LTV ratio for the marginal buncher, calculated using equation (2). Bootstrapped standard errors in parentheses are calculated by drawing random samples with replacement from the full sample of borrowers. We then re-calculate the LTV distribution and re-estimate all parameters at each iteration.

5.3 The amortization elasticity of mortgage demand

We now translate the bunching estimates into semi-elasticities. The amortization requirement creates a notch in mortgage payments for borrowers, where the rate above the threshold applies to the entire mortgage instead of to the excess amount above the threshold. In other words, the requirement creates a discontinuous change in the *average* amortization payment, instead of a discontinuous change in the *marginal* rate. This implies that we cannot use the jump in payments created by the requirement to calculate an elasticity, as elasticities relate marginal changes in costs to marginal changes in quantities. We instead follow DeFusco & Paciorek (2017) and Kleven & Waseem (2013) and calculate an implicit marginal amortization rate on the mortgage. The idea behind the approach is to relate the reduction in LTV ratios to the change in the implicit marginal amortization rate created by the notch. Specifically, define the implicit marginal amortization rate α^* for $LTV > \overline{LTV}$ such that:

$$(LTV - \overline{LTV}) \cdot \alpha^* = LTV \cdot (\alpha_0 + \Delta\alpha) - \overline{LTV} \cdot \alpha_0 \tag{6}$$

The above equation states that the implicit marginal amortization rate α^* on the mortgage in excess of the requirement threshold $(LTV - \overline{LTV})$ is equal to the amortization rate above the threshold $(\alpha_0 + \Delta\alpha)$, minus the amortization rate at the LTV threshold (α_0). Solving this equation for α^*, we have

$$\alpha^* = \alpha_0 + \Delta\alpha + \Delta\alpha \cdot \frac{\overline{LTV}}{(LTV - \overline{LTV})} \tag{7}$$

The equation shows that α^* is equal to the amortization rate below the threshold plus the change in the amortization rate above the threshold, plus the change times a term that is decreasing in the distance between the LTV ratio and the threshold. Placing yourself just above the threshold gives a small increase in the LTV but a large increase in amortization payments, as the jump in the rate applies to the whole mortgage. Loans just above the limit therefore imply a very large marginal amortization rate: for example, the marginal amortization rate for a mortgage with an LTV of 51 percent on the last 1 percent of the LTV is then equal to $\alpha^* = 0 + 0.01 + 0.01 \cdot \frac{50}{(51-50)} =$ 51 percent. In our case, the behavioral response at the lower threshold was 2.57, giving us an implicit marginal amortization rate of $\alpha^* = 0 + 0.01 + 0.01 \cdot \frac{50}{(52.57-50)} = 20.4$ percent. The marginal amortization rate at the upper threshold is equal to 27.6 percent.

We can relate these marginal amortization rates to the reduction in LTV. The semi-elasticity of borrowing with respect to the amortization rate is equal to:

$$e^{\alpha} = \frac{\Delta LTV}{\alpha^*(\overline{LTV} + \Delta LTV) - \alpha_0} \tag{8}$$

where we relate the change in the LTV ratio induced by the requirement to the implicit marginal amortization rate for the marginal buncher. Plugging in the bunching estimates and the marginal amortization rate, the semi-elasticity at the lower threshold at LTV ratios of 50 percent is equal to 0.25: a one percentage point increase in amortization rate decreases LTV ratios by 0.25 percent. For the upper threshold, the corresponding elasticity is 0.15.[13] Mortgage debt therefore declines by 0.15 to 0.25 percent for a percentage point increase in the amortization rate.

5.4 Robustness

In this section we summarize the results of several different specifications. Table 2 shows the robustness of our estimates to the specific choice of bin width and the lower limit of the excluded

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[13] The numerator is equal to the percent change in LTV ratios. With the estimated ΔLTV of 2.57 evaluated at the lower threshold, the numerator is then equal to $2.57/50 = 0.0514$. Using the implicit rates from equation (7), the denominator is equal to $\alpha^* = 0 + 0.01 + 0.01 \cdot \frac{50}{(52.57-50)} = 0.204$, and the semi-elasticity is equal to $0.0514/0.204 = 0.25$.

Table 2. Robustness to choice of bin width and lower limit

	Notch at LTV = 50							
	Bin width = 0.5					Bin width = 1		
			Preferred					
Lower limit (L)	47.5	48	48.5	49	49.5	47	48	49
Bunching (B)	8.00	7.92	7.47	7.12	6.43	7.98	7.80	7.03
	(0.34)	(0.34)	(0.31)	(0.30)	(0.27)	(0.36)	(0.34)	(0.32)
Excess mass (b)	1.02	1.16	1.28	1.50	1.80	0.80	0.99	1.22
	(0.06)	(0.07)	(0.08)	(0.10)	(0.12)	(0.05)	(0.06)	(0.08)
Δ LTV	3.05	2.91	2.57	2.26	1.80	3.20	2.97	2.43
	(0.18)	(0.18)	(0.16)	(0.15)	(0.12)	(0.19)	(0.18)	(0.16)
Elasticity	0.35	0.32	0.25	0.19	0.12	0.39	0.33	0.23
	(0.04)	(0.04)	(0.03)	(0.03)	(0.02)	(0.04)	(0.04)	(0.03)

	Notch at LTV = 70							
	Bin width = 0.5					Bin width = 1		
			Preferred					
Lower limit (L)	67.5	68	68.5	69	69.5	67	68	69
Bunching (B)	13.82	13.43	12.93	12.28	10.75	13.82	13.39	12.37
	(0.41)	(0.39)	(0.38)	(0.37)	(0.34)	(0.44)	(0.41)	(0.38)
Excess mass (b)	1.12	1.23	1.36	1.53	1.75	0.85	1.07	1.30
	(0.05)	(0.05)	(0.06)	(0.07)	(0.08)	(0.03)	(0.04)	(0.06)
Δ LTV	3.36	3.06	2.73	2.29	1.75	3.42	3.21	2.61
	(0.14)	(0.13)	(0.12)	(0.10)	(0.08)	(0.14)	(0.13)	(0.12)
Elasticity	0.22	0.18	0.15	0.10	0.06	0.23	0.20	0.13
	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)	(0.02)	(0.02)	(0.01)

Notes: The table summarizes the robustness of the bunching estimates. *Bunching* is the percent of households bunching, calculated using equation (3). *Excess mass* scales the estimate of bunching by the counterfactual distribution, calculated using equation (4). Δ LTV is the estimate of the behavioral response, or the change in LTV ratio for the marginal buncher, calculated using equation (2). *Elasticity* is the amortization elasticity of mortgage demand, calculated using equation 8. Bootstrapped standard errors in parentheses are calculated by drawing random samples with replacement from the full sample of borrowers. We then re-calculate the LTV distribution and re-estimate all parameters at each iteration.

region. Larger excluded regions typically inflate the estimates; our preferred results are in the center of the tabulated estimates, and are robust to these free parameters.

More importantly, we show that our results are robust to using the standard approach of fitting a flexible polynomial[14] to the observed distribution (See Appendix B for details of the estimation and robustness). Figure 7 shows the counterfactual distribution resulting from the standard approach. While the counterfactual distribution fits the observed distribution well in general, by design it does not feature any spike around the thresholds due to a preference for round numbers or due to the SBA's recommendation. As a result, the bunching estimates B and b as well as the behavioral response are all larger compared to our earlier results that account

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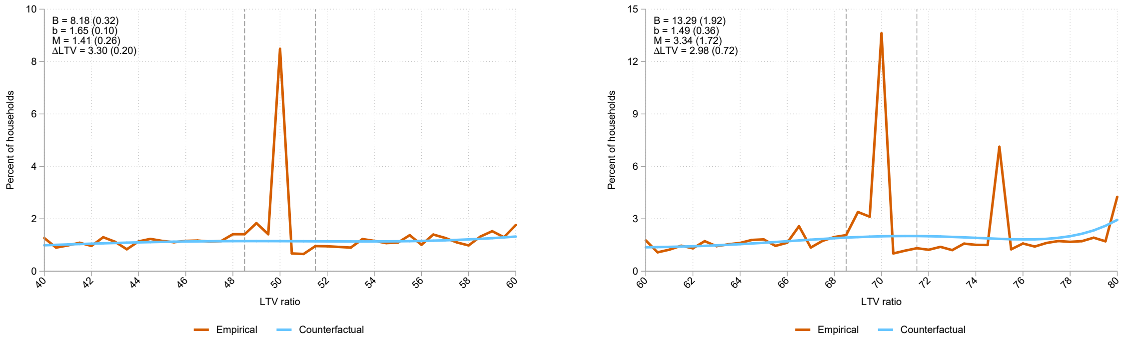
[14] The degree of the polynomial is chosen such that the difference between bunching (B) and missing mass (M) is smallest across specifications (Kleven, 2016).



a) Lower threshold

b) Upper threshold

Figure 7. Bunching estimates from polynomials

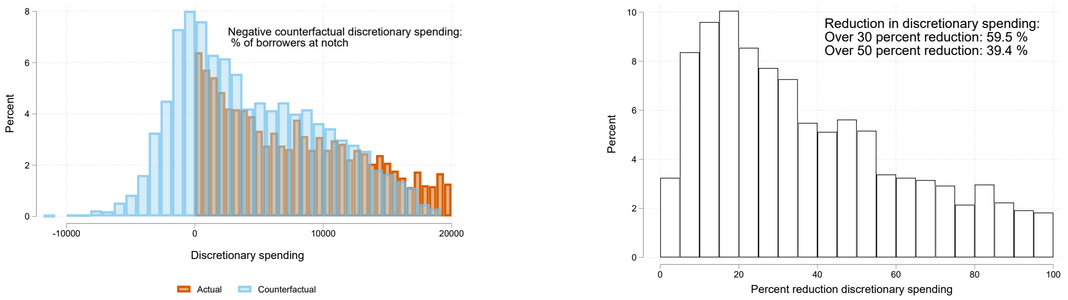
Notes: The figure plots the empirical and counterfactual density of mortgage loans by LTV ratio, in the region around the notch at LTV = 50 (Panel a) and the notch at LTV = 70 (Panel b). The orange line is the empirical density, where each dot represents the percent of mortgages within each 0.5 percent LTV bin. The blue line is the counterfactual density, estimated by fitting a flexible polynomial to the observed distribution, excluding the region around the notch. The figure also reports the estimated percent of loans that bunch at the threshold (B), excess mass at the threshold (b), the missing mass (M), and the behavioral response by borrowers (ΔLTV). The calculation of these numbers is described in Section 4. Standard errors are calculated using a bootstrap procedure and are shown in parentheses.

for spikes from pre-requirement data. Our preferred results are conservative compared to the polynomial estimates. For a comparison between our preferred estimates using previous years and the polynomial estimates, see Appendix B and specifically Figure B1.

Finally, Table C5 provides additional result by collateral valuation method. Swedish banks use several different valuation methods when assessing the value of the collateral: Internal valuation, external valuation and purchase price. Overall, while there is some differences across the valuation methods in the bunching estimate and the elasticity, the results are consistent. We discuss how these results help inform us on whether banks are manipulating the collateral values in Section 6.

5.5 Mechanisms

Why do households try to minimize amortization payments around the thresholds? One potential explanation for the observed bunching is that Swedish borrowers face a payment-to-income constraint. Swedish banks evaluate whether the borrower has sufficient income to afford living expenses as well as mortgage payments. Since this credit assessment includes amortization payments, borrowers just below the threshold may be unable to borrow a higher amount. Panel a) of Figure 8 shows that for a substantial share of borrowers, higher amortization payments would entail a large decrease in their discretionary income. The figure plots the distribution of discretionary income with actual amortization payments (orange bars) and with counterfactual



a) Discretionary spending in SEK/month

b) Reduction in discretionary spending

Figure 8. Discretionary spending

Notes: The figure plots calculations for discretionary spending for borrowers located at the notches. We select borrowers with LTV values between 48.5 and 50, and 68.5 and 70. We update the bank's discretionary income calculation to include higher amortization payments by increasing LTV ratios to one percentage point above the threshold. We use a stressed interest rate of 7 percent for the increase in debt, according to standard practice in Sweden. Panel a) plots the distribution of discretionary spending ("KALP") for borrowers located at the notches. The orange distribution plots the actual KALP distribution, and the blue, transparent, distribution plots the counterfactual KALP where we calculate discretionary spending if households were to amortize their mortgage according to the requirement (1 percent of the mortgage at the lower notch, 2 percent of the mortgage at the upper notch). Panel b) plots the reduction in discretionary spending from higher amortization payments as a share of actual discretionary spending.

amortization payments (blue bars), where we increase the LTV ratio to 1 percentage point above the threshold, and consequently increase amortization payments to comply with the requirement. The question is whether households would meet the payment-to-income constraint if they would have chosen to borrow 51% of the value of their home, instead of 50% (or 71% rather than 70% for the upper threshold). The figure pools borrowers just below either threshold, and selects borrowers who do not amortize more than the minimum amount.

We find that 26.3 percent of new borrowers would have negative discretionary income, and thus would not comply with the payment-to-income constraint set by Swedish banks. A large fraction of borrowers would also end up close to the limit. Panel b) shows the reduction in discretionary spending that higher amortization payments would entail: 59.5 percent of borrowers would have a reduction of 30 percent or more of their discretionary income, and 39.4 percent would have a reduction of over 50 percent. While some of those higher payments may be compensated for by a change in the composition of savings, amortizing clearly implies a large reduction in discretionary spending for a substantial portion of borrowers who bunch.

The implication of these results is twofold. First, amortization payments represent a financial constraint that reduces borrowing. Second, if given a choice, households may reduce amortization payments to comply with payment-to-income constraints. Alam *et al.* (2019) report that payment-to-income constraints (debt-service to income in their terminology) are prevalent in advanced economies as well as in emerging market and developing economies.[15] Policymakers should be aware that households may reduce amortization payments to comply with such constraints, especially as lower amortization payments may lead to lower wealth accumulation over time (Bernstein & Koudijs, 2021).

We unfortunately lack data that would allow us to examine whether borrowers avoid amortizing in order to consume, or invest more in risky assets. Table C4 in the appendix highlights that the characteristics of the borrowers who place themselves at the threshold to avoid amortization payments (Column 1 and 4, denoted *Conforming*) skews towards households with higher income and higher housing wealth who live in large cities, households who are ex-ante more likely to invest in risky assets (Campbell *et al.*, 2007). It is therefore reasonable to suspect that at least a part of the lower borrowing because of higher amortization payments is due to households wanting to invest in other assets.

6 Assessing threats to identification

In this section we discuss several threats to identification, starting with the counterfactual LTV distribution in the post-requirement years. Note that our difference-in-bunching strategy eliminates many possible confounders that might affect LTV distributions, as they will be differentiated out. Only factors that systematically impact borrowers at one side of the amortization requirement thresholds, which change exactly when introducing the requirement, potentially threaten the identification of causal effects. We discuss interest rates around the threshold, bank incentives, collateral assessments by banks, LTV dynamics, and salience. We conclude that none of these factors can explain the observed bunching.

Placebo tests – We start by providing evidence that the counter-factual density presents a good estimate of the fraction of borrowers in each bin. To do this, we create a placebo test to assess whether the counter-factual distribution presents a good estimate of the fraction of borrowers in the absence of the requirement (DeFusco *et al.*, 2020). Specifically, each pre-requirement year from 2011 to 2015 is designated as a "placebo" year. We then estimate the counterfactual distribution for both requirement thresholds in these years. By estimating the counterfactual distribution as if the requirement had passed in a placebo year, we can

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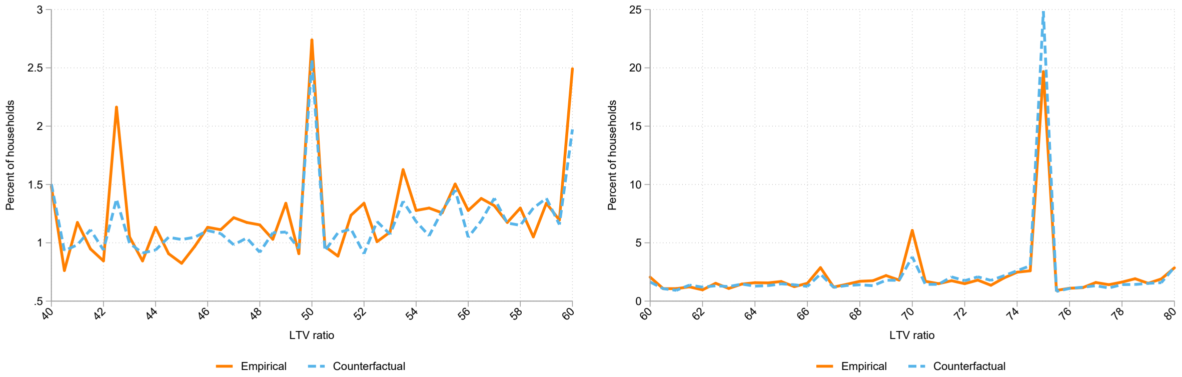
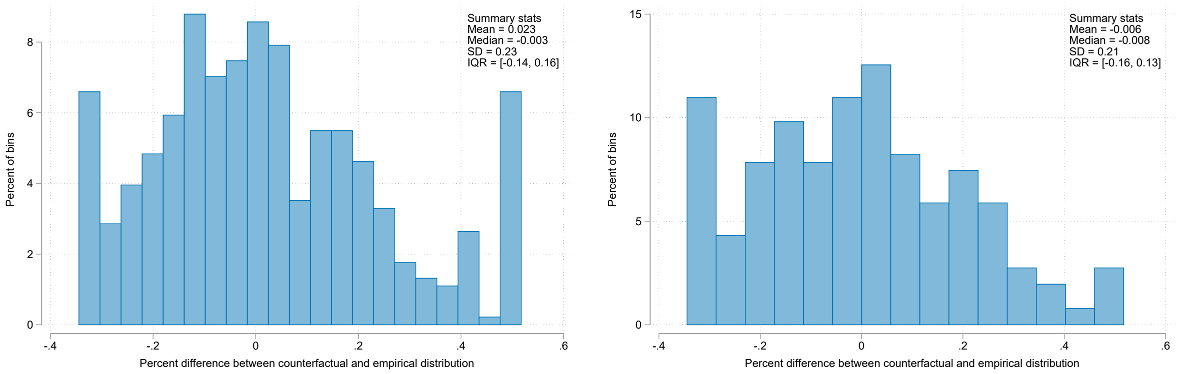
[15] Table 2 of Alam *et al.* (2019) reports that 15 out of 36 advanced economics in their sample used debt-service-to-income constraints in 2016. Out of 98 emerging market and developing economies, 20 countries employ such constraints. The definition of debt-service-to-income includes loan-to-income provisions.


a) Lower threshold: Placebo reform in 2014

b) Upper threshold: Placebo reform in 2014


c) Lower threshold: Ratio, empirical to counterfactual

d) Upper threshold: Ratio, empirical to counterfactual

Figure 9. Counter-factual and empirical distribution in placebo years

Notes: Panels a) and b) plot the empirical (solid orange line) and estimated counter-factual (dashed blue line) distribution of LTV ratios for 2014 for the upper and lower amortization requirement. Plotted LTV ratios are limited to be between 40 and 60 percent (panel a) and between 60 and 80 percent (panel b). The figures designate the placebo treatment to take place in 2014 and uses data from 2011, 2012, 2013, and 2015 to create the counter-factual. Panels c) and d) provide a histogram of the ratio between the empirical and counter-factual distribution, for all bins in all placebo years. For each year we use data from the other pre-requirement years as the counter-factual. LTV ratios are restricted to be between 40 and 60 in panel c) and between 60 and 80 in panel d).

assess whether the procedure can yield a good match between the empirical and counter-factual distribution in a year without an amortization requirement. If our assumption is valid, the two distributions should coincide and the bunching estimate should be zero.

Figure 9 shows that using other years as the counter-factual closely approximates the distribution in years without the requirement. Panels a) and b) plot the empirical and counter-factual distribution in 2014 for the upper and lower amortization requirement, showing a close correspondence between the distributions in both cases.[16] Importantly, the spikes at 50, 70, and 75 percent LTV ratios are well approximated by this procedure. Panels c) and d) provide histograms of the ratio between the percent of borrowers in each bin in the empirical and

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[16] Using other years than 2014 yields similar charts.

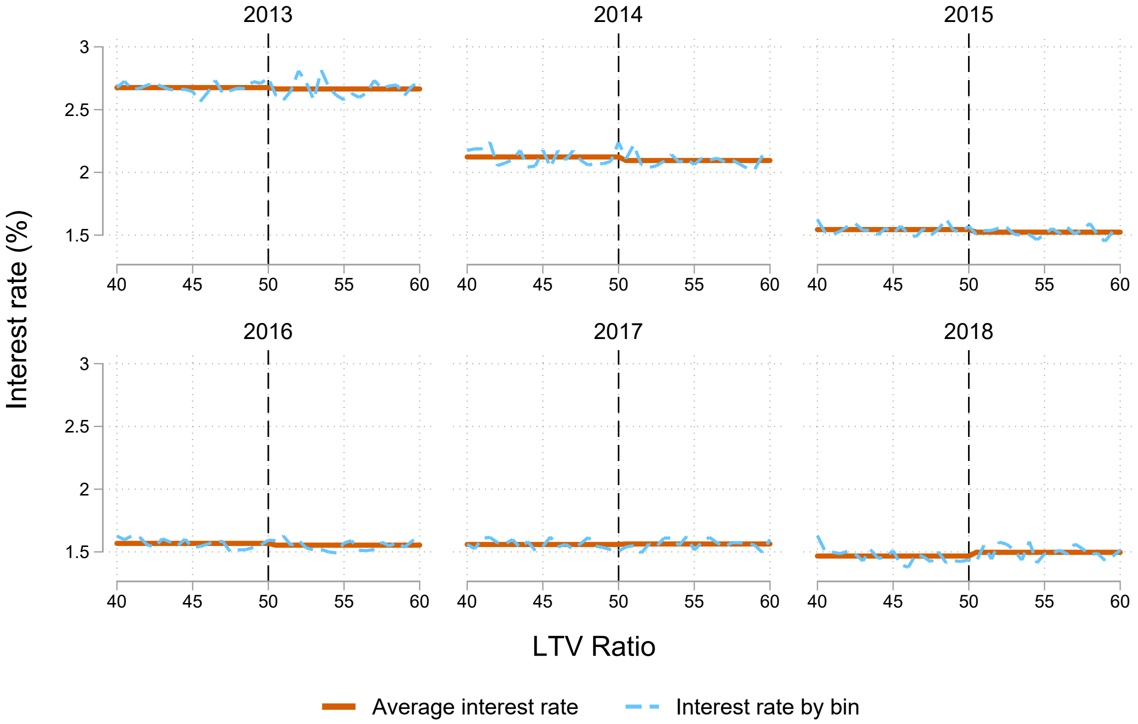

Figure 10. Interest rates around the lower LTV threshold

Notes: The figure plots the average mortgage rate by LTV bin (blue dashed line) and the average mortgage rate (orange solid line) above or below the lower threshold at an LTV of 50 percent marked by the dashed black line.

counter-factual distribution for all the pre-requirement years. In both panels, the mean and median percentage difference is close to zero, and the inter-quartile range covers zero. There is therefore little evidence that our approach creates a systematic bias in either direction. The intuition behind this result is that the LTV distribution is stable over time, except for changes near the amortization requirement thresholds, see Figure D1 in the Appendix. Overall, this supports our identification strategy.

Mortgage interest rates around the notches – Figure 10 shows that a plausible explanation for why borrowers place themselves at the thresholds, the mortgage interest rate, does not vary around the threshold. While it is possible that banks charge different interest rates for borrowers around the threshold in response to higher credit risk for borrowers who do not amortize (Garmaise, 2013; Elul *et al.*, 2010), we do not find any evidence of this in our setting. Figure 10 plots the interest rate by LTV ratios around the lower threshold. Although the level of the interest rate is different in each year, reflecting Swedish monetary policy, there are no systematic differences in interest rates over the threshold in any year. Similar results hold for the upper threshold, available in Figure D2. There is therefore little evidence that mortgage banks charged higher mortgage rates to households placing themselves right below the threshold. As we discuss below, lower amortization payments in a full-recourse setting do not imply higher credit risk, and therefore limit the incentive for banks to charge higher interest rates for borrowers that do not amortize.[17]

Despite the evidence displayed in Figure 10, there might be an additional premium charged for borrowing more than 50 percent of the property value due to, for example, capital requirements. Because of selection, the average rates displayed in the chart would not reveal this premium, as borrowers not wanting to pay the premium would already choose to borrow less, and these individuals might be different from non-bunchers. If this premium is constant over time, however, our identification strategy would difference these effects away. Note that the flat interest rate combined with linear repayment schedules of Swedish mortgages implies that the increase in total payments around the notches are fully due to the higher amortization payments, and not interest payments.

Banks' incentives and collateral assessments – Banks may have an incentive to recommend their clients to place themselves below the threshold, or may have an incentive to manipulate the collateral assessments to obtain lower amortization rates on behalf of their customers (Mayordomo *et al.*, 2020). The LTV ratio could be manipulated by overstating collateral assessments, which could reduce capital requirements and required amortization rates when crossing the threshold. Below we argue that this is unlikely to explain our results, primarily because of institutional features in Sweden.

One feature in particular would limit the ability of banks to overstate the collateral assessments around the thresholds: in Sweden borrowers apply for a pledge by the bank before making the purchase decision. This pledge states the maximum amount the bank is willing to lend, which depends on the household's income and composition and the value of the collateral. Based on this maximum loan promise and available net worth, the household purchases a home. The household's borrowing decision comes after the assessment, provided the requested amount does not exceed the promised amount. In other words, the bank makes an assessment of the value of the collateral *before* the borrower makes their purchase decisions. If the household purchases

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[17] Figure 10 also implicitly shows that the fixation period was similar across the threshold, as borrowers are charged a premium for longer fixation periods. A shorter fixation period would lead to lower interest rates, but this is not apparent in the figure.

a new home, appraisal values come from transaction prices, which cannot be manipulated by the bank. In case of a home equity loan, valuations are done by appraisers or statistical models employed by the bank. However, since the assessments are done prior to the borrowing decision and are done by statistical models without much discretion on behalf of the loan officer, it is very unlikely that banks are systematically manipulating the values just around the threshold to create the kind of bunching that we observe. Figure D4 plots the distribution of house value by LTV ratio using data from 2016 to 2018. There is little evidence in the figure that the house values from the assessments are manipulated around either threshold.

Table C5 provides further supportive evidence, by noting that the estimates of bunching are rather similar for the households that purchase a home, for which the transaction price is used to value to property, relative to internal valuations done by the bank or using external appraisals. The estimates suggest that loans with internally valued collateral have either the same or *less* bunching compared to loans for which the (not-manipulable) transaction price is used.

Moreover, since Swedish banks are reliant on covered bonds and other wholesale funding to a large extent, manipulation could have large repercussions for the banks' reputation and funding costs.[18] Indeed, Svensson (2016) argues that banks have an incentive to provide more credit to offset amortization payments. The fact that we observe lower LTV ratios in the data is consistent with active choices made by borrowers, not lenders.

Even though revenues increase with borrower LTV ratios, expected profits need not when expected losses (due to credit risk) or funding costs increase for banks. Regarding credit risk, it is clear that a loan with a higher LTV ratio should be riskier than a corresponding loan with a lower LTV ratio. However, we expect the marginal increase in credit risk to be negligibly small when moving from a loan with an LTV ratio of 50 percent to a loan with an LTV ratio of 51 percent. In either case, the properties' market value is more than sufficient to compensate the lender in case of default. Furthermore, a house price shock that pushes a loan with a 51 percent LTV ratio "underwater" is highly unlikely. Finally, given full recourse, households have no strategic motive to default.

Regarding funding costs, all loans with LTV below 75 percent are eligible for covered bond funding. In addition, according to the standardized approach to credit risk, all loans secured

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[18] Nearly 50 percent of total funding comes from wholesale funding, half of which is covered bonds (Sandström *et al.*, 2013).

by residential real estate receive the same (35 percent) risk weight. In practice, most Swedish banks use the IRB approach to credit risk, and higher LTV ratios should therefore require more (expensive) capital funding. We are not aware of any evidence to suggest that risk weights increase discontinuously at the thresholds. Even if they do, the effect would be differenced out by the counter-factual distribution if it stays constant over time.

LTV dynamics – The amortization requirement relates the minimum rate of amortization to the LTV ratio. Yet the LTV ratio decreases over time because of amortization. At some point, the household will cross the threshold. Anecdotal evidence suggests that the amortization rate is not automatically lowered when crossing the threshold, and borrowers would need to actively apply for a lower amortization rate. This suggests that bunching could be in part driven by inertia: a borrower who knows she will likely forget to apply for a lower rate of amortization could decide to bunch just below the threshold.

It also suggests that banks may have an incentive to nudge borrowers just below the threshold. Indeed, if borrowers do not actively apply for lower amortization payments, the bank may get higher interest income when borrowers enter an interest-only loan compared to a loan just above the lower threshold, simply because over the lifetime of the loan (typically 6-7 years), the average debt balance is larger for the non-amortizing loan.[19] The extra interest income from this nudge is likely small and depends on how long the loan stays on the banks' balance sheet and the interest margin. In any case, such a strategy is second-best for the bank: simply informing the borrower when they cross the LTV threshold yields higher revenues.

Salience – Finally, the amortization requirement may have increased the salience of the thresholds. In this case, however, there is no reason to expect that the salience would only increase for borrowers above the threshold. Indeed, if threshold saliency increased we should observe bunching from above and below, which we do not.

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[19] A similar argument holds for the upper LTV threshold, assuming loans above this threshold keep amortizing at a rate of 2 percent even after crossing the 70 percent threshold.

7 Housing and credit market impact of the requirement

Our main empirical exercise identifies a local average treatment effect around the notches. However, none of the explanations for why amortization payments are costly is specific to the area around the thresholds or a Swedish context, suggesting that our results generalize to other parts of the distribution and to other countries. In this section we discuss two potential aggregate effect of the requirement briefly: credit and housing market impacts of the requirement.

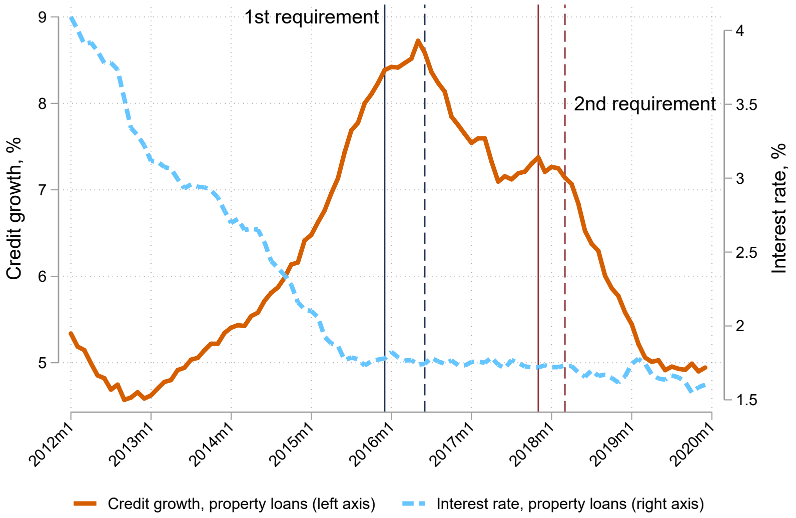

Figure 11. Credit growth for property loans

Notes: The figure plots the time series of annual credit growth and the interest rate for property loans. The first solid line in December 2015 indicates the date when the first amortization requirement was proposed by the FSA. The second dashed line in June 2016 indicates when the first amortization requirement went into effect. This is the policy that we study. The second solid line in November 2017 indicates when the second requirement was proposed by the FSA. The second dashed line in March 2018 indicates when the second amortization requirement went into effect. The second requirement added an additional 1 percent in amortization payments for new mortgages with a debt-to-income ratio above 4.5. We do not examine this requirement. Source: Statistics Sweden and authors' calculations.

The aggregate trends in housing credit growth strongly suggest that the effect we identify is global. The orange line in Figure 11 plots the credit growth rate for property loans. The key takeaway from the figure is that both amortization requirements coincided with a sharp reduction in the credit growth rate. There is also some evidence of an anticipation effect, as the growth rate slows down in the same month as the these policies were proposed. These declines are difficult to explain by other fundamentals, such as the interest rate. The blue line shows that the mortgage rate is flat between mid-2015 and 2020. The aggregate-level evidence thus suggests that the effect that we identify is not simply a local effect around the notches, but that it applies throughout the distribution. Interestingly, and consistent with our findings, the short-lived acceleration in credit growth between the requirement's proposal and its implementation in 2016 suggests households were eager to take out loans before mandatory amortization was required.

The introduction of the amortization requirement also coincided with a sharp reduction in the house price growth rate, as seen in Figure 12. The figure plots year-over-year house price growth, showing a clear break in the trend in the quarter when the requirement was formally proposed by the FSA. Again, this pattern is not consistent with a local effect around the threshold, but instead consistent with a global effect of the requirement.

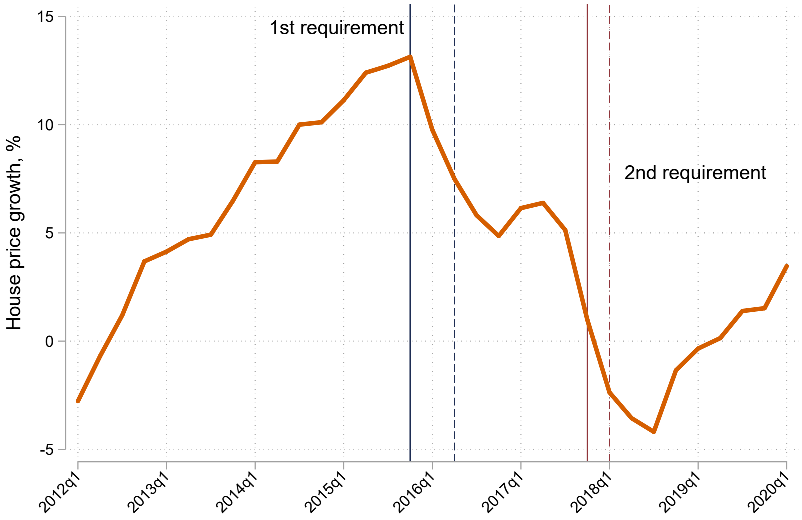

Figure 12. House price growth

Notes: The figure plots the time series of house price growth. The first solid line in December 2015 indicates the date when the first amortization requirement was proposed by the FSA. The second dashed line in June 2016 indicates when the first amortization requirement went into effect. This is the policy that we study. The second solid line in November 2017 indicates when the second requirement was proposed by the FSA. The second dashed line in March 2018 indicates when the second amortization requirement went into effect. The second requirement added an additional 1 percent in amortization payments for new mortgages with a debt-to-income ratio above 4.5. We do not examine this requirement. Source: Statistics Sweden and authors' calculations.

8 Conclusion

We show that the amortization requirement in Sweden had a direct impact on household loan-to-value ratios at the time households were taking out mortgages. New borrowers reduce their loan-to-value ratios by 4-5 percent in response to a 1 percentage point higher amortization rate. Our results indicate that household borrowing depends on the total mortgage payments including amortization, and not simply on the interest rate. By extension, explaining credit growth requires that we examine all features of the mortgage contract, including amortization payments.

While the elasticity that we estimate is modest, the aggregate effects of changing amortization payments can still be large. A naive comparison would suggest that the 1 percentage point higher amortization rate would have led to a 0.25 percent decline in LTV ratios, which seems unlikely to explain the large decline in aggregate credit growth. However, a large fraction of borrowers presumably held mortgage debt before the requirement, and thus face a potentially large increase in their amortization rate. The correct comparison for a borrower with existing mortgage debt would be more akin to the calculation of the marginal rate: what is the increase in the amortization rate on the difference between my current and future mortgage debt? As we showed, the marginal rate can be substantial. Conversely, the reduction in payments from choosing an interest-only mortgage can also be substantial: at an interest rate of 4 percent, amortization payments are approximately 30 percent of total payments. While the elasticity may be low, the aggregate effect may well be largely due to the large change in payments. Looking at the developments in the United States in the run-up to the financial crisis, the rapid expansion of mortgages with lower payments therefore likely led to an expansion of credit. Moreover, the disappearance of products with low amortization payments from 2008 (Amromin *et al.*, 2018) implies a rapid contraction of credit. The change in cash flow for a borrower who previously had an interest-only mortgage but who now has to start amortizing would be considerable: the annual expense for an interest-only mortgage with a 5 percent interest rate would increase by 32 percent (see Table C1). The disappearance of interest-only mortgages in the United States in 2008 would by itself cause a decline in borrowing.

Our results speak towards the intensive margin of amortization payments. There may also be extensive margin effects of the requirement that affect aggregate credit growth. We have deliberately chosen not to estimate extensive margin effects, as we feel this would entail making difficult-to-motivate assumptions over the counterfactual distribution. DeFusco *et al.* (2020) estimate the extensive margin by examining missing mass induced by the Dodd-Frank "Ability-to-Repay" requirement. This requirement effectively led to a reduction in high debt-to-income mortgages and affected roughly 5 percent of the total loan market in 2014. In contrast, the amortization requirement affected almost the entire market – 90 percent of mortgages in the pre-requirement years had an LTV ratio above 50 percent. While the extensive margin may be an important channel for quantifying the effect on the requirement for credit growth, our main point remains: forced amortization payments are costly and cause borrowers to change their behavior. We believe that the evidence on the intensive margin is sufficient to prove this point.

Finally, our results do not signify that the amortization requirement necessarily has a positive impact on financial stability.[20] The requirement reduced borrowing and increased the amortization rate, both of which slow down the growth of debt. If rising debt levels represent a danger to financial stability, as in the debt-overhang hypothesis (Mian *et al.*, 2013, 2017), the policy reduced macroeconomic risk. Higher amortization payments could also lead to higher wealth accumulation and a larger buffer for borrowers. However, households that avoid higher amortization expenses by bunching at the threshold might end up spending the extra cash. Moreover, a shift from liquid to illiquid savings because of higher amortization payments could also reduce households' ability to smooth consumption in response to income or interest rate shocks. Accessing illiquid housing wealth in response to a shock requires borrowing in credit markets or selling the underlying property, a difficult proposition in a recession. In the end, whether the requirement improves financial stability is an empirical question not ideally suited to our data, and left for future research.

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[20] The requirement could have no impact on macroeconomic stability if households can undo the requirement by either refinancing or by borrowing to fund amortization payments at a later stage (Hull, 2017; Svensson, 2016).

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A Appendix: Model

A.1 Baseline model

This appendix provides the basic model used to construct Figure 4. We present a simple three-period model of mortgage choice. The highly stylized model emphasizes the most important feature of the amortization requirement and shows how households respond to a notch in the amortization payment schedule. In reference to the channels listed in Section 3, the model provides intuition through the consumption smoothing channel. Adding the other channels to this exposition would entail complicating the model unnecessarily.

Households live for three periods.[21] In period 1, households purchase a home at price p and consume c_1, financed by a mortgage loan L, income y_1 and predetermined wealth A_0. We assume an exogenous, constant housing price without choice of housing size to keep the model as simple as possible. In period 2, the household simply consumes its income minus debt service, which consists of interest rL plus amortization αL. In period 3, the house is sold at the same price p, the remaining mortgage (plus interest) is repaid, and the household consumes its remaining wealth. Formally, the household maximizes:

$$\max_{c_1,c_2,c_3} U(c_1,c_2,c_3) = u(c_1) + \beta u(c_2) + \beta^2 u(c_3) \tag{9}$$

$$\begin{aligned} \text{s.t. } c_1 + p &= A_0 + L + y_1 \\ c_2 &= y_2 - (r+\alpha)L \\ c_3 &= y_3 + p - (1+r)(1-\alpha)L \\ 0 &< L < p \end{aligned}$$

We assume that households in the population are identical in all aspects except for initial wealth, which is smoothly distributed according to the density function $f(A_0)$. Each household can therefore be uniquely indexed by its position in the initial wealth distribution. Given A_0, the utility function $U(\cdot)$ is concave in the loan size L. Hence, every household simply chooses

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[21] Note that we require at least three periods for amortization payments to matter for consumption smoothing. In a two-period model, any required mortgage repayments in the first period could be undone by simply borrowing more directly. Amortization payments and the increase in debt would therefore be interchangeable, allowing no scope for amortization payments to affect borrowing.

the loan size L to maximize its lifetime utility. It does so under each of two amortization schedules:

$$\text{Linear schedule: } \alpha = \alpha_0$$

$$\text{Notched schedule: } \alpha = \alpha_0 + \mathbb{1}(L/p > \overline{LTV})\Delta\alpha$$

Under the linear schedule, the amortization rate is constant. Under the notched schedule, however, the amortization rate increases by $\Delta\alpha$ whenever the households' LTV ratio exceeds the threshold at $\overline{LTV}$. With a notched amortization schedule, a fraction of households located to the right of the threshold $\overline{LTV}$ will find it optimal to borrow less in period 1 compared to the linear amortization schedule. For households with counterfactual LTV ratios (under the linear schedule) close enough to the threshold, borrowing exactly $\overline{LTV}$ is optimal. Figure 4 denotes the simulated densities for 100,000 households differing in their initial wealth A_0, which is drawn from a uniform distribution on the interval $(0.75, 1.2)$. We use log per-period utility, $\beta = 1.02^{-1}$, $p = 1$, $y_t = 1\ \forall t$, $r = 0.02$, $\alpha_0 = 0$ and $\Delta\alpha = 0.01$ to construct the figure.

A.2 Svensson's model

This section further discusses the model of Svensson (2016) alluded to in Section 3. In that model, debt and LTV ratios would increase as a result of implementing amortization requirements. As we show here, the model would not predict any spike in the LTV distribution around the notch.

Households choose consumption, debt and savings in each period, plus constant housing, to maximize their intertemporal utility. Formally,

$$\max_{c,L,s,h} U = \sum_{t=1}^{T} \beta^{t-1} \ln\left(c_t^{1-\theta} h^{\theta}\right) \tag{10}$$

$$\begin{aligned}
\text{s.t. } & c_1 + s_1 + ph \leq A_0 + L_1 + y_1 \\
& c_t + s_t + \delta ph \leq L_t + y_t + (1 + r^s)s_{t-1} - (1 + r^L)L_{t-1}, t = 2..T \\
& A_T \leq (1 + r^s)s_T + (1 - \delta)ph - (1 + r^L)L_T \\
& L_t \leq L_{t-1} - \alpha L_1, t = 2..T
\end{aligned}$$

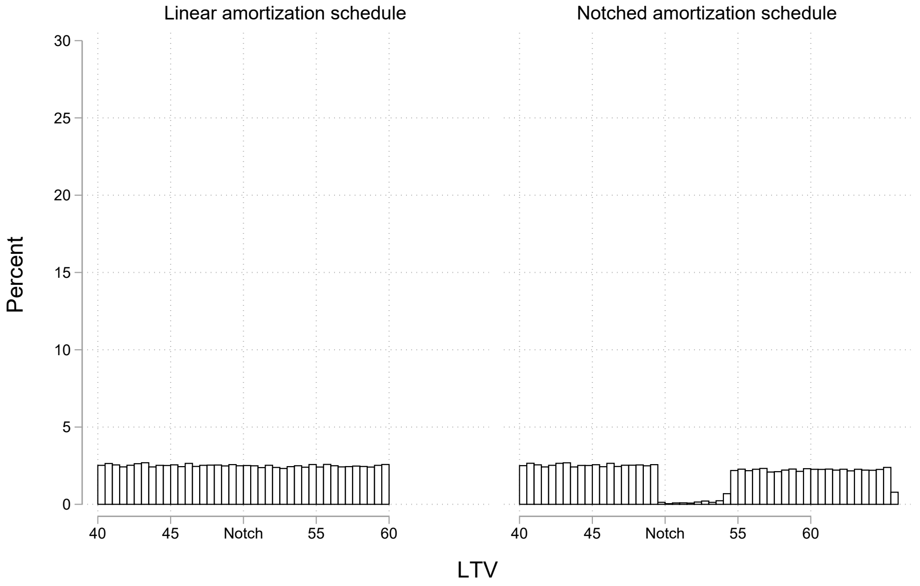
Here, $c = \{c_t\}_{t=1}^{T}$ denotes consumption in each period, $L = \{L_t\}_{t=1}^{T}$ denotes debt, $s = \{s_t\}_{t=1}^{T}$ denotes savings and h denotes the (constant) number of housing units. Furthermore, $\beta = 1/(1+\rho)$ is the discount factor, p the (exogenous) house price, y_t denotes (exogenous) income in period t, r^L and r^s are the (constant) interest rates on debt and savings, and δ is the maintenance cost for housing. The last $T-1$ constraints depict a linear amortization schedule, where debt declines by a fraction α of the initial debt level L_1.

We solve the model numerically for many households with different levels of initial wealth A_0. All households in the simulation are identical except for their initial wealth, which is uniformly distributed. Each household optimizes utility under both a linear schedule, where the amortization rate is constant, and a notched schedule, where the amortization rate jumps when debt L_t exceeds the threshold $ph\overline{LTV}$.

Figure A1 plots the simulated LTV distributions. With a linear amortization schedule, the LTV distribution is uniform. With a notched schedule, however, the LTV distribution features missing mass to the right of the notch, and a smooth distribution to the left of the notch. Households close to the LTV threshold in the linear amortization schedule optimally choose *higher* (gross) leverage to finance the required amortization payments in the notched schedule. Note that there is no spike in Svensson's model. This is in contrast to the prediction of our previous model (Figure 4) from Section 3, where the LTV distribution has a large spike exactly at the notch.

Hence, the two models differ in the effect of the requirement on leverage, and yield different LTV distributions. Although the LTV distribution from our model more closely resembles the actual distribution in the data, this should not necessarily be seen as a rejection of the prediction of Svensson (2016). Indeed, some households might well behave similar to that model.

Figure A1. LTV distribution from Svensson's model



Notes: The figure plots the LTV distribution using simulated data from the model of Svensson (2016), see section A in the appendix. We use $T = 10$, $\beta = 1.02^{-1}$, $\theta = 0.3$, $p = 100$, $y_t = 100$ $\forall t$, $r^L = 0.02$, $r^s = 0.01$, $\delta = 0.05$, $\alpha_0 = 0$ and $\Delta\alpha = 0.01$. There are 100,000 households, differing by their initial wealth A_0, which is drawn from a uniform distribution on the interval $(120, 280)$.

B Appendix: Bunching Estimates from Polynomials

This section provides additional results where we estimate the counter-factual distribution using the standard approach in the literature of fitting a flexible polynomial to the distribution and excluding an area around the threshold (see Kleven, 2016, for an overview).

We begin by grouping households into bins based on their Loan-to-Value ratio and calculate the fraction of households in each bin. We then fit the following regression:

$$n_j = \sum_{i=0}^{p} \beta_i (m_j)^i + \sum_{k=L}^{U} \gamma_k \mathbf{1}(m_k = m_j) + \epsilon_j, \tag{11}$$

where n_j is the fraction of households in bin j and m_j is loan-to-value ratio of the loan. The first term is a p-th degree polynomial in LTV ratios, and the second term is a set of dummy variables for each bin in the excluded region $[L, U]$. The estimates of the counter-factual distribution are given by the predicted values from the above regression while omitting the effect of the dummies in the excluded region:

$$\hat{n}_j = \sum_{i=0}^{p} \hat{\beta}_i (m_j)^i \tag{12}$$

The identifying assumption to estimate the causal effect of the amortization requirement is that the counter-factual LTV distribution is smooth. This precludes spikes in the distribution at the thresholds that are unrelated to the amortization requirement.

As in the main analysis, the estimates of bunching and missing mass are calculated by comparing the counter-factual distribution to the empirical distribution in the relevant regions (see equations 3 and 5). We use the procedure in Chetty *et al.* (2011) to calculate standard errors for all estimated parameters. Specifically, we randomly draw from the residuals in equation 11 with replacement to generate new bootstrapped bin fractions. We then re-estimate the bunching parameters. Standard errors are calculated as the standard deviation of the bootstrap estimates.

Figure 7 plots the empirical and counterfactual density of mortgage loans by LTV ratio, in the region around the notches in the amortization requirement. The figure is generated using the same bin width and width of the excluded region (L and U) as for the difference-in-bunching

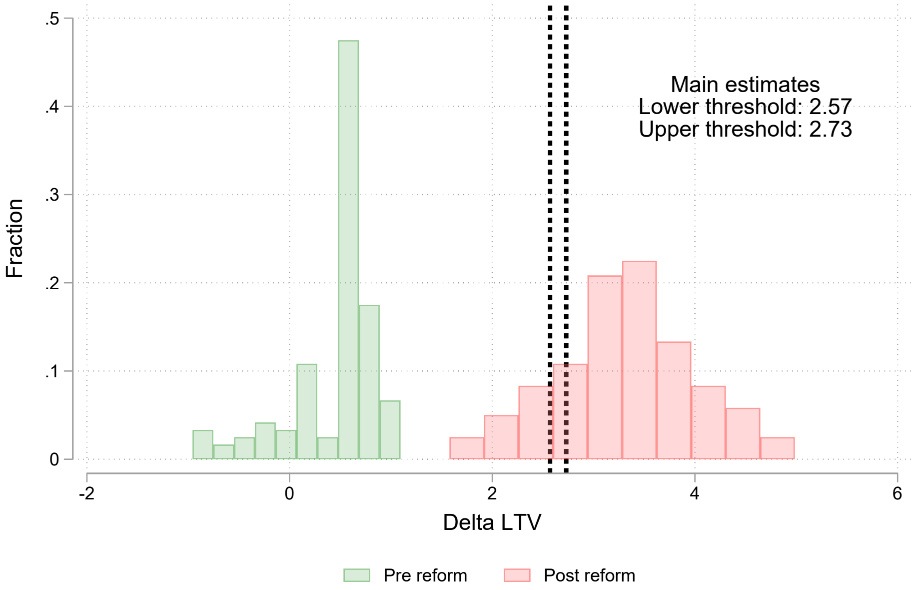


Figure B1. Robustness of estimated behavioral responses

Notes: The figure plots the distribution of estimated behavioral responses (ΔLTV) using the flexible polynomial approach. The red bars use post-requirement data only (years 2016-2018) while the green bars use pre-requirement data (years 2011-2015). The vertical black dashed lines depict our main estimates of the behavioral response using the difference-in-bunching approach. The specifications differ in their bin width (0.5 or 1 percent bins), the order of the polynomial ($p \in [3, 5, 7, 9, 11, 13]$) and the initial width of the excluded region to the left of the notch ($L \in [0.5, 1, 1.5]$ for a bin width of 0.5, and $L \in [1, 2]$ using a bin width of 1).

approach, while the order of the polynomial (p) was determined to minimize the difference between bunching and missing mass. To demonstrate robustness, we follow Kleven & Waseem (2013) and DeFusco & Paciorek (2017) and estimate many specifications that vary in the order of the polynomial (p), the bin width and the width of the excluded region to the left of the notch (L), while the width of the excluded region to the right of the notch (U) is determined by an iterative procedure that aims to equate the degree of bunching with the missing mass. Figure B1 provides a histogram of the estimated behavioral response ΔLTV across all these specifications. Our main estimates are in the conservative region of the outcomes using post-reform data; the figure shows that a 2 percentage points decline in LTV is roughly the lower bound. Interestingly, using pre-reform data, some specifications still result in significant, albeit lower, estimated behavioral responses, while there shouldn't be any response. Most likely, this comes from the presence of rounding and/or the SBA's prior recommendation to amortize loans with LTV above 70. This strengthens our choice to use pre-requirement years as the counterfactual, which controls for such factors directly and does not rely on the identifying assumption of smooth counterfactual distributions.

C Internet Appendix: Tables

Table C1. Mortgage payments for payment schedules and interest rates

	Interest rate				
	1%	1.5%	3%	5%	10%
Payments under each schedule					
Interest-only mortgage	10,000	15,000	30,000	50,000	100,000
Annuity schedule	38,597	41,414	50,592	64,419	105,309
Sweden: Lower threshold	20,000	25,000	40,000	60,000	110,000
Sweden: Upper threshold	30,000	35,000	50,000	70,000	120,000
Reduction in payments (%)					
(Annuity - IO) / Annuity	74.09	63.78	40.70	22.38	5.04
(Lower - IO) / Lower	50.00	40.00	25.00	16.67	9.09
(Upper - Lower) / Upper	33.33	28.57	20.00	14.29	8.33

Notes: The table reports mortgage payments in the first year under different interest rates and repayment schedules. We calculate mortgage payments for a 1,000,000 mortgage, using the annual interest rate in the top row. All calculations assume that payments are made monthly. For the annuity schedule the contract term is assumed to be 30 years. *Interest-only mortgage* is calculated as the mortgage amount times the effective annual interest rate. *Annuity schedule* is calculated using an annuity formula where the payments are the same in every period. *Sweden: Lower threshold* and *Sweden: Upper threshold* are calculated as the interest costs from a interest-only mortgage plus an amortization rate of 1% and 2%, respectively. The last three rows under **Reduction in payments (%)** calculate the percent reduction in total mortgage payments from choosing a mortgage with a lower amortization rate. For example, (*Annuity - IO*) compares the total mortgage expense for an interest-only mortgage with the total expense for a mortgage with an annuity schedule: (Annuity schedule - Interest-only mortgage)/Annuity schedule. *Lower - IO* and *Upper - Lower* are calculated similarly.

Table C2. Summary Statistics

	(1) Full Sample	(2) LTV 40-60	(3) LTV 60-80
Demographics			
Main borrowers age	44.64	49.73	43.74
	(14.88)	(14.48)	(13.49)
Household size	2.18	2.15	2.23
	(1.14)	(1.15)	(1.17)
Large city	0.45	0.49	0.49
	(0.50)	(0.50)	(0.50)
Disposable income, KSEK	40.76	43.23	41.86
	(83.03)	(105.75)	(30.64)
Loan sizes (MSEK)			
Total debt	1.87	1.95	2.16
	(1.63)	(1.81)	(1.75)
Mortgage debt	1.50	1.57	1.78
	(1.25)	(1.32)	(1.40)
House price	2.47	3.12	2.52
	(2.16)	(2.63)	(2.01)
Interest Rates			
Mortgage rate	2.18	2.04	2.14
	(0.83)	(0.81)	(0.82)
Mortgage fixation period	13.28	12.13	13.34
	(15.64)	(15.54)	(15.57)
Adjustable rate mortgage	0.61	0.67	0.60
	(0.49)	(0.47)	(0.49)
Amortization			
Amortization, KSEK	1.60	1.17	1.62
	(1.92)	(1.87)	(2.06)
Amortization rate	1.72	1.45	1.40
	(2.60)	(2.48)	(1.92)
Amortization to income	4.08	2.97	3.98
	(4.15)	(4.15)	(4.34)
Mortgage Characteristics			
Loan to value	65.44	50.37	71.27
	(22.89)	(5.74)	(5.32)
Total debt to income	379.00	379.88	424.43
	(218.74)	(224.31)	(225.20)
Net interest to income	5.55	5.11	6.05
	(3.75)	(3.55)	(3.89)
Debt service to income	10.82	8.70	10.81
	(6.79)	(6.03)	(6.16)
N	121,313	18,283	35,449

Notes: The table reports means and standard deviations (in parentheses). Column 2 and 3 splits the sample according to LTV ratio. KSEK is thousands of Swedish krona, and MSEK is million of Swedish krona. Demographic variables include the main borrower age and household size. *Large city* is a dummy variable equal to one if the borrower lives in one of the three largest cities (Stockholm, Malmö or Gothenburg). *Disposable income, KSEK* is disposable income adjusted for inflation in thousands of Swedish krona per month. *Total debt* is defined as mortgage debt plus unsecured credit. *House price* is the collateral value in millions of SEK, which in most cases is based on bank's internal valuations of properties, or transaction prices otherwise. These internal valuations use previous transaction prices and local hedonic price indices. *Mortgage fixation period* is the number of months for which the mortgage has a fixed interest rate. *Adjustable rate mortgage* is a dummy equal to one if the fixation period 3 months or less, i.e. if the mortgage has a variable interest rate. *Mortgage amortization, KSEK* is the monthly amortization payment in thousands of SEK. *Mortgage amortization rate* is calculated as mortgage amortization divided by mortgage debt. *Mortgage amortization to income* is calculated as mortgage amortization divided by disposable income. *Loan to value* is calculated as mortgage debt divided by house price. *Total debt to income* is calculated as total debt divided by annual disposable income. *Net interest to income* is calculated as interest payments divided by disposable income. *Debt service to income* is calculated as the sum of interest payments and amortization payments, divided by disposable income.

Table C3. Are amortization payments a cost or a form of savings?

	Cost	Savings	Do not know	Count
All respondents	38%	44%	18%	1004
Gender				
Male	38%	51%	12%	485
Female	38%	38%	24%	519
Age				
18-22	39%	16%	45%	69
23-35	34%	40%	26%	235
36-55	41%	45%	15%	358
56-80	37%	52%	11%	342
Household income before taxes				
Less than 100000 SEK	42%	21%	38%	48
100000 - 300000 SEK	48%	32%	21%	286
300001 - 500000 SEK	39%	51%	10%	263
500001 - 700000 SEK	30%	58%	13%	172
More than 700000 SEK	22%	75%	3%	95
Prefer not to say	34%	28%	38%	140
Education level				
No finished education	50%	50%	0%	2
Primary school	44%	32%	24%	169
High School	40%	41%	19%	518
University	31%	57%	13%	312
Prefer not to say	33%	0%	67%	3

Notes: Source: SBAB (2018).

Table C4. Conforming & Non-Conforming Borrower Characteristics

	Lower threshold			Upper threshold		
	(1) Conforming	(2) Non-conforming	(3) Difference	(4) Conforming	(5) Non-conforming	(6) Difference
Demographics						
Main borrowers age	50.13	46.31	-3.82	41.59	41.86	0.27
	(15.10)	(14.51)	[-4.92]	(12.66)	(12.31)	[0.54]
Household size	2.11	2.12	0.01	2.34	2.41	0.07
	(1.10)	(1.21)	[0.18]	(1.14)	(1.28)	[1.54]
Large city	0.58	0.40	-0.17	0.59	0.43	-0.16
	(0.49)	(0.49)	[-6.82]	(0.49)	(0.50)	[-8.06]
Disposable income, KSEK	48.30	41.50	-6.80	48.79	43.97	-4.83
	(40.85)	(28.37)	[-3.45]	(44.07)	(19.20)	[-3.09]
Loan sizes (MSEK)						
Total debt	2.57	1.91	-0.66	2.90	2.35	-0.56
	(2.19)	(2.15)	[-5.85]	(1.93)	(1.71)	[-7.43]
Mortgage debt	1.87	1.47	-0.41	2.38	1.97	-0.41
	(1.41)	(1.20)	[-5.80]	(1.50)	(1.37)	[-6.95]
House price	3.77	2.96	-0.81	3.41	2.83	-0.58
	(2.83)	(2.42)	[-5.73]	(2.15)	(1.97)	[-6.88]
Interest Rates						
Mortgage rate	1.47	1.60	0.13	1.50	1.57	0.07
	(0.29)	(0.32)	[8.47]	(0.27)	(0.32)	[6.53]
Mortgage fixation period	10.97	12.09	1.12	12.47	11.93	-0.54
	(15.10)	(15.30)	[1.42]	(14.62)	(14.81)	[-0.92]
Adjustable rate mortgage	0.72	0.68	-0.05	0.63	0.67	0.03
	(0.45)	(0.47)	[-1.97]	(0.48)	(0.47)	[1.68]
Amortization						
Amortization, KSEK	0.00	2.15	2.15	1.82	3.07	1.25
	(0.00)	(1.97)	[40.93]	(1.26)	(2.18)	[20.09]
Amortization rate	0.00	2.44	2.44	0.94	2.20	1.27
	(0.00)	(2.57)	[35.54]	(0.24)	(1.68)	[35.78]
Amortization to income	0.00	5.57	5.57	3.91	7.12	3.21
	(0.00)	(4.19)	[49.78]	(1.94)	(4.01)	[30.39]
Mortgage Characteristics						
Loan to value	49.73	49.62	-0.12	69.73	69.56	-0.17
	(0.43)	(0.49)	[-5.09]	(0.42)	(0.48)	[-9.58]
Total debt to income	448.02	359.86	-88.16	495.70	429.21	-66.50
	(212.11)	(212.75)	[-8.00]	(189.82)	(197.13)	[-8.69]
Net interest to income	4.52	3.83	-0.69	5.12	4.56	-0.56
	(2.21)	(2.09)	[-6.06]	(2.01)	(2.08)	[-6.86]
Debt service to income	4.53	10.50	5.98	9.73	12.90	3.17
	(2.22)	(6.10)	[31.37]	(3.82)	(6.02)	[17.66]
N	1,400	505	1,905	2,392	851	3,243

Notes: Summary statistics and t-test for different notches and groups. Sample consists of borrowers with LTV ratios of 48.5-50 percent in Columns 1-3, and of borrowers with LTV ratios of 68.5-70 percent in Columns 4-6. Conforming borrowers amortize according to the requirement, i.e. zero percent if they are at the 50-threshold and 1 percent if they are at the 70-threshold. Non-confirming borrowers amortize a higher percentage of their mortgage than required. KSEK is thousands of Swedish krona, and MSEK is million of Swedish krona. Demographic variables include the main borrower age and household size. *Large city* is a dummy variable equal to one if the borrower lives in one of the three largest cities (Stockholm, Malmö or Gothenburg). *Disposable income, KSEK* is disposable income adjusted for inflation in thousands of Swedish krona per month. *Total debt* is defined as mortgage debt plus unsecured credit. *House price* is the collateral value, which in most cases is based on bank's internal valuations of properties, or transaction prices otherwise. Internal valuations use previous transaction prices and local hedonic price indices. *Mortgage fixation period* is the number of months for which the mortgage has a fixed interest rate. *Adjustable rate mortgage* is a dummy equal to one if the fixation period 3 months or less, i.e. if the mortgage has a variable interest rate. *Mortgage amortization, KSEK* is the monthly amortization payment. *Mortgage amortization rate* is calculated as mortgage amortization divided by mortgage debt. *Mortgage amortization to income* is calculated as mortgage amortization divided by disposable income. *Loan to value* is calculated as mortgage debt divided by house price. *Total debt to income* is calculated as total debt divided by annual disposable income. *Net interest to income* is calculated as interest payments divided by disposable income. *Debt service to income* is calculated as the sum of interest payments and amortization payments, divided by disposable income. Standard deviations in parentheses. Columns 3 and 6 compute the difference between non-conforming and conforming borrowers' averages, with t-statistics in square brackets.

Table C5. Bunching estimates by type of valuation

Valuation	Internal	External	Purchase price
Panel A: Notch at LTV=50			
Bunching	7.10	7.38	9.30
	(0.34)	(0.88)	(1.46)
Excess mass	1.22	1.44	1.09
	(0.08)	(0.23)	(0.28)
Missing mass	-0.81	-0.81	-1.25
	(0.19)	(0.48)	(0.76)
Δ LTV	2.44	2.89	2.18
	(0.17)	(0.47)	(0.56)
Elasticity	0.23	0.32	0.18
	(0.03)	(0.10)	(0.09)
Panel B: Notch at LTV=70			
Bunching	12.88	6.40	19.13
	(0.43)	(1.05)	(1.01)
Excess mass	1.36	0.58	2.68
	(0.07)	(0.11)	(0.32)
Missing mass	-1.38	-0.53	-1.68
	(0.24)	(0.66)	(0.54)
Δ LTV	2.72	1.17	5.36
	(0.13)	(0.23)	(0.63)
Elasticity	0.15	0.03	0.54
	(0.01)	(0.01)	(0.12)

Notes: The table compares the bunching estimates across valuation modes for collateral assessments. *Bunching* is the percent of households bunching, calculated using equation (3). *Excess mass* scales the estimate of bunching by the counterfactual distribution, calculated using equation (4). *Missing mass* is the percent of households missing at the right of the threshold, calculated using equation (5). Δ LTV is the estimate of the behavioral response, or the change in LTV ratio for the marginal buncher, calculated using equation (2). *Elasticity* is the amortization elasticity of mortgage demand, calculated using equation 8. Bootstrapped standard errors in parentheses are calculated by drawing random samples with replacement from the full sample of borrowers. We then re-calculate the LTV distribution and re-estimate all parameters at each iteration.

D Internet Appendix: Figures

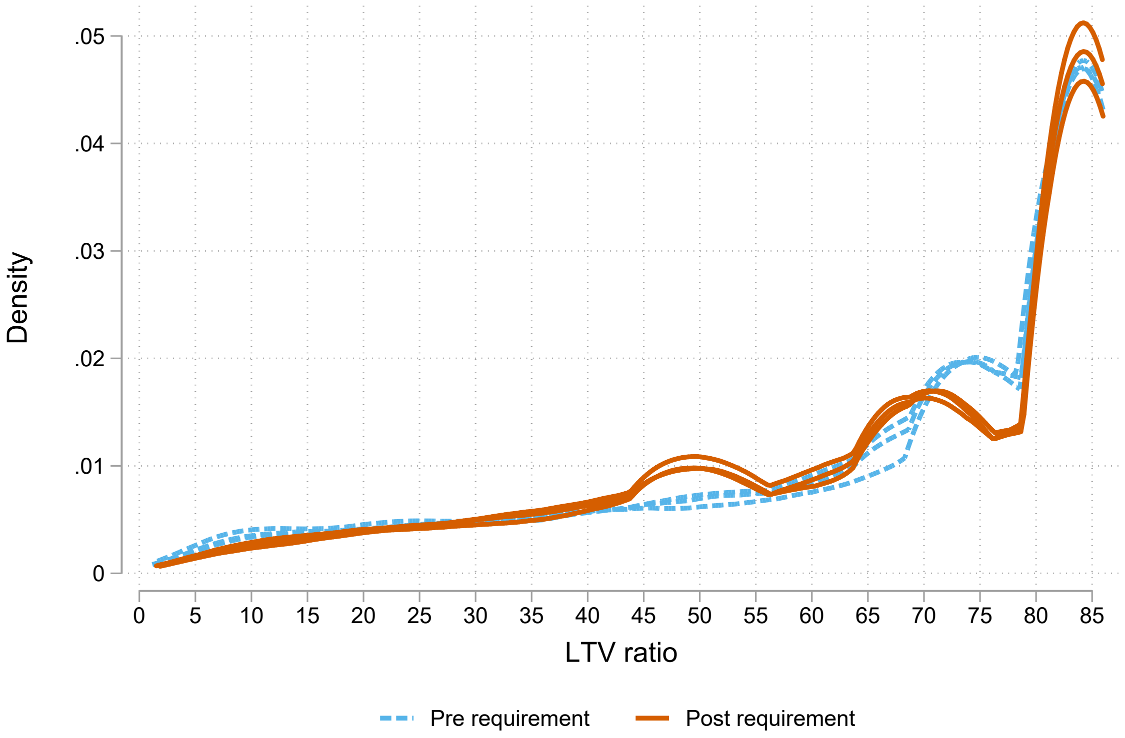


Figure D1. LTV distributions over time

Notes: The figure plots kernel density estimates of LTV ratios in pre-requirement years (blue dashed line) and post-requirement years (orange solid line).

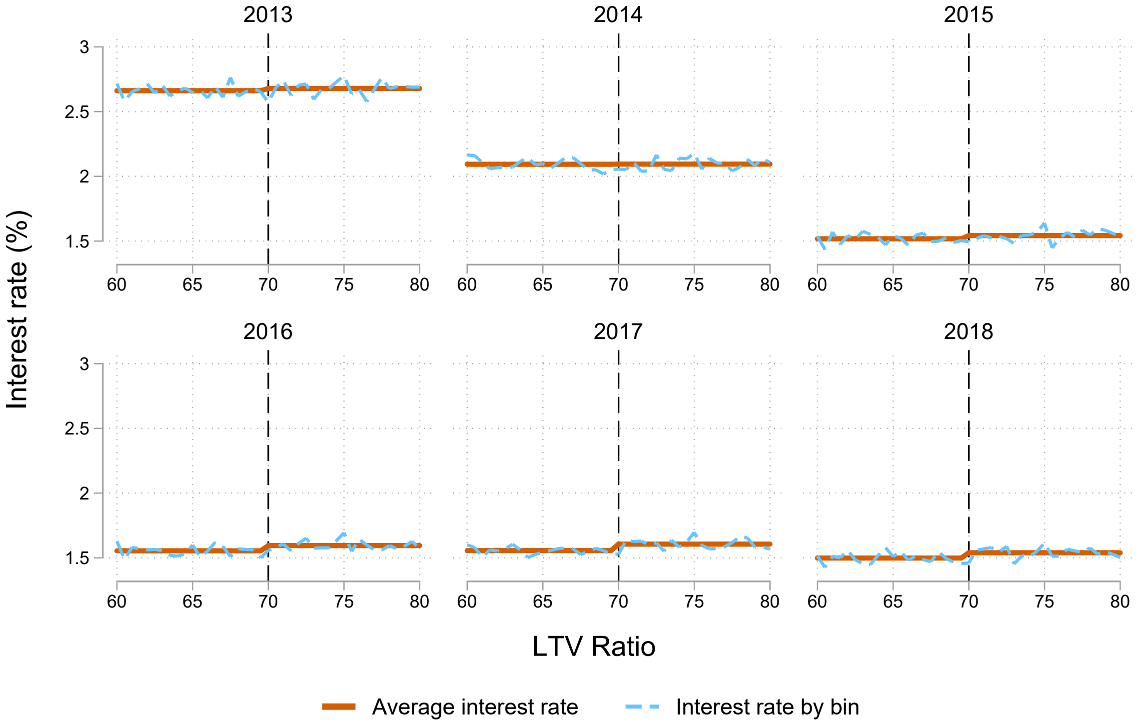


Figure D2. Interest rates around the upper LTV threshold

Notes: The figure plots the average mortgage rate by LTV bin (blue dashed line) and the average mortgage rate (orange solid line) above or below the upper threshold at an LTV of 70 percent marked by the black dashed line.

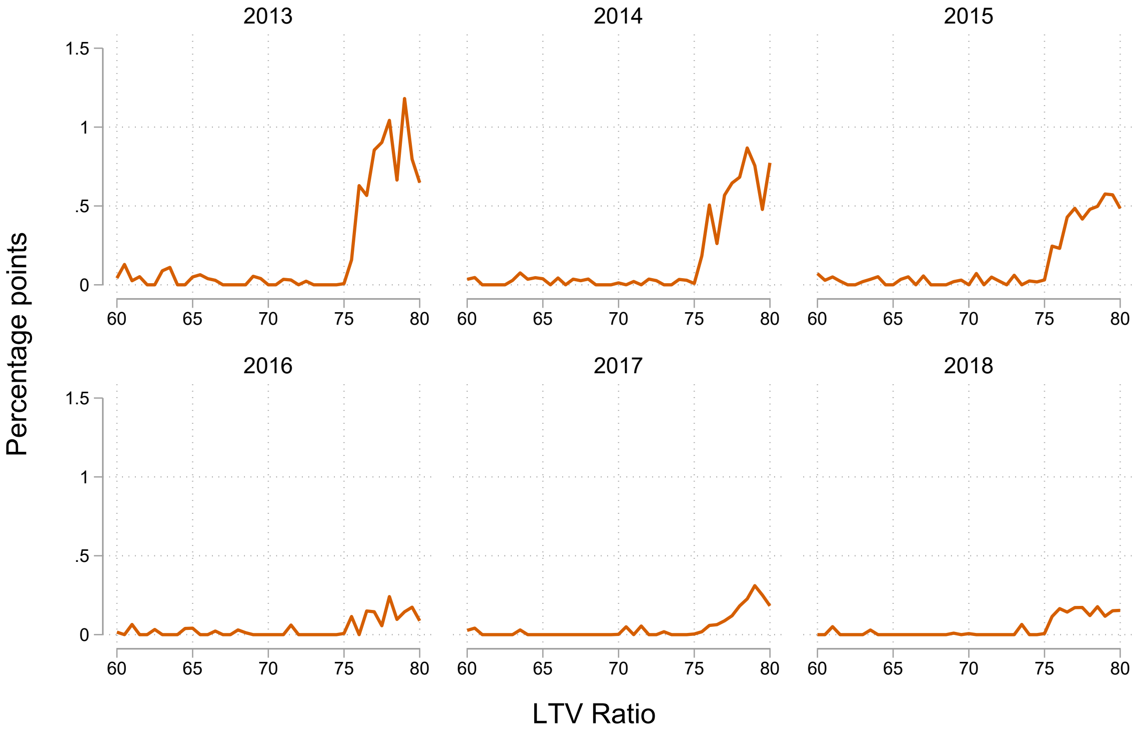
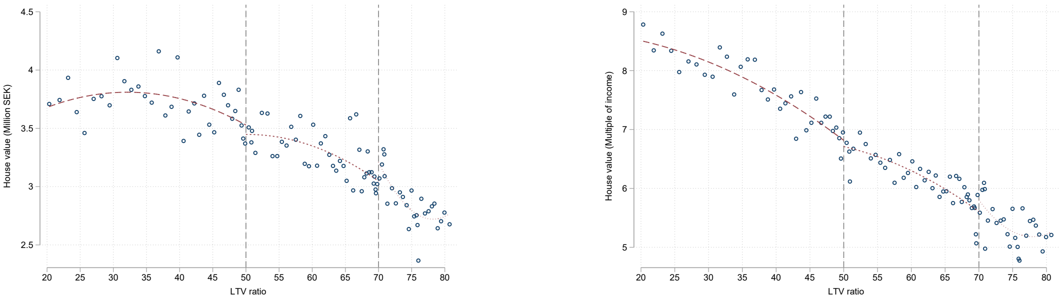


Figure D3. Difference between top and bottom interest rates

Notes: The figure plots the difference between the average top and bottom interest rate, conditional on the borrower having a top and bottom loan, by LTV bin.



a) House value

b) House value to income

Figure D4. Housing values by LTV ratio

Notes: The figure plots the distribution of house values by LTV ratio. Using data for 2016-2018, each dot displays the average house value per LTV bin, after filtering out region-by-year fixed effects. The quadratic fitted curves are estimated separately for the LTV intervals ranging from 20-50, 50-70 and 70-80, respectively. Panel a) plots the distribution of house values in levels. Panel b) plots the distribution of house values as a multiple of annual disposable income. The dashed vertical lines display the amortization requirement's LTV thresholds at 50 and 70 percent.