Restricted mortgage offering in the Great Recession

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Abstract

The literature has studied the ex-ante consequences of introducing teaser-rate mortgages (TRMs) on the housing and mortgage markets. We study how the ex-post restricted access to TRMs during the Great Recession amplified the housing bust. TRMs start with a low initial rate, with the expectation of a rate hike in the future. Empirically, we show that lower-income and younger households chose TRMs during the housing boom. At the onset of the crisis, the government-sponsored enterprises tightened restrictions on their purchases of TRMs, which induced intermediaries to increase their lending standards. To evaluate the impact of eliminating TRMs during the crisis, we use a dynamic general equilibrium housing model with long-term mortgages and a contract choice between fixed-rate mortgages (FRMs) and TRMs. The restricted contract choice amplifies the house price drop by 1 percentage point. Without the availability of TRMs, low-income and younger households are excluded from the mortgage market, leading to a decrease in housing demand that triggers a downward spiral effect on house prices. Without the restricted supply, the share of TRMs would nearly have doubled during the crisis.

Keywords: Housing market, mortgage contracts, equilibrium model.

JEL: E2, E4, E6, G2, G5

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1 Introduction

During the housing market boom of 2001-2006, the composition of mortgages originated and outstanding in the United States changed in several important ways. Nontraditional mortgages with back-loaded payment structures became more popular relative to then-common Fixed Rate Mortgages (FRMs; Corbae and Quintin (2015)). While the pool of these nontraditional mortgages had a varying array of features, they often had variable payments and were therefore called Adjustable Rate Mortgages (ARMs). ARMs are composed of an introductory period and an adjustment period. The introductory period generally lasts about two to five years and is characterized by a low fixed interest rate, while the adjustment period is characterized by variable mortgage payments which change annually based on a short-term market interest rate plus a fixed margin set at origination. Relative to the common FRMs, the ARMs were seen as more risky as they were characterized by lower initial interest rates (sometimes referred to as teaser rates), higher loan-to-value ratios, and lower borrower credit scores.

While the rise of these nontraditional mortgages around 2005 was staggering, their decline was even faster. Figure 1 presents an overview of the mortgage originations of FRMs and ARMs, with ARMs split by different lengths of introductory periods. We see that the total share of mortgages which were adjustable rate increased from 14 percent in 2002 to 37 percent in 2004-2005. After that, the share declined rapidly to reach a low of one percent in 2009, and has stayed below six percent afterwards. Among purchase mortgages outstanding in December 2005, 65.69% were fixed rate mortgages, 7.72% were ARMs with a teaser period of one year or less, 9.48% were ARMs with a teaser period of between one and (or equal to) three years, 11.26% were ARMs with teaser periods between three and (or equal to) five years, and 5.85% teasers with strictly more than five years as an introductory period.[1]

The fall in popularity of ARMs since 2008 is a heavily discussed topic (Corbae & Quintin, 2015; Moench, Vickery, & Aragon, 2010). Arguments can generally be split between demand and supply side factors. Within the demand factors, a second distinction can be made between time-series and cross-section. On the time-series side, one factor is the role of interest rate expectations. For instance, Koijen, Hemert, and Van Nieuwerburgh (2009) find that time variation in the ARM share is driven by the difference between expected mortgage payments of the two contracts, where the ARM expected payments can be calculated using a simple average of recent short-term rates. Another demand-side time-series factor influencing mortgage choice is the presence of liquidity constraints, which vary over the business

[1] For comparison, across outstanding purchase mortgages in December 2007, 74.40% were fixed-rate, 4.65% were ARMs with a teaser of one year or less, 5.62% were ARMS with teaser periods between one and (or equal to) three years, 9.55% were ARMs with teaser periods between three and (or equal to) five years, and 5.78% were ARMs with strictly more than five years as an introductory period.

[2] In Section 3 we provide more information regarding this data set and the selections we make. See Appendix A for an overview in terms of percentages, and for an overview for refinance mortgages.

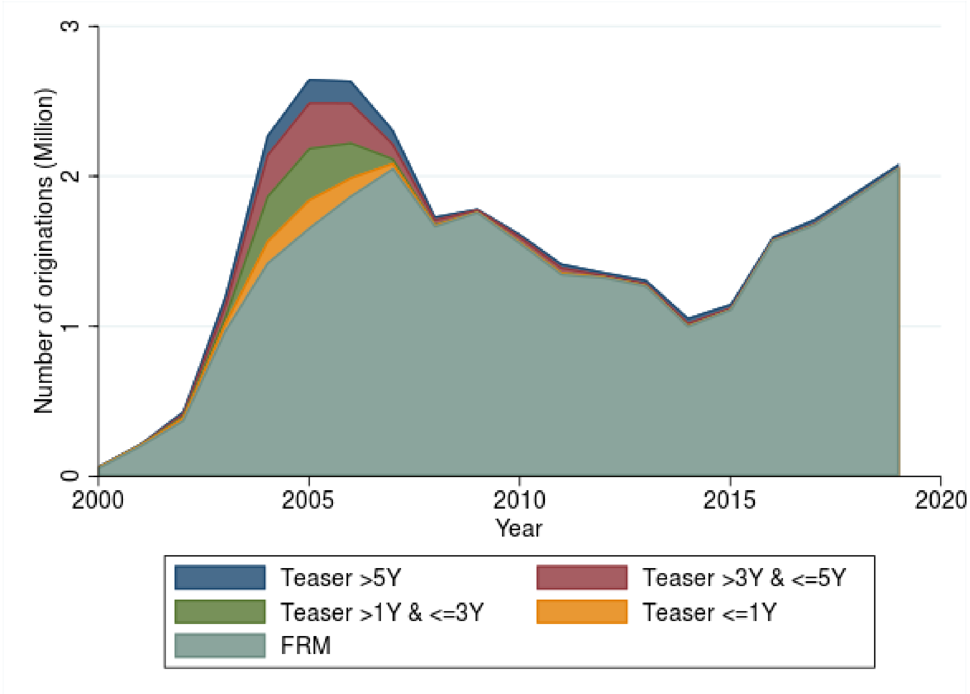


Figure 1: Mortgage Originations (Millions) for ARMs and FRMs, split by length introductory period for ARMs. Constructed with data by Black Knight McDash (McDash) data. Purchase Mortgages only. [2]

cycle. In terms of cross-sectional demand factors that explain the ARM-share, Campbell and Cocco (2003) argue that a household with a large mortgage, high risk aversion, and a low probability of moving is less likely to prefer an ARM. Johnson and Li (2014) find that ARM borrowers exhibit behavior that is consistent with being borrowing constrained.

While the demand side is relevant, we argue that the supply side is key to explaining the fall in ARM originations. First, the subprime mortgage market, where a large fraction of the ARMs were issued, collapsed in 2008. This event relates to the banking sector, where financially constrained lenders may have had to reduce their risk-taking incentives in 2007, lowering their offerings to more risky borrowers and/or increasing their lending standards (Moench et al., 2010). Second, during 2007 to 2010, the GSEs tightened restrictions on their purchases of ARMs, particularly ARMs with nontraditional features and layers of risk (FHFA, 2018). Third, the Federal Reserve's Large-Scale Asset Purchase (LSAP) program was targeted only to fixed-rate agency mortgage backed-securities between 2008 and 2010. The program could have disproportionately increased the supply of fixed-rate mortgages, lowering the ARM share (Moench et al., 2010). In sum, all these supply factors could have reduced lenders' incentives to originate ARMs, partially explaining the fall in the ARM share.

To understand the exact implications of restricting mortgage availability, it is important to first study mortgage choices among households prior to the crisis. While ARM contracts had a wide array of features observed during the housing boom,[3] in this paper we focus on the teaser rate structure of the ARMs found in the data. The teaser rate structure refers to the initial interest rate of an ARM which is almost always lower than the fixed rate a household receives on a thirty-year FRM contract.[4] In Section 2, we justify the relevance of the teaser rate mortgage features. Additionally, in Section 3, we provide an overview of the homeowner characteristics which shape a household's mortgage selection. We show that mainly younger low-income households chose these mortgages during the housing boom.

The primary goal of this paper is to evaluate the impact that mortgage restrictions had on the housing market, given the combination of mortgage features and household characteristics observed in the data. In particular, we study the effect that this policy had on house prices and the number of foreclosures. Foreclosures rose substantially during the housing bust, especially among TRM mortgagors (see Appendix B for a detailed description of foreclosure by mortgage type). While these nontraditional mortgages allowed many households to either buy a house or refinance with ARMs during the housing boom, the exact timing of the supply restriction on these mortgages (at the onset of the crisis) may have had detrimental effects on households. First, buyers and movers may have seen their access to mortgages shut down due to the new restrictions on ARMs. Second, existing mortgagors could not refinance anymore into new ARMs. Then, at the onset of the crisis when prices and demand for housing collapsed, the restriction on nontraditional mortgages may have driven down the equilibrium house price even further, given that these constrained households did not have the option to get a suitable mortgage anymore. This decrease may have further impacted refinancing households as they now faced lower house equity, which in turn could spur homeowner default and depress house prices even more. In sum, the restricted supply of ARMs had feedback effects on house prices, deepening the fall compared to the scenario where the ARM supply was not restricted.

To evaluate and quantify the impact of mortgage availability restrictions on the housing market, we develop a life-cycle model with mortgage choice. In the model, households face uninsurable labor income risks, and make decisions with respect to consumption (goods and housing services) and asset allocations (risk-free asset and housing investment). All households start their life as a renter, with the option of buying a house later on. To finance their housing choice, households can choose between two long-term contracts: a fixed rate mortgage (FRM) and a teaser rate mortgage (TRM). The TRM features a low initial inter-

[3] Many "new" contract features were observed: variable payments, balloon payments, teaser rates, interest-only periods, subprime mortgagors, and lower down payments. See Section 2 for more detail.

[4] Most ARMs have an introductory and an adjustment period. The interest rate is expected to rise after the introductory period (Pennington-Cross and Ho (2010)). A consequence of this structure is that mortgagors have low home equity and an expected spike in monthly payments, reflecting the riskiness of the mortgage.

est rate in the introductory period, which adjusts upwards once[5] the introductory period ends. When a household owns a house, it can choose to pay its mortgage payments due, sell, refinance, move, or default. Both the mortgage interest rates and the house price are determined in equilibrium. The first exercise we perform is to match both the household's selection into mortgage products and the interest rate offered by financial intermediaries for each mortgage type observed during the housing boom around 2005-2006.

After matching the cross-section of the mortgage market in 2005-2006, we use the model to simulate a bust-episode with MIT shocks using a housing preference shock and an aggregate income shock as modelled by Kaplan, Mitman, and Violante (2017). We evaluate the effect of restricted mortgage offerings by comparing a simulated crisis episode with a counterfactual crisis episode. In both episodes we start with the observed pre-crisis interest rate differential between mortgage products, which is not restrictive for young low-income households. Then, the simulated crisis episode would transition the economy through the crisis while eliminating access to TRMs, as experienced in 2007-2008. The counterfactual episode induces an otherwise-equivalent crisis without restricting the TRMs supply. Then, we analyze the difference between these two episodes to measure the effect of the restricted mortgage offering, especially regarding the house price drop and the number of foreclosures.

We find that the restricted offering particularly impacts house prices: the house price with restricted offering drops by 0.9 percentage points more than in the case without restricted offering; the magnitude of the fall is 7% larger. Moreover, the recovery without the restricted offering is faster, and the number of foreclosures is lower. In the simulated crisis, the unavailability of TRMs causes housing demand to fall, which lowers the house price directly. In addition, as the house price falls, mortgage default rises, which lowers the house price even further. The counterfactual experiment shows that households would have increased their use of teaser rate mortgages during the housing bust episode to better smooth out consumption over time. This result strongly suggests that the timing of the TRMs restrictions could have exacerbated consequences of the crisis.

Literature Review We mainly build upon two strands of literature. First, we add to the mortgage choice literature (Campbell & Cocco, 2003; Chambers, Garriga, & Schlagenhauf, 2009; Corbae & Quintin, 2015; Garriga & Schlagenhauf, 2010) by modelling a mortgage choice for the households. Campbell and Cocco (2003) were the first to construct a stylized life-cycle model with two types of mortgage contracts: a fixed rate and an adjustable rate mortgage, exogenously imposing the (mortgage) interest rates and house price shocks in the model. Later on, Chambers et al. (2009) developed an enriched framework to examine

[5] The implication here is that the "adjustment period" observed in ARMs is not modelled. Instead of facing a variable interest rate in this second period, the mortgagor will face a (higher) fixed rate mortgage that satisfies a financial intermediary's zero-profit condition.

mortgage choices leading up to the housing boom in 2005-2006, including the lender's expected zero profit condition and mortgages of fixed length. In this framework, they evaluate alternative mortgages pairwise relative to fixed-rate mortgages. Garriga and Schlagenhauf (2010) extend this framework to evaluate the importance of an increased leverage in driving the rise in foreclosures, accounting for a mortgage choice between a fixed and a graduated payment loan. Corbae and Quintin (2015) also build a mortgage choice life-cycle model, with the aim to quantify the effect of nontraditional mortgages on the foreclosure rates in the housing bust. Their nontraditional mortgage features no down-payment and constant no-amortization payments for the initial period, where after it adjusts upwards. Our contribution is to evaluate to which extent the restricted supply of TRMs contributed to the bust, focusing on the foreclosure rate and the house price in general equilibrium.

The second literature we add to is the mortgage design literature. Empirically it is found that state-contingent mortgages that front load payment reductions alleviate household liquidity constraints in crisis episodes, reducing liquidity default (Ganong & Noel, 2018). Theoretical literature has since evaluated different kinds of mortgages that act as automatic stabilizers for the economy. Eberly and Krishnamurthy (2014) propose an automatic stabilizer mortgage contract (priced ex-ante): one that reduces payments during recessions and reduces debt when home prices fall. Guren, Krishnamurthy, and McQuade (2018) quantitatively compare an all-ARM economy with an all FRM-economy. Raising mortgage payments in booms and lowering them in recessions increase welfare significantly. Greenwald, Landvoigt, and Van Nieuwerburgh (2018) find that indexing mortgage payments to local house prices reduces financial fragility and improves risk-sharing. Our contribution to this literature is to evaluate the macroeconomic effects of eliminating one stylized mortgage choice.

An outline of the paper follows. In Section 2 we describe the features of ARMs itself, evidence on the backloaded payment structure during the housing bust, and the role of the government in the mortgage market. In Section 3, we describe empirical evidence of the mortgage choice during the housing boom. Section 4 describes the model economy and defines the equilibrium. Section 5 discusses the calibration of the model to the U.S. economy during the housing boom. Section 6 analyzes the performance of the model's steady state relative to the data. Section 7 performs the crisis episodes to evaluate the effects of the restricted mortgage offering. Section 8 concludes and describes future developments.

2 Nontraditional mortgages

2.1 Key features

The wave of nontraditional mortgages in the early 2000s carried several new features relative to FRMs: variable payments (Corbae & Quintin, 2015), balloon payments (Demyanyk &

Van Hemert, 2011), teaser-rates (Levitin, Lin, & Wachter, 2019), interest-only periods (Levitin et al., 2019), subprime borrowers (Fang, Kim, & Li, 2016), and lower down-payments (Corbae & Quintin, 2015). As discussed, the features we consider most relevant for our purposes are the teaser-rates and the lower down-payments. We briefly go over the left-out characteristics, afterwards we discuss the key evidence for the features we selected.

There are several features that we do not pursue further, as they are either already examined in the literature or not of key importance in the pool of ARMs. For instance, interest-only periods are already examined (Corbae & Quintin, 2015) and are found in less than half of the subprime market during the housing boom (Chomsisengphet, Murphy, & Pennington-Cross, 2008; Levitin et al., 2019), and even less so in the prime market. Balloon payments were uncommon, reaching at best to a quarter of the subprime market during the housing boom (Chomsisengphet et al., 2008; Demyanyk & Van Hemert, 2011; Levitin et al., 2019). Even though the subprime market experienced a higher fraction of ARMs (above 60 percent) than the prime market (above 20 percent, Amromin and Paulson (2009); Chomsisengphet et al. (2008)), the rise and subsequent fall of ARMs is prevalent in both markets. Hence, we do not make a distinction between the market types, focusing on the overall mortgage market instead. Furthermore, a common characteristic of ARMs is the variable interest rate charged after the introductory period ends. We do not model this variable payment characteristic of ARMs after the introductory period ends, as the purpose of our research question is to focus on the front-loading specification embedded in these contracts which results in borrowers expecting an interest rate spike after the introductory period is over (i.e. the teaser rate structure itself).

Another common feature of the nontraditional mortgages introduced in the mid 2000s are the lower down payments, or equivalently higher LTV ratios. There are two reasons for higher observed LTV ratios of nontraditional mortgages: a difference in mortgage markets and a difference within markets. First, as the ARMs are more common in the subprime market relative to the prime market and subprime markets exhibit higher LTV ratios (Amromin, Paulson, et al., 2010; Elul, 2016), it follows that ARMs in general have higher LTV ratios than FRMs. More specifically, Amromin et al. (2010) find that LTV ratios were between three to six percentage points lower in prime relative to subprime markets for 2003-2007, similarly the debt service to income ratios were between one to four percentage points lower in prime markets. Second, even within these markets it is found that ARMs in general exhibit higher LTV ratios than FRMs (Elul, 2016; Pennington-Cross & Ho, 2010). More specifically, Elul (2016) finds that the loan to value ratios in 2005-2006 for ARMs in prime markets were one percentage point higher and in subprime markets were two percentage points higher, relative to FRMs. Pennington-Cross and Ho (2010) confirm this view for subprime markets, reporting a difference of five percentage points for the period 1998-2005. In Section 6, we compare the constructed LTV distribution from the McDash data to the resulting LTV distribution from our model.[6]

2.2 Backloaded payment structure

By focusing on the teaser-rate structure of ARMs we follow Pennington-Cross and Ho (2010), who argue that many ARMs have initial interest rates that are below the fully indexed rate. Hence, even if the market rate remains constant, the interest rate and the monthly payment for the ARM mortgagor are expected to increase after the initial period is over. In this section, we provide evidence on this.

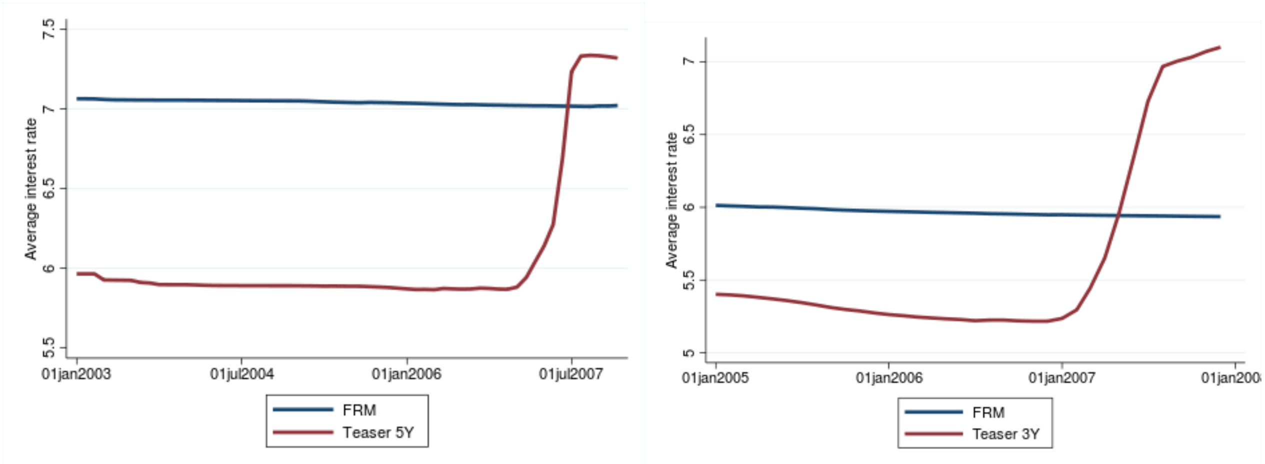
Using the McDash data, we construct various time series of average current mortgage interest rates, we do this for two distinct waves of mortgages. The first wave is composed of mortgages that were originated in the first 6 months of 2002. For this wave we compare the average interest rate faced by borrowers with a fixed rate mortgage and the average interest rate faced by borrowers with an adjustable rate mortgage with a 5-year introductory (teaser) phase. The second wave is composed of mortgages originated in the first 6 months of 2004. For this wave we compare the average interest rate faced by borrowers with a fixed rate mortgage and the average interest rate faced by borrowers with an adjustable rate mortgage with a 3-year introductory (teaser) phase. The specific waves and mortgage types were chosen carefully so that these adjustable rate mortgages had their introductory period end just before the crisis and were thus confronted with the increase in rates right before the Great Recession started.

In Figure 2, we show the average current interest rates of the mortgages described above. In Panel (a) we see that the teaser rate for 5-year adjustable rate mortgages is initially approximately 100 basis points below the fixed rate for mortgages originated in the first 6 months of 2002. Later on in 2007, right after the introductory period of 5 year ends, the rate faced by the teaser rate mortgage holders jumps above the rate paid by the fixed rate mortgagors by around 50 basis points. Similarly, in Panel (b) the 3-year adjustable rate mortgage rate starts below the fixed rate, but then jumps higher right after the introductory period ends. Appendix C shows that (a) this pattern holds even if we construct the time average only with mortgages active at the end 2007, and (b) this pattern holds even if we control for loan characteristics.

2.3 Restricted Offering of Nontraditional Mortgages in the Bust

After the introduction of the nontraditional mortgages in the early 2000s, the originations of these mortgages fell dramatically at the onset of the crisis (see Figure 1). At the same time,

[6] To construct these statistics, we use mortgages with origination years 2001-2006, using the same data selection as in Section 3.



(a) 5 Year Teasers orig. 2002m1-m6.

(b) 3 Year Teasers orig. 2004m1-m6.

Figure 2: Average current interest rates over time for (a) fixed rate and 5 year adjustable rate mortgages originated in 2002m1-2002m6, and (b) fixed rate and 3-year adjustable rate mortgages originated in 2004m1-2004m6. Figure constructed with data set of McDash. See Section 3 for the selections we make.

while the GSEs bought both prime and subprime ARMs during the boom, they severely lowered their purchases of ARMs during 2007 to 2010, resulting in an ARM share of around 2.3 percent ($27 billion) of their purchases of single-family mortgages in 2009. This tightening coincided with the Federal Housing Finance Agency (FHFA) placing the GSEs in conservatorship (Sale, 2009), to stabilize the troubled institutions.

More specifically, during 2007 to 2010, the GSEs tightened restrictions on their purchases of ARMs leading to a reduction in the purchase share of ARMs, in particular ARMs with nontraditional features and layers of risk (FHFA, 2018). For instance, in 2007 Freddie Mac discontinued purchases of ARMs with the nontraditional feature of payment-options and announced that it would “limit the use of low-documentation underwriting” for ARMs. In 2009, Fannie Mae discontinued the purchase of newly originated Alt-A loans, which primarily consisted of ARMs (Sale, 2009). In 2010, Fannie Mae updated its selling guide, requiring higher down payments and credit scores for interest-only loans. That year, Freddie Mac discontinued purchases of interest-only ARMs. Over the next few years, the ARM share of the GSEs’ single-family acquisitions remained relatively low. To explain this observation, Krainer et al. (2010) argue that government programs geared towards supporting the housing market during 2008-2009 had a potentially substantial effect on mortgage choices, favoring FRMs over ARMs. For instance, the Federal Reserve began large-scale purchases of GSE mortgage-backed securities starting in January 2009, adding significant secondary market demand for FRMs. The Fed’s purchase program did not include securities containing ARMs. This program therefore is likely to have lowered intermediaries’ incentives to provide ARMs to households, next to its (lowering) impact on the FRM interest rate.

3 Household selection in data

In this section we describe household selection into mortgage products. The goal is to identify the household characteristics choosing ARMs during the housing boom, and to show how these characteristics changed during and after the housing bust. To examine the household selection we use the Equifax Credit Risks Insight Servicing and Black Knight McDash data (CRISM) data set. This data set is a match between loan-level mortgage data from McDash and credit bureau data from Equifax, and is available beginning in June 2005. Personally identifiable information is not included in the data set. Below, we first describe the McDash data briefly, where after we describe the additional variables we use from the CRISM data set.

The McDash data is divided into a static file, whose values do not change over a time, and a dynamic file. The static file contains variables measured at time of origination, such as the loan amount, house price, FICO score at origination, mortgage documentation status, type of loan, lien type, mortgage type, occupancy type, property type, interest type, mortgage term, number of units and the loan purpose. The only relevant dynamic variable for us is the current mortgage interest rate. For the purposes of this paper we focus on 30 year first mortgages, which are meant for single unit, single family residences. In terms of the loan purpose we use only purchase and refinance mortgages. We drop all jumbo mortgages.[7] Within that selection, to reduce survival bias, we also restrict attention to loans that entered the McDash data set within 12 months of their origination date (Elul, 2016; Foote, Gerardi, Goette, & Willen, 2010).

The CRISM data set matches the McDash data with credit bureau data, thereby enriching the previous framework with borrower credit data. For the purposes of this section, we include the borrower's age and estimated income at time of origination to the selected data set. Given that the CRISM data set only starts in June 2005, we evaluate the selection over the first twelve months after the start of the data set (June 2005 to May 2006). We then focus on mortgages with a maximum LTV-ratio of 110 percent, and we focus on mortgages with a nominal value less than one million. In terms of summary statistics of the data set used, we have 5,638,128 total observations. Prime mortgages make up 90.42 percent of this data

[7] In terms of variables, we thus drop records with more than 1 unit. Moreover, we property types of COOP, 2-4 units, 5+ units, condotel, manufactured housing, manufactured home - chattel, manufactured home - land, manufactured home - land in lieu, unknown. For mortgage type, we keep first mortgages and first mortgages of grade B or C. For interest rate types, we drop ARMs/buydowns, graduated payment mortgages and buydown/subsidy loans. Hence, we only keep fixed and adjustable rate mortgages. We drop any mortgage with a purpose of anything else than purchase or refinance. We do not make a selection based on loan type (Conventional, VA, FHA, etc.).

set (5,098,129 prime vs. 539,999 subprime). Purchase mortgages are less common than refinance mortgages (2,782,827 purchase mortgages vs. 2,855,301 refinance mortgages). At last, we have that the ARM share in this data set is 33.12 percent (1,867,577 are adjustable rate while 3,770,551 mortgages are fixed rate). In Appendix D we provide summary statistics split by fixed rate and adjustable rate mortgage categories, as in Figure 1.

In the rest of this section we discuss household selection in ARMs based on age and income during the boom-period. In Appendix E, we perform an equivalent analysis using the Survey of Income and Program Participation (SIPP) from 2001 to 2008.

3.1 Household selection in mortgage products

In this section we discuss the household selection we observe during the housing boom from June 2005 up to and including May 2006, using the CRISM data set. We run a probit regression on the probability of having an ARM with age group, income group as the main independent variables, we also add other observable as control variables. In Appendix E we discuss a similar probit regression specifications using the SIPP. The income groups are constructed to have three equally sized groups within each age group (sample weighted after selections are made), while the age groups are: 18-32, 33-45, 45+.[8] The regression specification is:

$$
\begin{aligned}
\Pr(\text{ARM}) &= \beta_0 + \sum_{j=1}^{J} \beta_{1,j} \cdot \text{Agegroup}_j + \sum_{i=1}^{I} \beta_{2,i} \cdot \text{Incomegroup}_i \\
&\quad + \sum_{j=1}^{J} \sum_{i=1}^{I} \beta_{3,ji} \cdot \text{Agegroup}_j \cdot \text{Incomegroup}_i + \text{Observables} + \epsilon
\end{aligned}
\tag{1}
$$

We use four regression specifications for the probit model. First, we only use the log mortgage size and log house value as control-variables. Second, we add state and month fixed effects. In the third specification we add numerous mortgage type controls: whether the mortgage is for purchase or refinance and whether it is a prime or subprime mortgage, and loan type (conventional, conventional with PMI, VA, FHA, etc.). Fourth, we add FICO score at origination from the McDash data as an individual control variable, to show that the effects of age and income are robust to the inclusion of this potentially conflicting variable. The maximum LTV ratio allowed is 110 percent, and we focus on mortgages with a nominal value less than one million. After estimating each of these probit specifications, we report the contrasts of the predictive margins.[9] All reported coefficients in table 1 can therefore be

[8] For completeness, for age group 18-32 the income groups are $\leq 30,000$, $> 30,000$ & $\leq 41,000$, and $> 41,000$. For age group 33-45 the income groups are $\leq 38,000$, $> 38,000$ & $\leq 52,000$, and $> 52,000$. For age group 45+ the income groups are $\leq 41,000$, $> 41,000$ & $\leq 55,000$, and $> 55,000$.

[9] Relative to reporting predictive margins, this allows us to report standard errors as in a regressions output.

interpreted as the predicted probabilities (percentage point changes) for the regressors relative to the lowest income group and the lowest age group. In Appendix D, we also provide the predicted probabilities for all income and age regressor combinations. In addition, we provide the regression results for purchase mortgages only, giving similar results.

Probit regression Pr(ARM)		(1)	(2)	(3)	(4)
Income group	2	-0.0919***	-0.0739***	-0.0384***	-0.0251***
		(0.0005)	(0.0005)	(0.0005)	(0.0005)
	3	-0.0727***	-0.0422***	-0.008***	0.0152***
		(0.0005)	(0.0005)	(0.0005)	(0.0006)
Age group	33-45	-0.0601***	-0.0526***	-0.0476***	-0.0447***
		(0.0006)	(0.0006)	(0.0005)	(0.0006)
	45+	-0.0628***	-0.0622***	-0.0484***	-0.0423***
		(0.0006)	(0.0006)	(0.0005)	(0.0006)
Income · Age	2 & (33-45)	-0.0306***	-0.0212***	-0.0143***	-0.0079***
		(0.0014)	(0.0013)	(0.0013)	(0.0014)
	2 & (45+)	0.0107***	0.0163***	0.0170***	0.0253***
		(0.0014)	(0.0013)	(0.0013)	(0.0013)
	3 & (33-45)	-0.0024	0.0024	0.0075***	0.0145***
		(0.0014)	(0.0014)	(0.0013)	(0.0014)
	3 & (45+)	0.0684***	0.0666***	0.0649***	0.0727***
		(0.0014)	(0.0013)	(0.0013)	(0.0013)
House value & mortgage		Y	Y	Y	Y
Individual fixed effects		N	N	N	Y
Mortgage type controls		N	N	Y	Y
Month fixed effects		N	Y	Y	Y
State fixed effects		N	Y	Y	Y
N		5,399,556	5,399,519	5,399,519	4,695,183
R^2		0.0250	0.0583	0.1441	0.1521

$^{***}p < 0.01$, $^{**}p < 0.05$
Standard errors are in parentheses.
Mortgage type implies refinance or purchase mortgages, prime or subprime, and loan type.
We list here the contrasts of predictive margins.

Table 1: Probit regression results CRISM data set.

Table 1 shows that the households most likely to choose an ARM during the housing boom were younger low-income households. Finally, another way of presenting these results is to plot the (raw) predicted probability of choosing an ARM under regression specification (1). In Figure 3 we do this, confirm the results in table 1 and, based on the slopes over age and income, find that the age seems to be a more relevant driver of the ARM-choice (relative to income). The exact results for the CRISM data set under specfication (1) are summarized in Table 9 in the appendix.

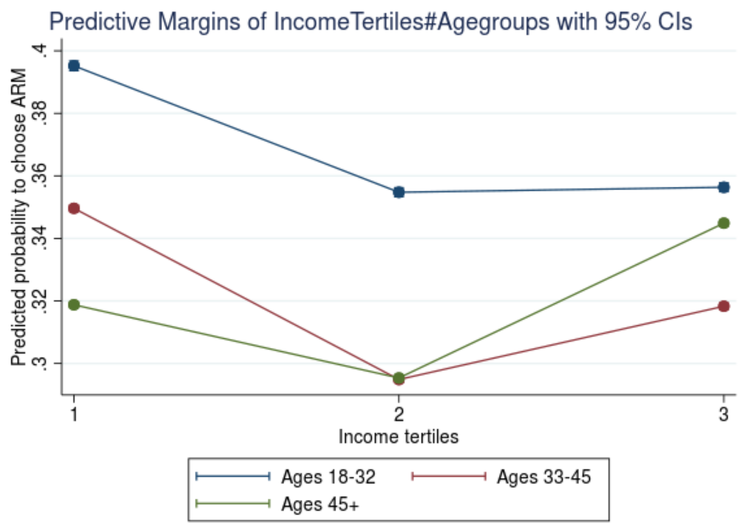


Figure 3: ARM predicted marginal effects from regression specification (1) in Table 9. Figure based on CRISM data set.

4 Model setup

The model economy consists of households, a financial intermediary, and a government sector. In this section, we discuss each of these elements in detail and define the market-clearing conditions.

4.1 Households

The household sector is populated by overlapping generations of ex-ante identical households that face both mortality risk and uninsurable labor productivity risk. The household age is denoted by j, where each household lives at maximum J periods. All households retire at age j^* and die with certainty after age J. Households have preferences over non-housing consumption c and housing services s.

The expected lifetime utility of a household is:

$$\mathbb{E}_0 \sum_{j=1}^{J} \beta^{j-1} u(c_j, s_j) + \beta^J v(\tilde{b}) = \mathbb{E} \sum_{j=1}^{J} \beta^{j-1} \left[\frac{(c_j^{\alpha_u} s_j^{1-\alpha_u})^{1-\rho_u}}{1-\rho_u} \right] + \beta^J \psi\big(log(b + \bar{b}) - 1\big) \tag{2}$$

where α_u is the share of consumption in non-housing services, and $1/\rho_u$ measures the intertemporal elasticity of substitution (IES). The last term measures the felicity from leaving bequests $\tilde{b} > 0$, where the term ψ measures the strength of the bequest motive and $\underline{b}$ measures the extent to which bequests are luxury goods (Kaplan et al., 2017).[10]

Next to the consumption decisions, households make portfolio decisions to smooth out income uncertainty. We consider two assets: a riskless financial asset b' with a real return r and a risky housing durable good h', with a market price p^h. In addition to housing being an investment good, the ownership of housing provides a flow of housing services equal to the size of the house: $s = h$. Housing investment is financed through long-term mortgage contracts and is subject to transaction costs.

Household real income during working years ($j < j^*$) is stochastic. We follow Kaplan et al. (2017) in modeling labor income. Working-age households receive an idiosyncratic labor income endowment y_j^w given by:

$$\log y_j^w = \Theta + \chi_j + \epsilon_j$$

where Θ is an index of aggregate labor productivity. Individual labor productivity has two components: (i) a deterministic age profile χ_j and (ii) an idiosyncratic component ϵ_j that follows a first-order Markov process. During the retirement years ($j \geq j^*$) we assume that a

[10]The bequest motive is in here to prevent households from selling their house and dis-saving too much during retirement.

household receives a retirement benefit θ from the government.

Given that the primary goal of this paper is to analyze how mortgage selection and restricted offering affected the housing bust, we now proceed to explain our modelling of the mortgage contracts with which households finance their housing investments.

4.1.1 Mortgage Types

In the model we use two types of mortgages. The first mortgage, representing a FRM, is characterized by constant mortgage payments over the length of the mortgage. The second mortgage, representing a TRM, is characterized by a lower introductory interest rate, at the expense of a higher interest rate in the future. Next, we list the key elements of each mortgage contract.

4.1.2 Mortgage Contract Elements

All mortgage contracts have the same fundamental elements: a down-payment, an outstanding principal, a mortgage term, an amortization schedule, and a mortgage payment schedule. Let $\mathscr{c} \in \mathbb{C} = \{1, .., C\}$ be a specific type of mortgage loan contract from the set of available contracts that the borrower can ask for to purchase a house. The mortgage contract then needs to specify the following characteristics:

- $\phi(\mathscr{c}) \in (0, 1)$, which represents the downpayment requirement.
- $D_0(\mathscr{c}) = (1 - \phi(\mathscr{c}))p^h h$, which represents the initial value of the debt owed.
- $Eq_0(\mathscr{c}) = \phi(\mathscr{c})p^h h$, which represents the initial amount of equity held by the borrower.
- $N(\mathscr{c})$, the term of the mortgage. We split the term in an initial and a residual period, i.e. $N^{in}(\mathscr{c}) + N^{re}(\mathscr{c})$. For TRMs, the first period represents the introductory phase in which the borrower pays the teaser rate. Then, the mortgagor is subsequently charged a higher interest rate in the residual $N^{re}(\mathscr{c})$ periods. FRMs can be seen as a special case, for which $N^{in}(\mathscr{c}) = 0$. [11]
- $r_t^m(\mathscr{c})$, the mortgage interest rate at time t.
- $m_t(\Omega(\mathscr{c}))$, represents the mortgage repayment schedule at time t. The set $\Omega(\mathscr{c})$ includes the relevant mortgage characteristics needed to calculate the payment schedule. We define $\Omega(\mathscr{c})$ for each mortgage contract separately.

[11] In this section we refer to t as the number of periods after origination, hence for any mortgage type $t \leq N(\mathscr{c})$.

4.1.3 Fixed Rate Mortgages (FRM)

These mortgages have a constant annuity in advance payment schedule over the term of the mortgage, with a fixed interest rate: $m_t(\Omega(\not{c}^{FRM})) = m_{t+1}(\Omega(\not{c}^{FRM})) = m(\Omega(\not{c}^{FRM}))$ and $r_t^m(\not{c}^{FRM}) = r_{t+1}^m(\not{c}^{FRM}) = r^m(\not{c}^{FRM})$. Then it can be shown that:

$$m(\Omega(\not{c}^{FRM})) = \lambda(\not{c}^{FRM}) \cdot D_0(\not{c}^{FRM}) \tag{3}$$

where $\lambda(\not{c}^{FRM})$ is the standard annuity in advance factor multiplying the initial mortgage debt, depending on r^m and N. For the the precise equation defining $\lambda(\not{c}^{FRM})$, we refer to Appendix F. There we are able to show that computing the mortgage payments and remaining debt in *any period t*, requires to keep track of (i) the initial debt balance, (ii) the mortgage interest rate at origination, (iii) the total term of a mortgage, and (iv) the periods of amortization since the mortgagor originated the contract (denoted by t),

$$\Omega(\not{c}^{FRM}) = \Big\{D_0(\not{c}^{FRM}), r^m(\not{c}^{FRM}), N(\not{c}^{FRM}), t\Big\}. \tag{4}$$

4.1.4 Teaser Rate Mortgages (TRM)

The TRMs have an introductory and a residual period: $N(\not{c}^{TRM}) = N^{in}(\not{c}^{TRM}) + N^{re}(\not{c}^{TRM})$. We use the following structure of interest rates over the mortgage term:

$$r_t^m(\not{c}^{TRM}) = \begin{cases} r^{m,in}(\not{c}^{TRM}) & t \leq N^{in}(\not{c}^{TRM}) \\ r^{m,re}(\not{c}^{TRM}) & t > N^{in}(\not{c}^{TRM}) \end{cases} \tag{5}$$

where it is the case that $r^{m,re}(\not{c}^{TRM}) > r^{m,in}(\not{c}^{TRM})$.

To compute the mortgage payments in any period, we follow a similar approach as for Equation (3). In the introductory period we can compute the mortgage payments as:

$$m^{in}(\Omega(\not{c}^{TRM})) = \lambda^{in}(\not{c}^{TRM}) \cdot D_0(\not{c}^{TRM}) \tag{6}$$

where $\lambda^{in}(\not{c}^{TRM})$ is the standard annuity in advance factor, which depends on $r^{m,in}$ and N. For the precise definition of $\lambda^{in}(\not{c}^{TRM})$, we refer to Appendix F. There we also show that for any period $t \leq N^{in}(\not{c}^{TRM})$ the remaining debt balance follows from multiplying the initial debt with an adjustment factor keeping track of the amortization up to period t: $\delta_t^{in}(\not{c}^{TRM})$,

$$D_t(\not{c}^{TRM}) = D_0(\not{c}^{TRM}) \cdot \delta_t^{in}(\not{c}^{TRM}) \tag{7}$$

$\delta_t^{in}(\not{c}^{TRM})$ itself depends on $r^{m,in}$, N, and t. For its precise definition, we refer to Appendix F. Equation (7) shows that to calculate the value of debt at any period t we do not need to keep track of the debt balance sequence, knowing the debt in period 0 suffices.[12]

[12]Notice that equation (7) also applies for the FRM.

For the adjustment period, the idea is to consider a "second" mortgage which has the following characteristics:

- $r^{m,re}(\not{c}^{TRM})$ as the interest rate[13],
- evaluate $D_t(\not{c}^{TRM})$ at the end of the introductory period, $D_{N^{in}(\not{c}^{TRM})}(\not{c}^{TRM})$, using equation (7). This will be the starting debt balance for this "second" mortgage,
- total term of the mortgage equal to $N^{re}(\not{c}^{TRM}) = N(\not{c}^{TRM}) - N^{in}(\not{c}^{TRM})$.

Using this result we can compute the mortgage payments in the adjustment period as:

$$m^{re}(\Omega(\not{c}^{TRM})) = \lambda^{re}(\not{c}^{TRM}) \cdot D_{N^{in}(\not{c}^{TRM})}(\not{c}^{TRM}) \tag{8}$$

where $\lambda^{re}(\not{c}^{TRM})$ is the standard annuity in advance factor. This factor multiplies the initial mortgage debt at the start of the residual period of a TRM, and depends on $r^{m,re}$ and N^{re}. For the exact expression, we refer to Appendix F. Similar to the mortgage payments, there we show that to compute the debt balance for any period $t > N^{in}(\not{c}^{TRM})$ we need to multiply the remaining debt at the end of the introductory period with an adjustment factor $\delta_t^{re}(\not{c}^{TRM})$, which itself depends on $r^{m,re}$, N^{re} and N^{in}, and t:

$$\begin{aligned} D_t(\not{c}^{TRM}) &= \delta_t^{re}(\not{c}^{TRM}) \cdot D_{N^{in}(\not{c}^{TRM})}(\not{c}^{TRM}) \\ &= \delta_t^{re}(\not{c}^{TRM}) \cdot \delta_{N^{in}(\not{c}^{TRM})}^{in}(\not{c}^{TRM}) \cdot D_0(\not{c}^{TRM}) \end{aligned} \tag{9}$$

where the last line follows from substituting expression (7). It shows that the only debt balance we need to keep track is that at origination. In sum, to compute mortgage payments and remaining debt in any period for the TRMs, we need to know the set,

$$\Omega(\not{c}^{TRM}) = \{D_0(\not{c}^{TRM}), N(\not{c}^{TRM}), N^{re}(\not{c}^{TRM}), r^{m,in}(\not{c}^{TRM}), r^{m,re}(\not{c}^{TRM}), t\} \tag{10}$$

In the model we simplify the state variables in (4) and (10) required to compute these expression by setting a fixed term for both mortgages $N(\not{c}^{TRM}) = N(\not{c}^{FRM}) = N$, setting a fixed term for the introductory period of the TRM $N^{in}(\not{c}^{TRM}) = N^{in}$, and calibrating the differential rates at origination between the two mortgages that matches the empirical spread, as shown in section 2.3, which pins down $r^{m,in}(\not{c}^{TRM})$. For any mortgage then we just need to track initial debt D_0, the periods since origination t, and the interest rates that solves the problem of the financial intermediary at origination, as described in section 4.2.

4.1.5 Decisions and Value Functions

In each period the agent starts in one of three states: Renter (R), Owner (O) or Defaulter (D).

[13] Computed from a zero profit condition that solves the problem of the financial intermediary described in detail in section 4.2.

- **Renter:** A renter can decide to either buy a house (B) or keep renting (R). Notice that by buying a house these agents will decide which type of mortgage they prefer, $\not{c}$.
- **Owner:** An owner can choose between five actions: keeping the current mortgage (K), selling (S), refinancing (RF), moving (M), or defaulting (D). When a household keeps the current mortgage it has to make the corresponding mortgage payments. Selling a house implies that the household becomes a renter for the rest of this period. Refinancing implies households choosing a different mortgage. Moving implies that the household sells the house and buys a different house in the same period. Defaulting implies that the household does not have to pay current mortgage payments, forcibly goes into renting, and loses the house but also its debt obligations. Agents at the end of life sell all their housing assets.
- **Defaulter:** A defaulter rents this period, but could exit the default stage next period with an exogenous probability. The defaulter incurs a defaulting penalty each period.

The state variable for each of these cases can be summarized as follows, where we keep track of age, income shock, assets, contract choice, mortgage states (MS), and aggregate states (AS) of the economy. To be more specific, $\not{c}$ represents the mortgage type that the agent chooses: $\not{c} \in \{frm, trm, no\}$. no means that the agent doesn't hold a mortgage. The mortgage states are: house, debt, initial interest rate, final interest rate, mortgage time left until full amortization ($n \leq N$) and mortgage remaining term (which is relevant only for TRMs). We specify the MS states for each contract choice separately. The aggregate states are the measures over the individual states. We generally describe the state variables (z) to be: $z \in \{j, y, b, \not{c}, MS, AS\}$. Next, we list the states for the owner, the renter and defaulter separately:

- **Owner:** $z = \{j, y, b, \{frm, trm\}, MS, AS\}$, and $MS = \{h, D, r^{m,in}, r^{m,re}, n, N^{re}\}$
  - For the FRM: $MS = \{h, D, 0, r^m, n, N\}$
  - For the TRM: $MS = \{h, D, r^{m,in}, r^{m,re}, n, N^{re}\}$
- **Renter and Past Defaulter:** $z = \{j, y, b, no, MS, AS\}$, and $MS = \{0, 0, 0, 0, 0, 0\}$
- **New Defaulter:** $z = \{j, y, b, \{frm, trm\}, MS, AS\}$, and $MS = \{h, D, r^{m,in}, r^{m,re}, n, N^{re}\}$.
  - For the FRM: $MS = \{h, D, 0, r^m, n, N\}$
  - For the TRM: $MS = \{h, D, r^{m,in}, r^{m,re}, n, N^{re}\}$

4.1.6 Renters

An agent who begins the period as a renter can either stay a renter or buy a house. Hence, the agent has the following lifetime utility:

$$\bar{V}^R(j, b, y) = \max\{V^R(j, b, y), V^B(j, b, y)\} \tag{11}$$

where $V_t^B(z)$ is the value of the agent choosing to buy a house, and $V_t^R(z)$ is the value of an agent choosing to stay renting.

An agent that buys a house has to choose the house size, the mortgage balance, and the type of mortgage she wants to have. At time of origination, the mortgage loan has to satisfy an LTV and debt-service to income (DTI) constraint.[14] As a new owner, the buyer has to pay a fixed exogenous housing maintenance cost in proportion to the house size νh. Finally, a buyer pays a cost of buying the house F^{buy} (i.e. transaction costs), and a cost of originating a mortgage F^{orig} (i.e. mortgage fees paid to originator).

$$
\begin{gathered}
V_t^B(z) = \max_{c,b',h',D',\not{c}'} \{u(c,h') + \beta \mathbb{E}[\bar{V}_{t+1}^O(z')]\} \\
s.t. \\
c + (1+F^{buy})p^h h' + \frac{b'}{1+r} + m + \nu h' + F^{orig}(D'>0) = y + b + D' \\
\not{c}' \in \{frm, trm\} \\
D' \leq \phi^{LTV}(\not{c}')p^h h' \\
m \leq \phi^{DTI}(\not{c}')y \\
n' = N(\not{c}') - 1 \\
r^m = \begin{cases} r^{frm} & \not{c}' = frm \\ r^{trm,in} & \not{c}' = trm \end{cases} \\
m = \begin{cases} \lambda^{frm} \cdot D' & \not{c}' = frm \\ \lambda^{trm,in} \cdot D' & \not{c}' = trm \end{cases}
\end{gathered} \tag{12}
$$

A renter solves the following maximization problem:

$$
\begin{gathered}
V_t^R(z) = \max_{c,b'} \{u(c,s) + \beta \mathbb{E}[\bar{V}_{t+1}^R(z')]\} \\
s.t. \\
c + p_r s + \frac{b'}{1+r} = b + y
\end{gathered} \tag{13}
$$

where p_r is the price of housing services available for rent.

At the buying stage, agents have to decide on three dimensions: house, mortgage size, and contract type. On top of that we assume that agents face an extreme value shock on the mortgage type choice, which makes the timing of the shock and choice variables non trivial. The *timing* assumptions we make on it are as follows:

1. When deciding to buy, agents ex-ante decide the house size, and the mortgage size for each feasible mortgage type (some agents might not be able to fund the housing purchase with one of the two mortgages).

[14] We also refer to this DTI constraint as a payment to income (PTI) constraint.

2. The extreme value shock is realized, based on this agents decide one of the two mortgages.

3. Since the house and mortgage size decisions were taken ex-ante, the new homeowners just need to adjust consumption and savings accordingly to satisfy their budget constraint.

We assume this timing only for tractability, in particular the expected value function at the moment of purchase will not depend on the whole set of houses available and the whole set of mortgage size, only on the extreme value shock.

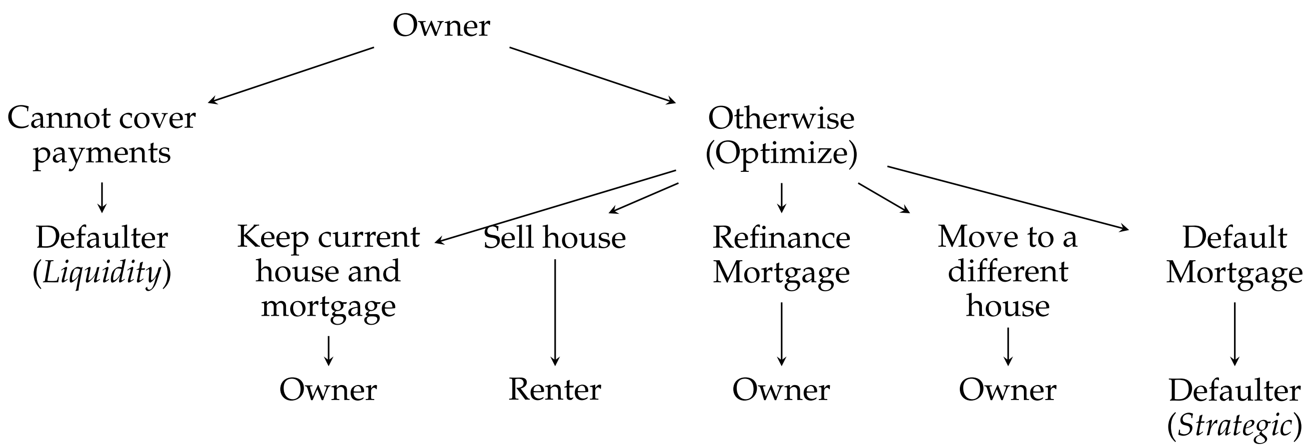
4.1.7 Owners

An owner faces three payments: the mortgage payment due (m, if any), a fixed exogenous housing maintenance cost (νh) and an idiosyncratic housing maintenance shock ($\phi^{liq} p^h h$). The agent also faces a perfectly correlated idiosyncratic housing value shock ($\phi^{eq} p^h h$) to the value of its house.

For simplicity we assume that $\phi^{liq} \in \{0, \bar{\phi}^{liq}\}$, and $\phi^{eq} \in \{\bar{\phi}^{eq}, 1\}$, where $\bar{\phi}^{liq}$ and $\bar{\phi}^{eq}$ are strictly between zero and one. Furthermore, we assume that these two exogenous shocks are perfectly correlated and i.i.d. with some probability $\Pr(\bar{\phi}^{liq}) = \Pr(\bar{\phi}^{eq})$. These two shocks are meant to reflect the risks of owning a house, potentially inducing default.

Given the shocks realization, an owner faces two possible situations: (1) she cannot make the mortgage and maintenance cost payments this period, (2) she can make the mortgage and maintenance cost payments this period. In case (1), the homeowner is forced to default. In case (2), the homeowner can choose either to keep the current house and mortgage, sell the house, refinance the mortgage debt, move to a different house or default on her mortgage. Hence, under case (2), default is still an option.

We will refer to the default in case (1) as *liquidity default*, and the one coming from case (2) as *strategic default*. The decision tree of the owner is shown below:



Situation 1: cannot make mortgage payment due

If the owner cannot make its mortgage payments and the total maintenance costs in the current period ($m + \nu h + \phi^{liq} p^h h > b + y$) then she is forced to default. We can calculate the mortgage payments due at the beginning of the period as:

$$D' = \begin{cases} D_0 & \not{c}' = frm \\ D_0 & \not{c}' = trm \ \ \& \ \ n' \geq N^{re}(\not{c}') \\ \delta^{trm,in}_{N(\not{c}) - N^{re}(\not{c})} \cdot D_0 & \not{c}' = trm \ \ \& \ \ n' < N^{re}(\not{c}') \end{cases}$$

$$m = \begin{cases} \lambda^{frm} \cdot D' & \not{c}' = frm \\ \lambda^{trm,in} \cdot D' & \not{c}' = trm \ \ \& \ \ n' \geq N^{re}(\not{c}') \\ \lambda^{trm,re} \cdot D' & \not{c}' = trm \ \ \& \ \ n' < N^{re}(\not{c}') \end{cases}$$

Her lifetime utility is then given by:

$$\bar{V}^O_t(z_t) = V^D_t(z_t) \tag{14}$$

where $V^D_t(z_t)$ is the value function of a defaulter. We give an explicit expression for it in the following sections.

Situation 2: can make mortgage payment due

A second possible situation is when the owner who begins the period with a mortgage of type $\not{c}$ is able to make its mortgage and maintenance payments and maintenance ($m + \nu h + \phi^{liq} p^h h \leq b + y$). Then, her lifetime utility is given by:

$$\bar{V}^O_t(z_t) = \max\{V^K_t(z_t), V^D_t(z_t, V^S_t(z_t), V^{RF}_t(z_t), V^M_t(z_t))\} \tag{15}$$

The owner thus can keep the house, default on the mortgage, sell, refinance, or move. Note that the latter three actions all involve incurring a case-specific fixed transaction cost, relative to keeping the house. An owner who does not default on the mortgage, sell, refinance, or move solves the following problem:

$$
\begin{gathered}
V_t^K(z) = \max_{c,b'}\{u(c,h') + \beta\mathbb{E}[\bar{V}_{t+1}^O(z')]\} \\
s.t. \\
c + \frac{b'}{1+r} + m + \nu h + \phi^{liq} p^h h = b + y \\
h' = h \\
\not{c}' = \not{c} \\
n' = n - 1 \\
r^m = \begin{cases} r^{frm} & \not{c}' = frm \\ r^{trm,in} & \not{c}' = trm \;\; \& \;\; n' \geq N^{re}(\not{c}') \\ r^{trm,re} & \not{c}' = trm \;\; \& \;\; n' < N^{re}(\not{c}') \end{cases} \\
D' = \begin{cases} D_0 & \not{c}' = frm \\ D_0 & \not{c}' = trm \;\; \& \;\; n' \geq N^{re}(\not{c}') \\ \delta^{trm,in}_{N(\not{c})-N^{re}(\not{c})} \cdot D_0 & \not{c}' = trm \;\; \& \;\; n' < N^{re}(\not{c}') \end{cases} \\
m = \begin{cases} \lambda^{frm} \cdot D' & \not{c}' = frm \\ \lambda^{trm,in} \cdot D' & \not{c}' = trm \;\; \& \;\; n' \geq N^{re}(\not{c}') \\ \lambda^{trm,re} \cdot D' & \not{c}' = trm \;\; \& \;\; n' < N^{re}(\not{c}') \end{cases}
\end{gathered}
\tag{16}
$$

The agent who is an owner and sells the house will transit to the renting stage, and has to repay the current mortgage balance. It then solves the problem as if it started the period without any housing, with financial assets equal to its saved assets plus the net proceeds from selling the house. It also faces some selling costs equal to F^{sell}, which are proportional to the house value. Notice that selling the house might come at a cost if the agent suffers the unexpected shock $\bar{\phi}^{eq}$[15]. The seller thus solves the following problem:

$$
\begin{gathered}
V_t^S(z) = \max_{c,b'}\{u(c,s) + \beta\mathbb{E}[\bar{V}_{t+1}^R(z')]\} \\
s.t. \\
c + \frac{b'}{1+r} + p_r s + D^{sell} + F^{sell} p^h h = b + y + \phi^{eq} p^h h \\
h' = 0 \\
D^{sell} = \begin{cases} \delta^{frm}_{N(\not{c})-n} \cdot D & \not{c} = frm \\ \delta^{trm,in}_{N(\not{c})-n} \cdot D & \not{c} = trm \;\; \& \;\; n \geq N^{re}(\not{c}) \\ \delta^{trm,re}_{N(\not{c})-n} \cdot D & \not{c} = trm \;\; \& \;\; n < N^{re}(\not{c}) \end{cases}
\end{gathered}
\tag{17}
$$

The agent can also choose to refinance, this homeowner incurs some refinancing costs equal to F^{refi}, on top of the origination cost for the newly originated mortgage F^{orig}. The

[15]In other words, if the shock is large enough the agent might decide to default instead

agent who is an owner and refinances solves:[16]

$$
\begin{gathered}
V_t^{RF}(z) = \max_{c,b',D',\cancel{c}'} \{u(c,h') + \beta \mathbb{E}[\bar{V}_{t+1}^{O}(z')]\} \\
s.t. \\
c + \frac{b'}{1+r} + m + D^{refi} + F^{refi} + F^{orig}(D' > 0) + \nu h = b + y + D' \\
\cancel{c}' \in \{frm, trm\} \\
D' \leq \phi^{LTV}(\cancel{c}')p^h h' \\
m \leq \phi^{DTI}(\cancel{c}')y \\
n' = N(\cancel{c}') - 1 \\
h' = h \\
D^{refi} = \begin{cases} \delta^{frm}_{N(\cancel{c})-n} \cdot D & \cancel{c} = frm \\ \delta^{trm,in}_{N(\cancel{c})-n} \cdot D & \cancel{c} = trm \;\; \& \;\; n \geq N^{re}(\cancel{c}) \\ \delta^{trm,re}_{N(\cancel{c})-n} \cdot D & \cancel{c} = trm \;\; \& \;\; n < N^{re}(\cancel{c}) \end{cases} \\
r^m = \begin{cases} r^{frm} & \cancel{c}' = frm \\ r^{trm,in} & \cancel{c}' = trm \end{cases} \\
m = \begin{cases} \lambda^{frm} \cdot D' & \cancel{c}' = frm \\ \lambda^{trm,in} \cdot D' & \cancel{c}' = trm \end{cases}
\end{gathered}
\tag{18}
$$

The agent who is an owner and moves has to repay the current mortgage balance and can choose to live in another house (with a corresponding new mortgage). This homeowner incurs some moving costs equal to F^{move}, on top of the origination cost for the newly originated mortgage F^{orig}, and the transaction costs of buying a new home F^{buy}.

[16] Notice that since we are assuming payments are done in advance, the homeowner will only pay the principal coming from the old mortgage, and the interest paid will come from the new mortgage. Notice that the values of δ related to D^{refi} are calculated using the interest rates from the old mortgage. On the other hand, the values of λ related to m are calculated using the fixed rate mortgage from the new mortgage if $\cancel{c}' = frm$, and using the rate of the introductory period of the new mortgage if $\cancel{c}' = trm$.

$$V_t^M(z) = \max_{c,b',h',D',\cancel{c}} \{u(c,h') + \beta \mathbb{E}[\bar{V}_{t+1}^O(z')]\}$$

$$s.t.$$

$$c + \frac{b'}{1+r} + m + D^{move} + (1+F^{buy})p^h h' + F^{move} + \nu h' + F^{orig}(D'>0) = b + y + \phi^{eq} p^h h + D'$$

$$D^{move} = \begin{cases} \delta^{frm}_{N(\cancel{c})-n} \cdot D & \cancel{c} = frm \\ \delta^{trm,in}_{N(\cancel{c})-n} \cdot D & \cancel{c} = trm \ \ \& \ \ n \geq N^{re}(\cancel{c}) \\ \delta^{trm,re}_{N(\cancel{c})-n} \cdot D & \cancel{c} = trm \ \ \& \ \ n < N^{re}(\cancel{c}) \end{cases}$$

$$\cancel{c}' \in \{frm, trm\}$$

$$D' \leq \phi^{LTV}(\cancel{c}')p^h h'$$

$$m \leq \phi^{DTI}(\cancel{c}')y$$

$$n' = N(\cancel{c}') - 1$$

$$r^m = \begin{cases} r^{frm} & \cancel{c}' = frm \\ r^{trm,in} & \cancel{c}' = trm \end{cases}$$

$$m = \begin{cases} \lambda^{frm} \cdot D' & \cancel{c}' = frm \\ \lambda^{trm,in} \cdot D' & \cancel{c}' = trm \end{cases} \tag{19}$$

4.1.8 Defaulters

Lastly, the homeowner can default on her mortgage. We ssume a defaulter incurs a persistent linearly added disutility from being in the default stage, a term which we call u^{def}. In addition, the new defaulter will have limited access to credit markets while the it is flagged as a defaulter. The agent exits this stage only with some probability ψ^d. Furthermore, χ represents the foreclosure costs, while D^{def} can be computed using the same formula as D^{refi}. The defaulter solves:

$$V_t^D(z) = \max_{c,b'} \{u(c,s) + \beta \mathbb{E}[\psi^d \cdot \bar{V}_{t+1}^R(z') + (1-\psi^d) \cdot V_{t+1}^D(z')]\}$$

$$s.t.$$

$$c + \frac{b'}{1+r} + p_r s = b + y + I^{def} \tag{20}$$

$$h' = 0$$

$$I^{def} = \begin{cases} \max\{(1-\chi)p^h h - D^{\text{def}}, 0\} & h \neq 0 \\ 0 & h = 0 \end{cases}$$

The agent can default for two reasons. The first one is strategic default. Intuitively this case will likely occur when the house equity turns negative ($p^h \cdot h < D$), hence the agent will walk away from the contract by giving the lender the collateral (the house), and since there is no-recourse in this model the agent will only pay the default costs F^{def} for the following periods in which she remains in the default stage. The second one is liquidity default, and happens whenever the agent is not able to keep up with the mortgage payments and total maintenance costs.

4.2 Financial Intermediaries

We assume the lender (facing perfect competition) has deep pockets, is owned by foreign agents, and hence is risk neutral. Let $(\mathcal{c}, z_0^L)$ denote the tuple of mortgage characteristics at origination, where $\mathcal{c}$ denotes the contract choice, and $z_0^L = (j, y, b, D_0, h)$ denotes the initial mortgagor characteristics. The lender discounts the future at some exogenous rate r_i.

As discussed, households can choose to take FRMs or TRMs. The problem of the lender is to choose a tuple of interest rates:

$$r_t^L = \left\{ r_t^{FRM}, \{ r_{t,init}^{TRM}, r_{t,final}^{TRM} \} \right\}$$

where the interest rates are set to satisfy the expected zero profit condition product by product, allowing for cross-subsidization within the same mortgage product. We define $\mathbb{1}^F(z_0^L) = 1$ and $\mathbb{1}^T(z_0^L) = 1$ as the indicator functions for agents with z_0^L characteristics choosing the FRM and TRM contracts respectively. We use two zero profit conditions to pin down r_t^{FRM}, and $r_{t,final}^{TRM}$. We pin down $r_{t,init}^{TRM}$ by assuming an exogenous initial spread between FRMs and TRMs, as observed in the data. Below, we discuss the zero-profit conditions for the lender for each mortgage product.

4.2.1 FRMs

The value to the lender of issuing FRMs is specified below.

$$\mathbb{W}_0^F = \int_{\mathbb{1}^F(z_0^L)=1} \left(m(r^{FRM}, z_0^L) + E_0 \left[\frac{1}{1+r_i} \cdot W_1^F(z', z_0^L) \right] \right) d\mu(z_0^L)$$

where $z' = \{j+1, y', b'(z_0^L), D_0, h\}$. The lender prices default, and prepayments risk. The continuation values are (for $0 < t < N$):

$$\begin{aligned} W_t^F(z, z_0^L) = &\ \mathbb{1}^{F,pay}(z) \cdot \left(m(r^{FRM}, z_0^L) + E_t \left[\frac{1}{1+r_i} W_{t+1}^F(z', z_0^L) \right] \right) \\ &+ \mathbb{1}^{F,def}(z) \cdot min \left\{ (1-\chi) p_h h, D_t^{rem} \left(r^{FRM}, z_0^L \right) \right\} \\ &+ \left(\mathbb{1}^{F,move}(z) + \mathbb{1}^{F,refi}(z) + \mathbb{1}^{F,sell}(z) \right) D_t^{rem} \left(r^{FRM}, z_0^L \right) \end{aligned}$$

where D_t^{rem} is the loan balance at period t. Hence the zero profit condition is:

$$\mathbb{W}_0^F(z_0^L) = \int_{\mathbb{1}^F(z_0^L)=1} \Big(D_0(z_0^L) \Big) d\mu(z_0^L) \tag{21}$$

What comes out of this problem is the interest rate r_t^{FRM} for any period t. The interest rate on a FRM at some period t is potentially different that the interest rate on a FRM originated at some period $t' \neq t$. In this setup, we account for differences not only on the aggregate state at the origination period but also on differences in the distribution of mortgagors originating FRMs.

4.2.2 TRMs

The value to the lender of issuing TRMs is specified below.

$$\mathbb{W}_0^T = \int_{\mathbb{1}^T(z_0^L)=1} \left(m(r_{init}^{TRM}, z_0^L) + E_0 \left[\frac{1}{1+r_i} \cdot W_1^T(z', z_0^L) \right] \right) d\mu(z_0^L)$$

where $z' = \{j+1, \epsilon', b'(z_0^L), D_0, h\}$. The continuation value for the lender during the initial period ($0 < t < N^{T,init}$) is:

$$\begin{aligned} W_t^T(z, z_0^L) = \mathbb{1}^{T,pay}(z) \cdot \left(m(r_{init}^{TRM}, z_0^L) + E_t \left[\frac{1}{1+r_i} \cdot W_{t+1}^T(z', z_0^L) \right] \right) + \\ + \mathbb{1}^{F,def}(z) \cdot min \left\{ (1-\chi) p_h h, D_t^{rem} \left(r_{init}^{TRM}, z_0^L \right) \right\} \\ + \left(\mathbb{1}^{F,move}(z) + \mathbb{1}^{F,refi}(z) + \mathbb{1}^{F,sell}(z) \right) D_t^{rem} \left(r_{init}^{TRM}, z_0^L \right) \end{aligned}$$

where D_t^{rem} is the loan balance at period t. Then, in the adjustment (final) period ($N^{T,init} \leq t < N$):

$$\begin{aligned} W_t^T(z, z_0^L) = \mathbb{1}^{T,pay}(z) \cdot \left(m(r_{final}^{TRM}, z_0^L) + E_t \left[\frac{1}{1+r_i} \cdot W_{t+1}^T(z', z_0^L) \right] \right) + \\ + \mathbb{1}^{F,def}(z) \cdot min \left\{ (1-\chi) p_h h, D_t^{rem} \left(r_{final}^{TRM}, z_0^L \right) \right\} \\ + \left(\mathbb{1}^{F,move}(z) + \mathbb{1}^{F,refi}(z) + \mathbb{1}^{F,sell}(z) \right) D_t^{rem} \left(r_{final}^{TRM}, z_0^L \right) \end{aligned}$$

Hence the zero profit condition is:

$$\mathbb{W}_0^T = \int_{\mathbb{1}^T(z_0^L)=1} \Big(D_0(z_0^L) \Big) d\mu(z_0^L) \tag{22}$$

What comes out of this problem is the interest rate at the adjustment period $r_{t,final}^{TRM}$ for any period t. The interest rate on a TRM during the adjustment phase at some period t is potentially different that the interest rate on a TRM during the adjustment phase originated at some period $t' \neq t$. In this setup, we account for differences not only on the aggregate state at the origination period but also on differences in the distribution of mortgagors originating TRMs.

4.3 Market clearing and equilibrium

There are two markets to clear for the equilibrium to hold: the housing market and the mortgage market. We describe both market clearing conditions in the equilibrium definition below.

In the definition of the equilibrium we denote the vector of individual states as $\tilde{z} = \{j, y, b, \{frm, trm, no\}, MS\}$.

The aggregate states AS = $\mu(z)$, where we define $\mu(\tilde{z}) = \{\mu_j^o(\tilde{z}), \mu_j^r(\tilde{z}), \mu_j^d(\tilde{z})\}_{j=1}^J$ such that

$$\sum_{j=1}^{J} \int_{\tilde{z}} \left(\mu_j^o(z) + \mu_j^r(z) + \mu_j^d(z)\right) dz = 1$$

Then, a Recursive Competitive Equilibrium (RCE) consists of:

- Value Functions: $\{\bar{V}^R(\tilde{z}, AS), V^R(\tilde{z}, AS), V^B(\tilde{z}, AS), \bar{V}^O(\tilde{z}, AS), V^K(\tilde{z}, AS), V^S(\tilde{z}, AS),$ $V^{RF}(\tilde{z}, AS), V^M(\tilde{z}, AS), V^D(\tilde{z}, AS)\}$,
- Decision Rules for Renters, Owners and Defaulters: $\{g^B(\tilde{z}, AS), g^R(\tilde{z}, AS), g^K(\tilde{z}, AS), g^S(\tilde{z}, AS),$ $g^{RF}(\tilde{z}, AS), g^M(\tilde{z}, AS), g^D(\tilde{z}, AS)\}$,
- Policy Functions that are common to all Renters, Owners and Defaulters: $c^O(\tilde{z}, AS)$, $c^R(\tilde{z}, AS), c^D(\tilde{z}, AS), b'^O(\tilde{z}, AS), b'^R(\tilde{z}, AS), b'^D(\tilde{z}, AS)$,
- Housing and Mortgage related Policy Functions that are common to Buyers, Movers and Refinancers: $h'^B(\tilde{z}, AS), h'^M(\tilde{z}, AS), h'^{RF}(\tilde{z}, AS), D'^B(\tilde{z}, AS), D'^M(\tilde{z}, AS), D'^{RF}(\tilde{z}, AS)$, $\tilde{c}'^B(\tilde{z}, AS), \tilde{c}'^M(\tilde{z}, AS), \tilde{c}'^{RF}(\tilde{z}, AS)\}$,
- A rental price p^r, a house price function $p^h(AS)$, and mortgage pricing functions $\{r^F, \{r^T_{init}, r^T_{final}\}\}$,
- A rental stock and a property housing stock.

such that:

1. Given prices p^r, $p^h(AS)$ and $\{r^F, \{r^T_{init}, r^T_{final}\}\}$, households optimize, by solving equations (11)-(20), with associated value functions, policy functions and decision rules.

2. The financial intermediary chooses the set of interest rates $\{r^F, \{r^T_{init}, r^T_{final}\}\}$ such that the zero profit conditions product by product determined by equations (21)-(22) hold.

3. The rental market clears at price p^r.

4. The housing market clears at price p^h, where net inflow equals net outflow:

$$\sum_{j=1}^{J-1} \Big[\int_{\tilde{z}} (g^{sell}(\tilde{z}, AS) + g^{def}(\tilde{z}, AS) + g^{move}(\tilde{z}, AS)) d\mu_j \Big] + \int_{\tilde{z}} \mathbb{1}\{h_J(\tilde{z}, AS) \neq 0\} d\mu_J$$
$$= \sum_{j=1}^{J} \Big[\int_{\tilde{z}} (g^{buy}(\tilde{z}, AS) + g^{move}(\tilde{z}, AS)) d\mu_j \Big]$$

The left-hand-side represents the inflow of houses on the owner-occupied market, which equals the sales of houses by owners and by movers, and sales of foreclosed properties by financial intermediaries. In addition, there is an inflow of houses sold on the market when the wills of the deceased are executed. The right-hand represents outflows, which equals owner-occupied houses purchased by new buyers and by movers.

5 Calibration

5.1 Demographics

The model period is equivalent to three years of life. Households enter the model at age 20 (model period 1), retire at age 65 (corresponding to $j^* = 16$) and live until age 86 (corresponding to $J = 23$). We assume equal sized cohorts, i.e. $\mu_j = 1/J$. In addition, using our model period of 3 years with a $52,000 median annual household wage income from the 1998 SCF, we have that one unit in the model equals $78,000.

5.2 Preferences

Period utility is given by:

$$u(c, s) = \frac{(c^{\alpha_u} s^{1-\alpha_u})^{1-\rho_u}}{1-\rho_u}$$

where α_u is the share of consumption in non-housing services, and $1/\rho_u$ measures the intertemporal elasticity of substitution (IES). Additionally, following Kaplan et al. (2017) we assume that the utility function for those agents in their last period of life (J) is:

$$u(c, h) = \frac{(c^{\alpha_u} s^{1-\alpha_u})^{1-\rho_u}}{1-\rho_u} + \beta\psi log(b + \bar{b}) \quad \text{for } t = J$$

The discount factor is determined by $\beta = \left(\frac{1}{1+\rho}\right)^3$ where $\rho = 0.04$. The bequest parameters are set to $\bar{b} = 5$ and $\psi = 12$, the latter is calibrated to better match the LTV distribution. The housing preference parameter is set to match the share of housing consumption in the utility function, and is set to $\alpha = 0.2$.

5.3 Endowments

Workers are assumed to have an inelastic labor supply, however the effective quality of this labor will depend on three components. The first component is an aggregate component Θ, which in the steady state we set to equal one. The second component is an age-specific component of income, which allows us to capture the humped-shaped profile of earnings over the life cycle. We take this profile from Hansen (1993). The third component captures the stochastic elements of earnings. This component of earnings (ϵ) is modeled as an AR(1) process with annual persistence of 0.925 and annual standard deviation of innovations of 0.25. We discretize this income process into a three-state Markov chain using the Rouwenhorst (1995) methodology. The associated values of ϵ are:

$$\epsilon \in \{1.1474, 1.8823, 3.0879\}$$

The associated transition matrix is:

$$\Pi(\epsilon'|\epsilon) = \begin{pmatrix} 0.8556 & 0.1387 & 0.0056 \\ 0.0694 & 0.8613 & 0.0694 \\ 0.0056 & 0.1387 & .08556 \end{pmatrix}$$

Each household is born with an initial asset position. This assumption is made to account for the fact that some of the youngest households who purchase housing have some wealth.

5.4 Housing

We have a discrete set of owner-occupied house sizes, $h \in \mathbb{H}$. We use $\mathbb{H} = \{1.5\}$. The rental house size is normalized to be 1, so that the average own to rent house size is 1.5 as in Chatterjee and Eyigungor (2012). We assume the fixed and exogenous maintenance costs (ν) in proportion to the house size. We set ν such that the annual maintenance cost is around \$2,500. This is consistent with estimates in the literature of Davidoff (2004).

When the agent does not default, she can choose between keeping the house, selling, moving or refinancing. We calibrate the respective fixed transaction costs for each of these to get similar shares than the ones observed in the data[17]. We calibrate these to be: $F^{sell} = 0.1$, $F^{move} = 0.3$, and $F^{refi} = 0.1$.

[17] On this version of the model we ony allow for selling.

For the idiosyncratic maintenance shock we assume $\bar{\phi}^{liq} = 0.5$, which implies that $\phi^{liq} \in \{0, 0.5\}$. On the other hand, for the idiosyncratic shock to the value of housing we assume $\bar{\phi}^{eq} = 0.85$, which implies that $\phi^{eq} \in \{0.85, 1\}$. These shocks occur with equal probabilities: $\Pr(\bar{\phi}^{liq}) = \Pr(\bar{\phi}^{eq}) = 0.007$.

When the agent suffers default, she incurs fixed utility default cost as long as she remains in the default state. These utility costs are equal to $u^{def} = 0.5$. As is common in the literature, the foreclosure loss is 22 percent, and the agent exits this default stage (and becomes a renter) with probability 0.8.

5.5 Mortgages

In this paper we focus on 30 year mortgages. As each model period is equivalent to 3 years, we set the mortgage length to $N = 10$. In line with the data we set the introductory period of TRMs to two periods, i.e. $N_{init} = 2$. We set the maximum LTV and DTI ratios as: $\phi^{DTI}_{FRM} = 0.5$, $\phi^{DTI}_{TRM} = 0.50$, $\phi^{LTV}_{FRM} = 0.85$, $\phi^{LTV}_{TRM} = 0.85$.

Table 2 lists each of the parameters:

Parameter	Value	Interpretation	Basis
Demographics			
J	23	Life 20-86	Standard in the literature
$j*$	16	Retire at 65	Standard in the literature
Preferences			
ρ_u	2	Risk aversion	Standard in the literature
α_u	0.8	Share non-housing in utility	Standard in the literature
β	1/(1+.04)	Annual discount factor	Standard in the literature
ψ	3	Strength bequest motive	Targeted
$\bar{b}$	5	Extent luxury goods bequest	Targeted
Endowments			
σ_ϵ	0.35	S.D. of earnings shocks	Standard in the literature
ρ_ϵ	0.925	Autocorrelation of earnings	Standard in the literature
b_0	$0.65y_0$	Initial wealth	Hatchondo, Martinez, and Sánchez (2015)
χ_j	-	Deterministic life-cycle profile	Hansen (1993)
θ	$0.4\ \bar{y}_{j^*-1}$	Retirement income	Kaplan et al. (2017)
Transitions			
ψ^d	0.80	Probability exit default stage	Standard in the literature
Houses			
$\mathbb{H}$	[1.5]	Owner-occupied house sizes	Chatterjee and Eyigungor (2012)
ν	0.1316	Fixed housing maintenance costs	\$2,500 annual maintenance costs
$\bar{\phi}^{liq}$	0.5	Housing maintenance shock	Targeted
$\bar{\phi}^{eq}$	0.85	Housing equity shock	Targeted
$\Pr(\bar{\phi}^{liq}) = \Pr(\bar{\phi}^{eq})$	0.006	Probability of Housing Shocks	Targeted
H_s	2/3	Fixed weighted housing supply	Standard in the literature
F^{sell}	0.1	Selling cost	Standard
F^{refi}	0.1	Fixed refinance cost	\$6,000 refinancing cost
F^{orig}	0.1	Fixed origination cost	\$6,000 origination cost
F^{move}	0.3	Fixed moving cost	Targeted
u^{def}	0.5	Utility Default costs each period	0.5% annual default
r	0.01	Free risk interest rate (Annual)	Standard in the literature
χ	0.22	Foreclosure loss	Kaplan et al. (2017)
Mortgages			
N	10	Mortgage length	30 year mortgages
N^{init}	2	Teaser mortgage initial period length	McDash Data
LTV_{FRM}	0.85	loan to value threshold FRM	Standard in the literature
LTV_{TRM}	0.85	loan to value threshold TRM	Standard in the literature
PTI_{FRM}	0.50	payment to income threshold FRM	Standard in the literature
PTI_{TRM}	0.50	payment to income threshold TRM	Standard in the literature

Table 2: Parameter values. The model period is three years. All values for which the time period is relevant are reported here annualized.

6 Steady State

In this section we present main results from the model's steady state, which allows us to evaluate the performance of the model with respect to the data. After matching the mortgage selection during the boom period we can evaluate the effect of the restricted offering policies during the subsequent bust episode, which we do in Section 7. First, we discuss the solution algorithm for the steady state, where after we discuss key moments of the model and the respective data counterparts.

6.1 Solution Strategy Steady State

The high dimensionality of the model makes the usual value function iteration and policy function iteration solution methods unfeasible. Hence, to solve the model, we use the Nested Endogenous Grid Method, as described by Druedahl (2019). In Appendix G, we discuss how we apply this method to our model. To solve the model, in each iteration we take a guess for the house price and the interest rates offered by lenders, solve the household problem, simulate the economy and compute the housing market clearing and zero profit conditions for the lender. With these last two conditions, we obtain new guesses for the house price and interest rates. We repeat this process until the model has converged.

6.2 Steady State Evaluation

The steady state is a good starting point if we want to inform about the effect of the restricted offering policies during the bust, we first need to match the mortgage selection during the boom period.

Table 3 provides data and model matched moments. We are able to match all data moments relatively closely, as we only overshoot the TRM share slightly.[18]

Variable	Model	Data
General Housing Targets		
Price to Income Ratio	3.3	3.5
Price to Rent Ratio	13.5	14
Share of Houses with Mortgage (%)	62%	68%
Mortgage Choice		
FRM	68.7 %	71.3%
TRM	31.3 %	28.7%
Mortgage Rates		
Annual Spread: FRM - $\text{TRM}_{initial}$	0.8 %	0.8 %
Annual Spread: $\text{TRM}_{final} - FRM$	0.5 %	0.7%

Table 3: Mortgage Distributions: Model and Data McDash for mortgage originations 2003-2004. See Section 3 for a description of the data set used.

[18]Total originations for 2003-2004 are from McDash, where we make the same selections as discussed in Section 3.

The mortgage rate spreads are taken from our analysis in section 2.3, where we calculate

$$TRM_{initial} : \overbrace{50\% \cdot 0.6\%}^{\text{3-year Teaser}} + \overbrace{50\% \cdot 1\%}^{\text{5-year Teaser}} = 0.8\%$$

$$TRM_{final} : \overbrace{50\% \cdot 1\%}^{\text{3-year Teaser}} + \overbrace{50\% \cdot 0.4\%}^{\text{5-year Teaser}} = 0.7\%$$

In Table 4 we describe the mean mortgage choice by wealth quintile and age group. We compute wealth in the model outcome as follows:

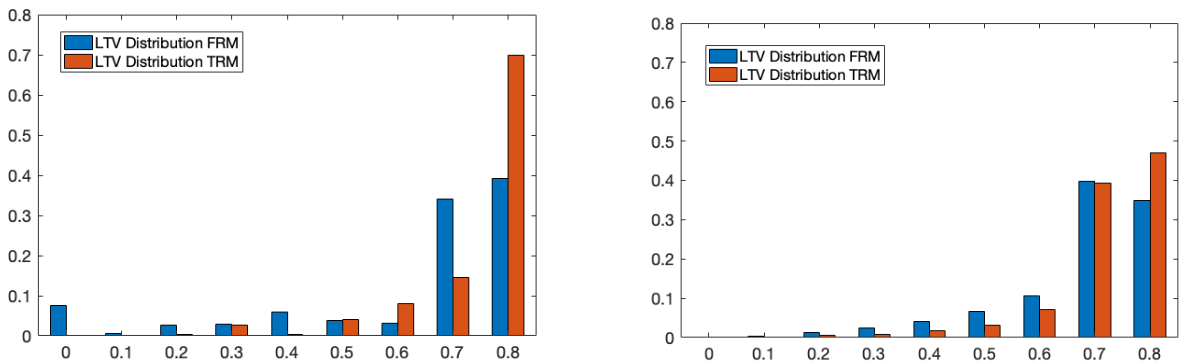
$$\text{Wealth}_i = \text{Liquid Assets}_i + \text{Income}_i \cdot \text{Income Life Cycle}_i$$

The model seems to perform reasonably well overall, as it captures the higher share of TRM for lower age groups, which in the data and the model is more important than the income groups, similar to what we observe in section 3.1. For older and richer households the benefit of the temporary teaser discount is not large enough to justify a larger rate later in life, which is why these households choose only fixed rate mortgages.

Wealth / Age	20-28	29-37	38-46	47-61
WQ1	2	1.44	1.04	1.13
WQ2	1.91	1.07	1	1
WQ3	1.95	1.01	1	1
WQ4	1.87	1.02	1	1
WQ5	1.79	1.18	1	1

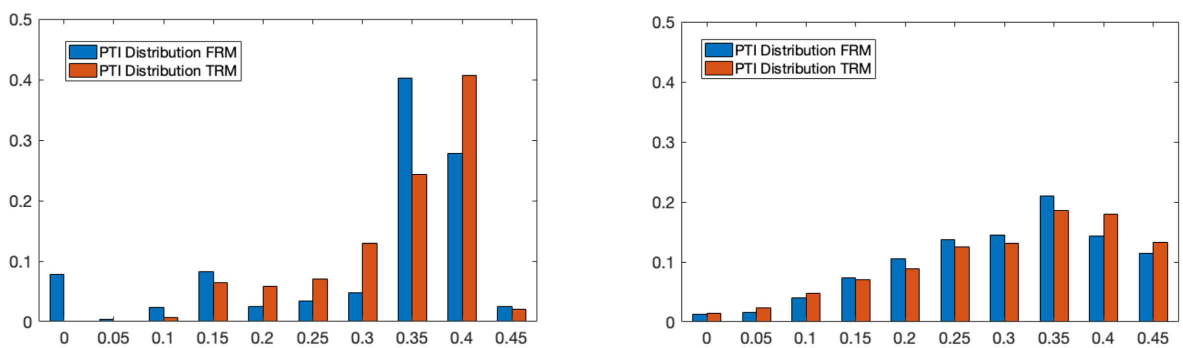
Table 4: Mortgage choice by wealth and age in the model. For each age group, we calculate wealth quintiles. Numbers presented are **mortgage choice means** by wealth quintile for each age group. $FRM = 1$, $TRM = 2$.

Finally, Figure 4 shows a comparison of the LTVs by mortgage type with respect to the McDash data. Overall we are able to capture two main desirable features: (1) the majority of mortgages are around the LTV conforming threshold, (2) FRM are relatively more prevalent for LTVs that go from 0% to 70% while TRM are more common for LTVs above 70%.



(a) LTV Distribution (Model) (b) LTV Distribution (Data 2000-2006)

Figure 4: LTV Distributions for the Model and Data McDash 2000-2006. For details regarding the data, see Section 3.



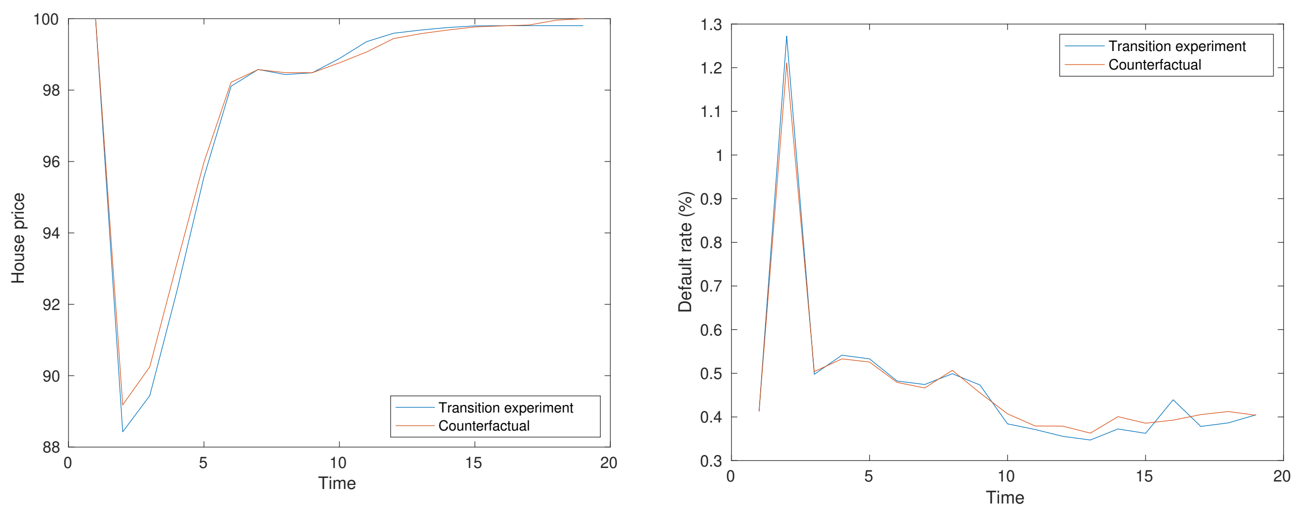
(a) PTI Distribution (Model) (b) PTI Distribution (Data 2000-2006)

Figure 5: PTI Distributions for the Model and Data McDash 2000-2006. For details regarding the data, see Section 3.

7 Transitional Dynamics

In this section, we simulate the bust-episode, using an MIT shock on the housing preference and aggregate income. To measure the effect of the restricted offering, we generate a crisis (explained in detail below) for two different economies: (i) what we call **the simulated crisis** which is an economy in which the TRMs are suddenly unavailable to originate (like in the 2007-2008 crisis), and (ii) what we define as the **counterfactual crisis** in which the TRMs are still available.

We start both the simulated crisis episode and the counterfactual crisis episode in the model's steady state in period 1. Then, both episodes have an induced housing bust by first lowering the housing preference parameter α from 0.2 to 0.15 for period 2 to period 5, and then back to its initial value of 0.2 form period 6 onward. And secondly, by dropping aggregate income (Θ) 10 percent in period 2, and steadily increasing it 2.5 percentage points each period, before converging back fully in period 6. For the counterfactual episode, this is the whole description of the housing bust. For the simulated crisis episode, we restrict mortgage offering of TRMs by lowering the maximum LTV ratio of TRMs to 0, a permanent shock. We compute the transitions back to the steady state separately for each economy, which generates different mortgage distributions along the path, and hence house prices, mortgage rates, and ultimately default rates. We summarize the main results in Figures 6 and 7 below. We use the Counterfactual label to describe the counterfactual crisis episode, while we use the Transition experiment label to describe the simulated crisis episode.



(a) House price relative to steady state (b) Foreclosures over number of homeowners

Figure 6: House price and foreclosures over the time of the bust-episode, for both the counterfactual and the transition experiment.

In the simulated bust-episode we find that the house price without the availability of TRMs drops about 11.6 percent, while the house price without restricted offering drops 10.7 percent. Therefore, the simulations reveal that the nonavailability of TRMs at the onset of

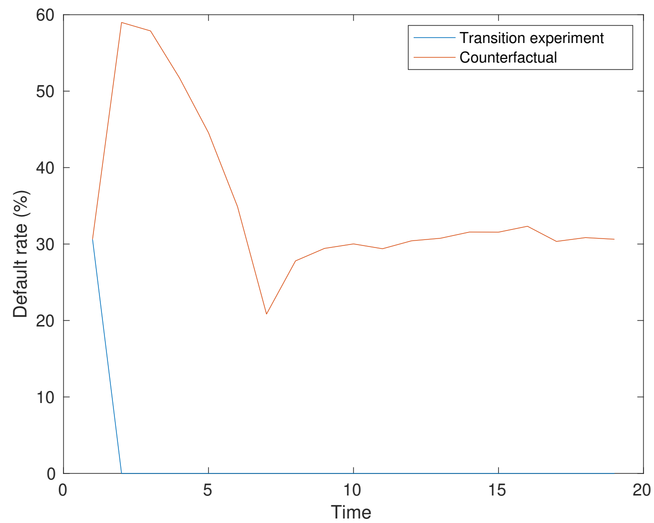


Figure 7: Mortgage choice statistics: total TRM share of mortgages originated.

the crisis could have reduced the house price by 0.9 percentage points more than was necessary, or by about 7% more than would otherwise have happened. Moreover, the recovery is slightly slower without TRMs relative to the counterfactual economy. The house price drop translates into foreclosures: during the bust-episode in the transition experiment is slightly higher at the onset of the crisis relative to the case where TRMs were still available.

In terms of the mortgage choices, in Figure 7 we see a large shift to TRMs during the bust-episode. This result relates to the desire to backload payments while being faced with the aggregate income shock.

8 Conclusion

During the housing boom of 2001-2005, there was a rise in originations of nontraditional mortgages. The subsequent fall of these mortgages during the housing bust was caused by both demand and supply factors. In this paper, we argue that, as both the private and government-backed mortgage markets collapsed, the supply side is key to explain this fall. We document that the mortgage restrictions at the onset of the crisis were particularly targeted on nontraditional mortgages. In this paper, we focus on the teaser structure of these nontraditional mortgages, intended to provide backloaded mortgage payments.

To evaluate the magnitude of the effect of this restricted supply on the house price itself, we build a quantitative model of mortgage choice. In the model, households face labor income risks and make decisions with respect to consumption and housing services. When households buy a house, they can finance their housing choice with two long-term contracts: a fixed rate mortgage and a teaser rate mortgage. For teaser rate mortgages the interest rate is lower for the initial periods, where after the interest rate rises to a fixed higher level. In the model's steady state, we are able to match the cross-section of mortgage shares, and provide summary statistics on the household's mortgage selection, which we also match.

In the paper's main experiment, we simulate a bust-episode with MIT shocks combining an aggregate income shock with a housing preference shock as modelled by Kaplan et al. (2017). In this episode we contrast the main experiment, where we shut down the teaser rate mortgage market altogether for the entire simulation, with a counterfactual economy which still allows for teaser rate mortgages. The resulting difference between these simulations is interpreted as the effect of the restricted mortgage offering. We find that the restricted offering especially has a big impact on the house price: the house price with restricted offering drops by about 0.9 percentage points more than without the restricted offering, or in relative terms about 7% more. We interpret the timing of this restricted offering of teaser rate mortgages as crucial, as the counterfactual experiment shows that households would otherwise have increased their use of teaser rate mortgages, to better smooth out consumption over time. We believe that keeping teaser rate mortgages available in the crisis could have made the bust-episode less deep.

In future versions we we want to dig deeper into the role that refinancing had on the housing crisis, specially the interaction between the existence of TRMs-type products and refinancing which seems to go hand in hand given the frontloaded benefit embedded in TRMs, and the desire to avoid the future rate increase. Second, we need to evaluate welfare effects, both in steady state and along the transition path, of restricting teaser rate mortgages. Finally, another interesting extension of our paper would to split the mortgage market into insured (mortgages securitized through the GSEs) and non-insured products (mortgages securitized through the private market). This would be a good way of understanding the role that the implicit subsidy provided by the government has on the mortgage market.

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Appendices

A Mortgage Originations

In this Appendix, we show how the mortgage originations distribution for ARMs and FRMs changes, for the total market, for purchase mortgages and for refinance mortgages. We use the same selection choices as in Section 3.

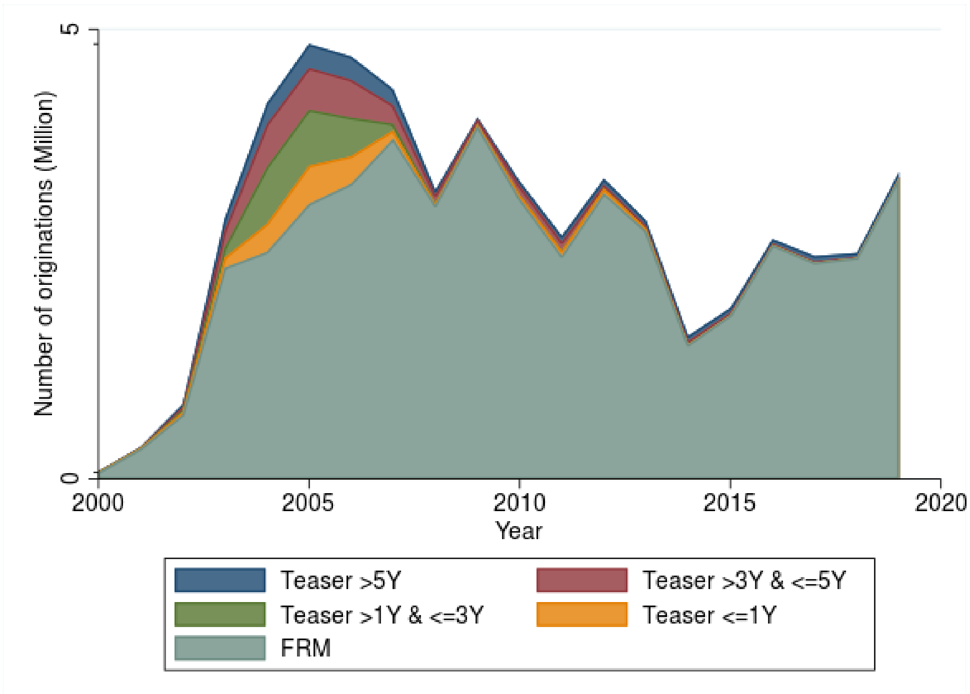


Figure 8: Mortgage Originations (Millions) for ARMs and FRMs, split by length introductory period for ARMs. Constructed with data by Black Knight McDash (McDash) data. All Mortgages.

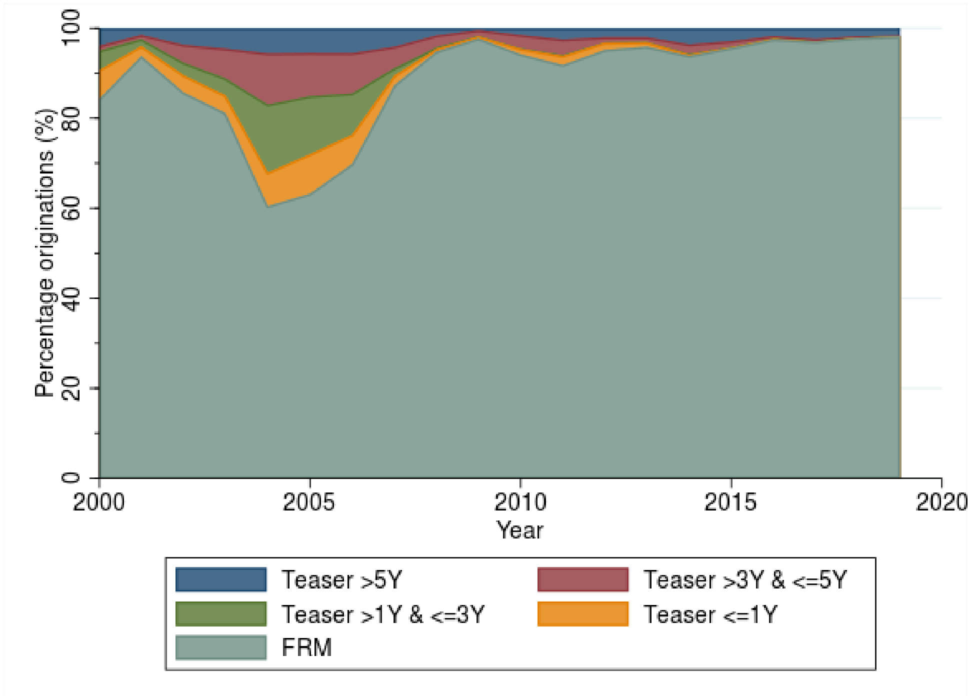


Figure 9: Mortgage Originations (percentage of total) for ARMs and FRMs, split by length introductory period for ARMs. Constructed with data by Black Knight McDash (McDash) data. All Mortgages.

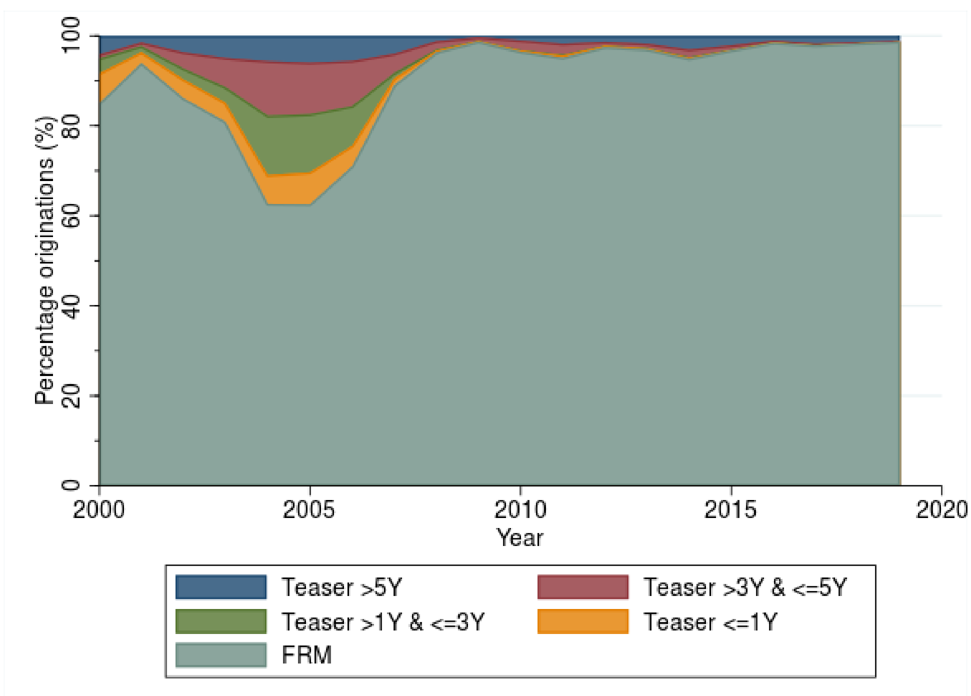


Figure 10: Mortgage Originations (percentage of total) for ARMs and FRMs, split by length introductory period for ARMs. Constructed with data by Black Knight McDash (McDash) data. Only Purchase Mortgages.

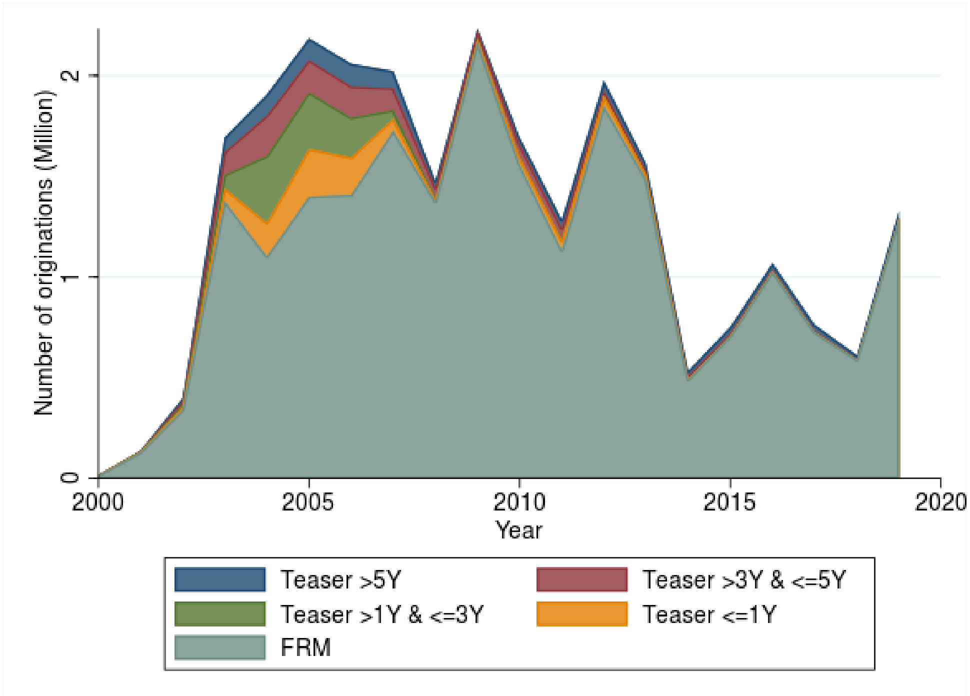


Figure 11: Mortgage Originations (Millions) for ARMs and FRMs, split by length introductory period for ARMs. Constructed with data by Black Knight McDash (McDash) data. Only Refinance Mortgages.

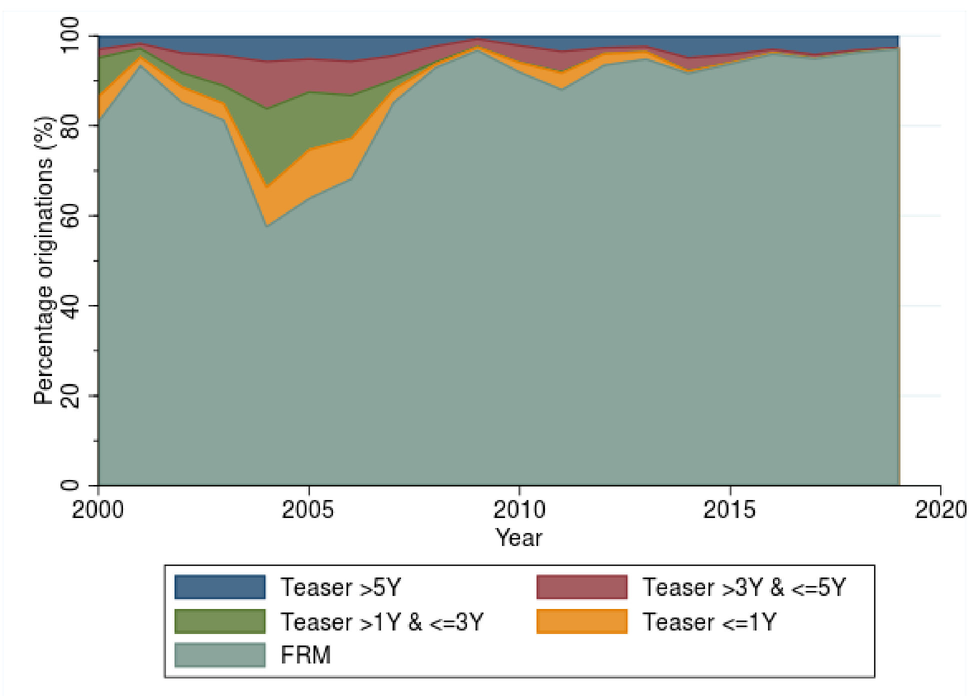


Figure 12: Mortgage Originations (percentage of total) for ARMs and FRMs, split by length introductory period for ARMs. Constructed with data by Black Knight McDash (McDash) data. Only Refinance Mortgages.

B Foreclosures by mortgage type

In this Appendix, we describe the evolution of foreclosures over 2001-2011. Empirically, nontraditional mortgages are shown a higher default rate (being more than 60 days overdue) during the housing bust of 2007-2008. Elul (2016) finds that the default rate is higher for ARMs than for FRMs in 2005-2006, both within prime (1 percentage point quarterly difference) and subprime (2 percentage point quarterly difference). Pennington-Cross and Ho (2010) find that default on hybrid loans increase dramatically when teaser rate increases are mixed with low equity in the home. In Figure 13 we summarize the foreclosure rates by aggregate product group (ARM versus FRM). We see that mainly ARMs show a rise in foreclosures over the housing bust.

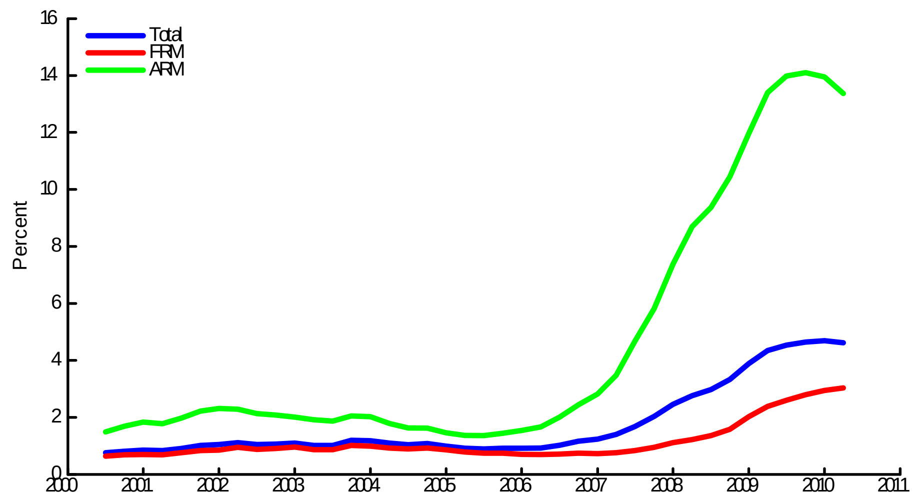


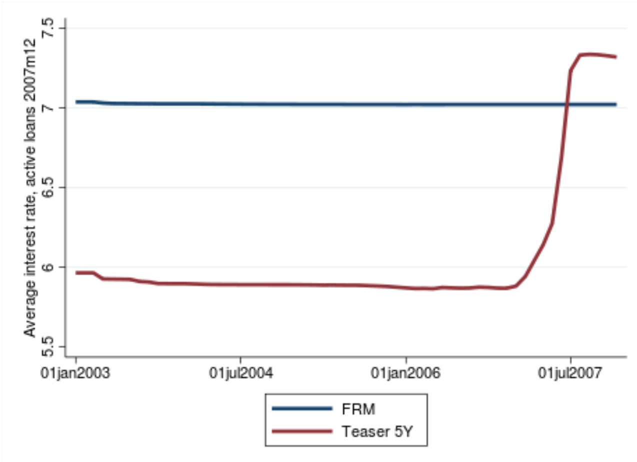
Figure 13: Annual foreclosure rate by product type, from Garriga and Schlagenhauf (2010). Data from Mortgage Bankers Association (2020).

C Average interest rates over time

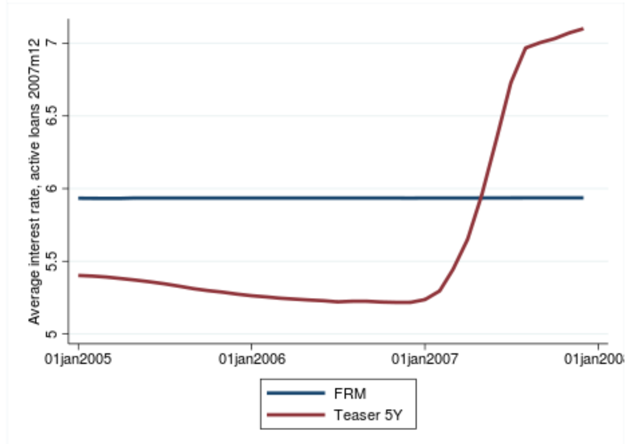
In this Appendix, we provide two robustness exercises for the average interest rates over time, for (1) fixed rate mortgages and 5-year adjustable rate mortgages originated between 2002m1-2002m6 and (2) fixed rate and 3-year adjustable rate mortgages originated between 2004m1-2004m6.

The first robustness exercise is to show the average current interest rate over time for mortgages still active at the end of 2007 (December 2007). Figure 14 shows that, relative to Figure 2, the pattern remains unchanged: the interest rate spikes up after the introductory period ends. The magnitudes are also comparable.

The second robustness exercise is to show that, even after controlling for loan-level characteristics, there is still a spike in the current interest rates for adjustable rate mortgages after



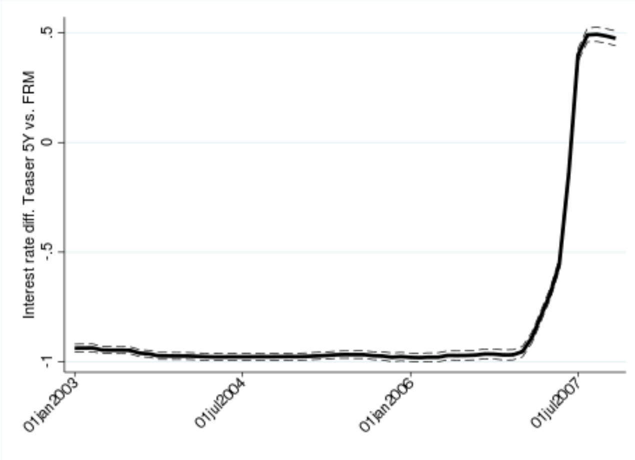
(a) 5-year Teasers orig. 2002m1-m6.



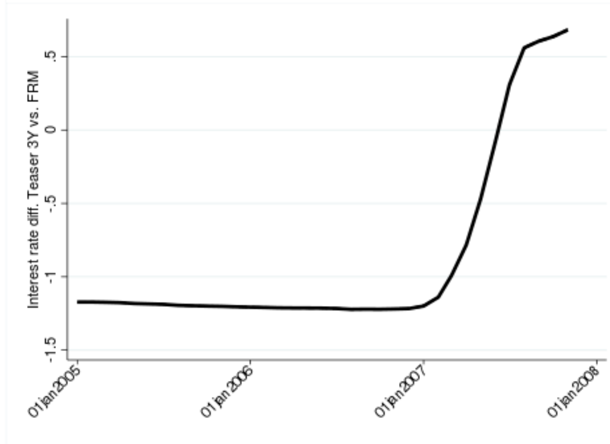
(b) 3-year Teasers orig. 2004m1-m6.

Figure 14: Average current interest rates over time for (a) fixed rate and 5 year adjustable rate mortgages originated in 2002m1-2002m6, and (b) fixed rate and 3 year adjustable rate mortgages originated in 2004m1-2004m6. Figure constructed with data set of McDash. Average computed for mortgages active up to at least December 2007. See Section 3 for the selections we make.

the introductory period ends. For this exercise, we regress the current interest rate on current month, adjustable rate mortgage indicator and its interaction with current month. Then, we include loan-level characteristics of payment-to-income ratio, the square of payment-to-income ratio, original fico score, the square of original fico score, ltv ratio, the square of ltv ratio, original loan amount, log original loan amount, interest only flag, loan type, property type, occupancy type, balloon flag, and mortgage type. Then, we plot the interaction effect between the ARM-indicator and the month-indicators to get to the predicted difference between the adjustable rate and fixed rate mortgages over time, controlling for loan-level characteristics. Figure 15 shows that, relative to Figure 2, the pattern remains unchanged: the interest rate of adjustable rate mortgages relative to fixed rate mortgages spikes up after the introductory period ends.



(a) 5-year Teasers orig. 2002m1-m6.



(b) 3-year Teasers orig. 2004m1-m6.

Figure 15: Average current interest rates over time for (a) fixed rate and 5 year adjustable rate mortgages originated in 2002m1-2002m6, and (b) fixed rate and 3 year adjustable rate mortgages originated in 2004m1-2004m6. Figure constructed with data set of McDash. The estimated coefficients of the interaction between current month and adjustable rate mortgages indicators are shown, including confidence interval. See Section 3 for the selections we make.

D Mortgage selection summary statistics and regression results

In this Appendix we provide summary statistics for the CRISM data set we use in Section 3. We distinguish by fixed rate and adjustable rate mortgages, and by length of introductory period for adjustable rate mortgages.

	FRM	ARM <= 1Y	ARM >1Y & <= 3Y	ARM >3Y & <= 5Y	ARM >5Y
FICO orig	710	708	627	723	721
ln(loan amt)	12.02	12.26	11.97	12.22	12.24
Initial LTV	72.86	74.19	79.08	73.50	71.62
IO	0.0234	0.1194	0.2898	0.6927	0.6817
Refi	0.5107	0.5789	0.4552	0.3705	0.4385
Borrower age	44	45	42	42	44
Borrower income (1000s)	47	49	38	51	52
Borrower PTI	35.78	35.60	38.68	33.04	34.29
Observations	3,770,551	455,577	565,700	517,193	329,107

Table 5: All mortgages: in CRISM. Both purchase and refinance mortgages

	FRM	ARM <= 1Y	ARM >1Y & <= 3Y	ARM >3Y & <= 5Y	ARM >5Y
FICO orig	721	717	645	729	726
ln(loan amt)	11.98	12.22	11.93	12.19	12.21
Initial LTV	77.68	77.70	80.87	76.92	75.79
IO	0.0282	0.1618	0.3354	0.7213	0.6878
Borrower age	43	43	40	41	42
Borrower income (1000s)	47	51	38	50	50
Borrower PTI	35.70	35.88	39.14	32.80	34.81
Observations	1,844,875	191,848	308,209	325,565	184,804

Table 6: All mortgages: in CRISM. Only purchase mortgages

D.1 Regression predictive probabilities

In here, we present the predictive margins for the results in Section 3.

Probit regression Pr(ARM)		(1)	(2)	(3)	(4)
Income · Age	1 & (18-32)	0.4407***	0.4238***	0.3952***	0.3878***
		(0.0008)	(0.0008)	(0.0008)	(0.0008)
	1 & (33-45)	0.3919***	0.3775***	0.3496***	0.3407***
		(0.0006)	(0.0006)	(0.0006)	(0.0006)
	1 & (45+)	0.3518***	0.3343***	0.3188***	0.3126***
		(0.0005)	(0.0005)	(0.0005)	(0.0005)
	2 & (18-32)	0.3556***	0.3508***	0.3548***	0.3547***
		(0.0008)	(0.0008)	(0.0007)	(0.0008)
	2 & (33-45)	0.2761***	0.2834***	0.2949***	0.2998***
		(0.0005)	(0.0005)	(0.0005)	(0.0005)
	2 & (45+)	0.2774***	0.2775***	0.2954***	0.3048***
		(0.0005)	(0.0005)	(0.0005)	(0.0005)
	3 & (18-32)	0.3397***	0.3522***	0.3564***	0.3664***
		(0.0008)	(0.0008)	(0.0007)	(0.0008)
	3 & (33-45)	0.2885***	0.3084***	0.3183***	0.3338***
		(0.0006)	(0.0006)	(0.0005)	(0.0006)
	3 & (45+)	0.3192***	0.3293***	0.3449***	0.3639***
		(0.0005)	(0.0005)	(0.0005)	(0.0005)
House value & mortgage		Y	Y	Y	Y
Individual fixed effects		N	N	N	Y
Mortgage type controls		N	N	Y	Y
Month fixed effects		N	Y	Y	Y
State fixed effects		N	Y	Y	Y
N		5,399,556	5,399,519	5,399,519	4,695,183
R^2		0.0250	0.0583	0.1441	0.1521

$^{***}p < 0.01$, $^{**}p < 0.05$.
Standard errors are in parentheses.
Mortgage type implies prime or subprime, and loan type.
We list here the predictive margins.

Table 7: Probit regression results CRISM data set. Only purchase mortgages.

D.2 Regression only for purchase mortgages

Next, we do the same regression as in Section 3, for the CRISM data set but now only using purchase mortgages. We get as results:

Probit regression Pr(ARM)		(1)	(2)	(3)	(4)
Income group	2	-0.1028***	-0.0792***	-0.0371***	-0.0202***
		(0.0007)	(0.0007)	(0.0006)	(0.0007)
	3	-0.0746***	-0.0398***	-0.0012	0.0268***
		(0.0007)	(0.0007)	(0.0007)	(0.0007)
Age group	33-45	-0.0539***	-0.0435***	-0.0371***	-0.0329***
		(0.0007)	(0.0007)	(0.0007)	(0.0007)
	45+	-0.0645***	-0.0691***	-0.0483***	-0.0389***
		(0.0008)	(0.0007)	(0.0007)	(0.0007)
Income · Age	2 & (33-45)	-0.0419***	-0.0323***	-0.0242***	-0.0153***
		(0.0018)	(0.0017)	(0.0016)	(0.0017)
	2 & (45+)	0.0050**	0.0054**	-0.0000	0.0077**
		(0.0018)	(0.0017)	(0.0016)	(0.0017)
	3 & (33-45)	-0.0001	-0.0014	0.0043**	0.0125***
		(0.0018)	(0.0018)	(0.0016)	(0.0017)
	3 & (45+)	0.0797***	0.0607***	0.0511***	0.0550***
		(0.0018)	(0.0017)	(0.0016)	(0.0017)
House value & mortgage		Y	Y	Y	Y
Individual fixed effects		N	N	N	Y
Mortgage type controls		N	N	Y	Y
Month fixed effects		N	Y	Y	Y
State fixed effects		N	Y	Y	Y
N		2,726,443	2,726,443	2,726,443	2,362,757
R^2		0.0227	0.0844	0.1996	0.2116

$^{***}p < 0.01$, $^{**}p < 0.05$.
Standard errors are in parentheses.
Mortgage type implies prime or subprime, and loan type.
We list here the contrasts of predictive margins.

Table 8: Probit regression results CRISM data set. Only purchase mortgages.

Probit regression Pr(ARM)		(1)	(2)	(3)	(4)
Income · Age	1 & (18-32)	0.4603***	0.4375***	0.4013***	0.3865***
		(0.0010)	(0.0010)	(0.0009)	(0.0010)
	1 & (33-45)	0.4204***	0.4049***	0.3704***	0.3542***
		(0.0008)	(0.0008)	(0.0008)	(0.0008)
	1 & (45+)	0.3675***	0.3462***	0.3347***	0.3259***
		(0.0008)	(0.0008)	(0.0007)	(0.0008)
	2 & (18-32)	0.3713***	0.3682***	0.3732***	0.3690***
		(0.0010)	(0.0010)	(0.0009)	(0.0010)
	2 & (33-45)	0.2895***	0.3033***	0.3749***	0.3214***
		(0.0008)	(0.0008)	(0.0007)	(0.0008)
	2 & (45+)	0.2835***	0.2824***	0.3065***	0.3161***
		(0.0008)	(0.0008)	(0.0007)	(0.0008)
	3 & (18-32)	0.3560***	0.3754***	0.3790***	0.3879***
		(0.0010)	(0.0010)	(0.0009)	(0.0010)
	3 & (33-45)	0.3159***	0.3414***	0.3525***	0.3681***
		(0.0008)	(0.0008)	(0.0007)	(0.0008)
	3 & (45+)	0.3428***	0.3449***	0.3635***	0.3822***
		(0.0008)	(0.0008)	(0.0007)	(0.0007)
House value & mortgage		Y	Y	Y	Y
Individual fixed effects		N	N	N	Y
Mortgage type controls		N	N	Y	Y
Month fixed effects		N	Y	Y	Y
State fixed effects		N	Y	Y	Y
N		2,726,443	2,726,443	2,726,443	2,362,757
R^2		0.0227	0.0844	0.1996	0.2116

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

Standard errors are in parentheses.

Mortgage type implies refinance or purchase mortgages, prime or subprime, and loan type.

We list here the predictive margins.

Table 9: Probit regression results CRISM data set.

E Mortgage selection robustness

In this Appendix we use the SIPP waves of 2001-2008 to confirm the findings of the CRISM data set in Section 3. As before, we discuss household selection in ARMs based on age and income during the boom-period.

In particular, we discuss household selection that we observe during the housing boom in 2001-2006, where we use a probit regression specification for the SIPP. We run a probit regression on the probability of having an ARM with age group, income group and other observables as independent variables. The other observables we use are mortgage type, year of origination, log real mortgage size, education, race, gender and maritial status. For the SIPP, additional controls are log real assets, the log real house value, and state. The income groups are constructed as to have five equally sized groups (sample weighted), while the age groups are: 18-32, 33-45, 45+. We focus on households who originated the mortgage no more than three years before the survey was conducted, and with an LTV-ratio between 0.4 and 1.1. The regression specification is as in Section 3:

$$\Pr(\text{ARM}) = \beta_0 + \sum_{j=1}^{J} \beta_{1,j}\text{Agegroup}_j + \sum_{i=1}^{I} \beta_{2,i}\text{Incomegroup}_i + \text{Observables} + \epsilon \qquad (23)$$

We estimate the probit model in four steps. First, we only include log real assets, the log real house value and log real mortgage size. Then, we add state and year fixed effects. In the third specification we add a mortgage type control (purchase or refinance mortgage). Finally, we include all the individual controls. After estimating the probit models, we evaluate the marginal effects of each variable at the conditional mean of others. Then, we evaluate the model's predictions using those estimated conditional effects. The results for the SIPP are summarized in Table 10. In Figure 16 we plot the predicted average probability of choosing an ARM under regression specification (4). The results confirm that the households most likely to choose an ARM during the housing boom were younger low-income households. Based on the size of the slopes over age and income, these results point to income as the most relevant driver of the ARM-choice.

Probit regression Pr(ARM)		(1)	(2)	(3)	(4)
Income group	2	-0.0165**	-0.0171**	-0.0171**	-0.0168**
		(0.0072)	(0.0070)	(0.0070)	(0.0070)
	3	-0.0298***	-0.0290***	-0.0294***	-0.0287***
		(0.0071)	(0.0069)	(0.0069)	(0.0070)
	4	-0.0254***	-0.0228***	-0.0235***	-0.0230***
		(0.0072)	(0.0071)	(0.0071)	(0.0073)
	5	-0.0332***	-0.0263***	-0.0269***	-0.0272***
		(0.0075)	(0.0075)	(0.0075)	(0.0077)
Age group	33-45	-0.0154***	-0.0157***	-0.0170***	-0.0163***
		(0.0052)	(0.0051)	(0.0052)	(0.0052)
	45+	-0.0066	-0.0081	-0.0107*	-0.0103*
		(0.0057)	(0.0056)	(0.0058)	(0.0058)
Ln(house value)		0.0389***	0.0168	0.0148	0.0138
		(0.0102)	(0.0105)	(0.0105)	(0.0105)
Ln(mortgage)		0.0208**	0.0260***	0.0292***	0.0295***
		(0.0101)	(0.0101)	(0.0103)	(0.0103)
Individual fixed effects		N	N	N	Y
Mortgage type controls		N	N	Y	Y
Year fixed effects		N	Y	Y	Y
State fixed effects		N	Y	Y	Y
N		25,976	25,976	25,976	25,976
R^2		0.0148	0.0388	0.0391	0.0411

$^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.
Standard errors are in parentheses.
Note that mortgage type implies refinance or purchase mortgages.
We list here the conditional mean effects evaluated at the mean value of other variables.

Table 10: Probit regression results SIPP.

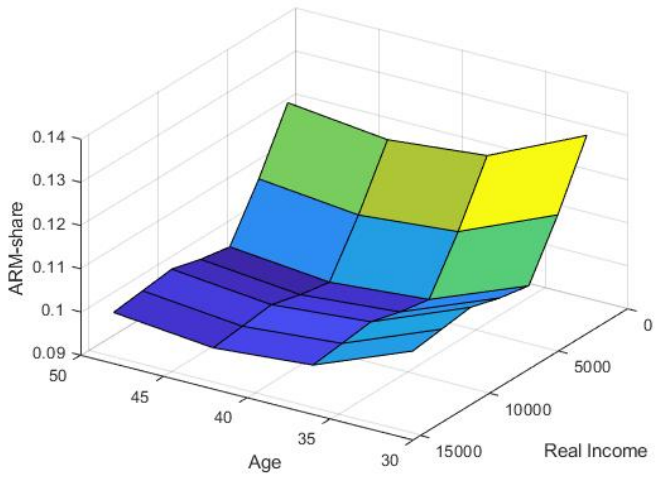


Figure 16: ARM conditional marginal effects from estimated full probit model.

F Formulas in Sections 4.1.3 and 4.1.4

FRM: $\lambda(c^{FRM})$ is the standard annuity in advance factor multiplying the initial mortgage debt for a FRM, depending on r^m and mortgage length N:

$$\lambda(c^{FRM}) = \frac{r^m(c^{FRM})}{1-(1+r^m(c^{FRM}))^{-N(c^{FRM})}}$$

TRM Introductory: $\lambda^{in}(c^{TRM})$ is the standard annuity in advance factor multiplying the initial mortgage debt for the introductory period of a TRM, depending on $r^{m,in}$ and *total* mortgage length N:

$$\lambda^{in}(c^{TRM}) = \frac{r^{m,in}(c^{TRM})}{1-(1+r^{m,in}(c^{TRM}))^{-N(c^{TRM})}}$$

Additionally, it can be shown that for any period $t \leq N^{in}(c^{TRM})$ the debt balance is:

$$\begin{aligned} D_t(c^{TRM}) &= \overbrace{D_0(c^{TRM}) \cdot (1+r^{m,in}(c^{TRM}))^t}^{\text{Accumulated debt after } t \text{ periods}} - \overbrace{\left(\frac{(1+r^{m,in}(c^{TRM}))^t - 1}{r^{m,in}(c^{TRM})}\right) \cdot \lambda^{in}(c^{TRM}) \cdot D_0(c^{TRM})}^{\text{Accumulated mortgage payments after } t \text{ periods}} \\ &= D_0(c^{TRM}) \left[(1+r^{m,in}(c^{TRM}))^t + \left(\frac{1-(1+r^{m,in}(c^{TRM}))^t}{1-(1+r^{m,in}(c^{TRM}))^{-N(c^{TRM})}}\right)\right] \\ &= \delta_t^{in}(c^{TRM}) \cdot D_0(c^{TRM}) \end{aligned} \tag{24}$$

and we can define,

$$\delta_t^{in}(\not{c}^{TRM}) = (1+r^{m,in}(\not{c}^{TRM}))^t + \left(\frac{1-(1+r^{m,in}(\not{c}^{TRM}))^t}{1-(1+r^{m,in}(\not{c}^{TRM}))^{-N(\not{c}^{TRM})}}\right)$$

TRM Remaining: $\lambda^{re}(\not{c}^{TRM})$ is the standard annuity in advance factor multiplying the mortgage debt at the start of the residual period of a TRM, depending on $r^{m,re}$ and remaining mortgage length N^{re}:

$$\lambda^{re}(\not{c}^{TRM}) = \frac{r^{m,re}(\not{c}^{TRM})}{1-(1+r^{m,re}(\not{c}^{TRM}))^{-N^{re}(\not{c}^{TRM})}}$$

In a similar fashion to what we did with the introductory period we can compute the debt balance for any period $t > N^{in}(\not{c}^{TRM})$:

$$D_t(\not{c}^{TRM}) = \overbrace{D_{N^{in}(\not{c}^{TRM})} \cdot (1+r^{m,re}(\not{c}^{TRM}))^{(t-N^{in}(\not{c}^{TRM}))}}^{\text{Accumulated debt } t \text{ periods after the initial period.}}$$

$$\underbrace{-\left(\frac{(1+r^{m,re}(\not{c}^{TRM}))^{(t-N^{in}(\not{c}^{TRM}))}-1}{r^{m,re}(\not{c}^{TRM})}\right) \cdot \lambda^{re}(\not{c}^{TRM}) \cdot D_{N^{in}(\not{c}^{TRM})}}_{\text{Accumulated mortgage payments } t \text{ periods after the initial period.}}$$

$$= D_{N^{in}(\not{c}^{TRM})}\left[(1+r^{m,re}(\not{c}^{TRM}))^{(t-N^{in}(\not{c}^{TRM}))} + \left(\frac{1-(1+r^{m,re}(\not{c}^{TRM}))^{(t-N^{in}(\not{c}^{TRM}))}}{1-(1+r^{m,re}(\not{c}^{TRM}))^{-N^{re}(\not{c}^{TRM})}}\right)\right] \tag{25}$$

and by defining,

$$\delta_t^{re}(\not{c}^{TRM}) = (1+r^{m,re}(\not{c}^{TRM}))^{(t-N^{in}(\not{c}^{TRM}))} + \left(\frac{1-(1+r^{m,re}(\not{c}^{TRM}))^{(t-N^{in}(\not{c}^{TRM}))}}{1-(1+r^{m,re}(\not{c}^{TRM}))^{-N^{re}(\not{c}^{TRM})}}\right)$$

we obtain that for any period $t > N^{in}(\not{c}^{TRM})$:

$$D_t(\not{c}^{TRM}) = \delta_t^{re}(\not{c}^{TRM}) \cdot \delta_{N^{in}(\not{c}^{TRM})}^{in}(\not{c}^{TRM}) \cdot D_0(\not{c}^{TRM})$$

G Nested Endogenous Grid Method

The two main advantages of the Nested Endogenous Grid Method (EGM) are (1) we can use the nested structure of our problem, and (2) we can solve efficiently for consumption using a variation of the class EGM by Carroll (2006).

Nested Structure

Consider the problem of a buyer (12) , and that of the keeper (16). One of the main difference between these two problem can be found on the budget constraint, the red terms represent those elements that only apply to the buyer:

$$c + p^h \cdot h' + \frac{b'}{1+r} + m + \nu h + \phi^{liq} h = b + y + D'$$

Notice that the continuation value is the same on both problems. Hence, the idea is to solve for the keeper's problem and later on using interpolation on the keeper's value function solve for the buyer's problem. We can use this same logic for: (1) the problem of the buyer (12) and then use this solution to solve the problems of the refinancer (18) and mover (19), and (2) the problem of the renter (13) and then use this solution to solve the problems of the seller (17) and defaulter (20).

Reinterpreting the Value Functions

First, let us introduce some notation. We define the cash at hand variable as x_t. Then, we have the following sub value functions, notice that we are reinterpreting them as being a function of the cash at hand:

1. For the keeper: $V_t^k(z_t^k)$, where $z_t^k = \{x_t, D_t, h_t, y_t, j_t, n_t, \tilde{c}_t\}$.
2. For the renter, seller and defaulter: $V_t^r(z_t^r)$, $V_t^s(z_t^r)$, $V_r^d(z_t^r)$, where $z_t^r = \{x_t, y_t, j_t\}$.
3. For the buyer, refinancer, and mover: $V_t^b(z_t^b)$, $V_t^{rf}(z_t^b)$, $V_t^m(z_t^b)$, where $z_t^b = \{x_t, y_t, j_t\}$.

Overarching Value functions

For the renter, we have an overarching value function:

$$\bar{V}_t(\bar{z}_t^r) = \max_{g_t \in \{b,r\}} \{V_t^{g_t}(z_t^{g_t})\}$$

where $\bar{z}_t^r = \{a_t, j_t, y_t\}$, hence we recover back the assets from the cash on hand. $g_t(\cdot)$ describes the optimal discrete choice between renting and buying.[19]

and similarly the post decision value function is:

$$\bar{V}_{t+1}^r(\bar{z}_{t+1}^r) = E_t\left[\max_{g_{t+1} \in \{b,r\}} \{V_{t+1}^{g_{t+1}}(z_{t+1}^{g_{t+1}})\}\right]$$

[19]Only in period $t = T$ we have a different value function (we have a bequest motive). For simplicity, let us solve that one with value function iteration.

For the owner that does not fall into default, we have an overarching value function:

$$\bar{V}_t(\bar{z}_t^o) = \max_{g_t \in \{b,r\}} \{V_t^{g_t}(z_t^{g_t})\}$$

where $\bar{z}_t^o = \{a_t, D_t, h_t, y_t, j_t, n_t, \tilde{c}_t\}$, hence we recover back the assets from the cash on hand. $g_t(\cdot)$ describes the optimal discrete choice between keeping the house, selling, refinancing, moving.

and similarly the post decision value function is:

$$\bar{V}_{t+1}^o(\bar{z}_{t+1}^o) = E_t\left[\max_{g_{t+1} \in \{k,s,rf,m\}} \{V_{t+1}^{g_{t+1}}(z_{t+1}^{g_{t+1}})\}\right]$$

Value functions (adding nesting strucutre)

Keeper

The Bellman equation for agent that decides to keep the house:

$$V_t^k(z_t^k) = \max_{c_t} u(c_t, s_t) + \beta \bar{V}_{t+1}^o(\bar{z}_{t+1}^o)$$

s.t.

$$a_{t+1} = (1 + r_t) \cdot (x_t - c_t - m_t - \nu \cdot h - \phi^{liq} \cdot h)$$

$$a_{t+1} \geq 0$$

Mortgage Related Constraints in (16)

Renter

The Bellman equation for agent that decides to remain a renter:

$$V_t^r(z_t^r) = \max_{c_t} u(c_t, s_t) + \beta \bar{V}_{t+1}^r(\bar{z}_t^r)$$

s.t.

$$a_{t+1} = (1 + r_t) \cdot (x_t - c_t - p_r \cdot s_t)$$

$$a_{t+1} \geq 0$$

Buyer

The Bellman equation for agent that decides to become a buyer (here we use the keeper's solution):

s.t.

$$a_{t+1} = (1 + r_t) \cdot (x_t^{buyer} - c_t - m_t - \nu \cdot h - \phi^{liq} \cdot h)$$
$$a_{t+1} \geq 0$$
$$x_t^{buyer} = x_t^{keeper} + D_t - p^h h_t - m_t$$
Mortgage Related Constraints in (12)

Seller

s.t.
$$a_{t+1} = (1 + r_t) \cdot (x_t^{seller} - c_t - p_r \cdot s_t)$$
$$a_{t+1} \geq 0$$

$$x_t^{seller} = x_t^{renter} + p^h h_t - D_t^{sell} - F^{sell}$$
Mortgage Related Constraints in (17)

Defaulter

s.t.
$$a_{t+1} = (1 + r_t) \cdot (x_t^{defaulter} - c_t - p_r \cdot s_t)$$
$$a_{t+1} \geq 0$$

$$x_t^{defaulter} = x_t^{renter} + I^{def} - F^{def}$$
where the definition of I^{def} is as in (20)

Refinancer

s.t.
$$a_{t+1} = (1 + r_t) \cdot (x_t^{refinancer} - c_t - m_t - \nu \cdot h - \phi^{liq} \cdot h)$$
$$a_{t+1} \geq 0$$

$$x_t^{refinancer} = x_t^{buyer} + p^h h_t - D_t^{refi} - F^{refi}$$
Mortgage Related Constraints in (18)

Mover

s.t.
$$a_{t+1} = (1 + r_t) \cdot (x_t^{mover} - c_t - m_t - \nu \cdot h - \phi^{liq} \cdot h)$$
$$a_{t+1} \geq 0$$

$$x_t^{mover} = x_t^{buyer} + p^h h_t - D_t^{move} - F^{move}$$
Mortgage Related Constraints in (19)

Algorithm

The solution algorithm for for all ages $j < J$.

1. Pre-compute $\bar{V}_{t+1}(\bar{z}^r_{t+1})$ on a grid of assets. Also pre-compute the $\bar{V}_{t+1}(\bar{z}^o_{t+1})$ on a grid of assets and debt for each value of income, house size, mortgage length and contract choice.

2. As this is a policy-function iteration technique dealing with discrete choices, we have to be able to invert the Euler equation to back out consumption. We assume $U = (1-\phi)\frac{c^{1-\gamma_c}}{1-\gamma_c} + \phi\frac{s^{1-\gamma_s}}{1-\gamma_s}$ as in Chambers et al. (2009). We then get as intertemporal condition:

$$(1-\phi)c_t^{-\gamma_c} = E_t\beta(1+r_t)(1-\phi)c_{t+1}^{-\gamma_c} \equiv q_t$$

   To back out consumption, we then have: $c_t = \left[\frac{q_t}{(1-\phi)}\right]^{\frac{1}{-\gamma_c}}$. In particular, we solve q_t for both the renter who will decide whether or not to buy ($\bar{V}^r$) and the owner who is not in default ($\bar{V}^o$).

3. We here solve for $V^k_t(z^k_t)$ on the cash on hand grid x_t for each combination of debt, house, income, mortgage length and type using a variation of EGM. In particular we use, Algorithm 1: EGM and Upper Envelope in Druedahl (2019).

4. Then, we solve $V^r_t(z^r_t)$ on the cash on hand grid x_t for each level of income using EGM. We also do this using Algorithm 1: EGM and Upper Envelope in Druedahl (2019).

5. We solve V^b_t on the cash on hand grid x_t for each income level. We do this by interpolation of the keeper's value function found in step 3, and taking in to account the constraints at mortgage origination and the mortgage choice.

6. **Keeper's Policy Functions:** At last, we construct the value functions of the keeper on a grid of income, asset, debt, contract choice, mortgage time left, and house size using interpolation on the cash on hand grid. We do this following Algorithm 5: Post-decision functions: Reordered loops in Druedahl (2019).[20]

7. **Refinancer and Mover Policy Functions:** Similarly, we construct the value and policy functions of the refinancer and mover on a grid of income, asset, debt, contract choice, mortgage time left, and house size using interpolation on the cash on hand grid. We do this by interpolating the buyer's solution found in step 5. The methodology is the same as before, Algorithm 5: Post-decision functions: Reordered loops in Druedahl (2019).

[20]Note: Druedahl (2019) is solving for V_{t+1}, so he is computing expectations in the algorithm. We are not doing that, as we do that in step 1 already. We are simply mapping the post decision states back to the cash at hand values, to extract the value and policy functions today.

8. **Renter and Buyer Policy Functions:** we construct the value functions of the renter and the buyer on a grid of income and assets using interpolation on the cash on hand grid. We do this following Algorithm 5: Post-decision functions: Reordered loops in Druedahl (2019).

9. **Seller and Defaulter Policy Functions:** Similarly, we construct the value and policy functions of the seller and past defaulter on a grid of income and assets, and the value and policy functions for the new defaulters on a grid of income, asset, debt, contract choice, mortgage time left, and house size using interpolation on the cash on hand grid. We do this by interpolating the renter's solution found in step 4. The methodology is the same as before, Algorithm 5: Post-decision functions: Reordered loops in Druedahl (2019).