Fixed rate mortgages: the cost of interest rate risk aversion

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Abstract

Mortgages play a significant role in the US economy. Americans predominantly use fixed-rate mortgages (FRMs) to avoid interest rate risk, but the related risk aversion cost has not been analyzed yet. This paper fills the gap by investigating the cost of choosing FRMs over adjustable-rate mortgages (ARMs). We find that *ex post*, FRM borrowers made 12% – 23% higher payments to avoid 0.66% – 1.62% potential ARM payment shocks. Consequently, we introduce a payment-saving strategy to absorb ARM payment shocks and analyze the results. Emerging data show that ARM borrowers are less financially constrained and less of a concern to policymakers.

JEL Classification: *G21; G51*

Keywords**:** Mortgage, Interest Rate Risk, Risk Aversion

Introduction

Mortgage loans play a significant role in the US housing market and the economy. In 2018 alone, there were 15 million mortgage loan applications[1]. As of 2019 Q3, mortgage debt outstanding hit $15 trillion. Considering the importance of mortgage loans in the US economy, it is crucial to understand the cost and risk of borrowers' mortgage choices.

Adjustable-rate (ARM) and fixed-rate (FRM) mortgages are most popular in the US. With an ARM contract, a borrower pays a varying interest rate, and bears interest rate risk. With an FRM contract, a borrower is charged a fixed interest rate, and interest rate risk is transferred to the lender. In return, the lender charges a higher interest risk premium on FRMs than ARMs. According to Freddie Mac's Primary Mortgage Market Survey (PMMS), FRM rates were about 0.7% higher than 5/1 ARM[2] rates on average.

FRMs account for 70 percent of newly issued mortgages from 1985 to 2001, while ARMs account for 30 percent (Campbell and Cocco 2003). Figure 1 displays the historical ARM share during the 2005 – 2010 period.

[Figure 1 here]

Historical mortgage rates are displayed in Figure 2. Even though an FRM is costlier when the contract is first signed, most mortgage borrowers tend to choose FRMs to avoid interest rate risk.

[Figure 2 here]

A period of high interest rates and high levels of unemployment in the US during the 1980s may have contributed to a continuing reliance on FRMs despite the interest rate caps that ARMs provide (Smith 1987). In contrast, ARMs are predominant in many other countries such as Austria, Greece, Italy, Portugal, and South Korea (Albertazzi et al. 2018). Lino (1992) finds that many US borrowers are unable to optimally

[1] The authors' calculation is based on Home Mortgage Disclosure Act (HMDA) data.
[2]The first number refers to the number of years before the interest rate can begin to adjust; the second number refers to how frequently the interest rate can subsequently adjust.

choose mortgage type, taking into consideration present value and cost, based on their own expectations of interest rate changes over the life of the loan.

Previous studies investigate the motivations of mortgage choice in the US (Statman 1982; Smith 1987; Brueckner 1993; Posey and Yavas 2001; Campbell and Cocco 2003; Koijen et al. 2009; Kim and Ziobrowski 2016). More recently, motivations are investigated in international markets (Badarinza et al. 2018; Naoi et al. 2019). However, prior literature has not evaluated whether these motives led to optimal mortgage financing *ex post*. Ghent and Yao (2016) suggest research investigating the *ex post* welfare of mortgage choice.

To fill the void, we investigate the pecuniary cost of interest rate risk aversion by choosing an FRM over an ARM in the US, both *ex ante* and *ex post*. We then introduce a payment-saving strategy to absorb ARM payment shocks. Finally, we show that recent ARM borrowers are less financially constrained in comparison to FRM borrowers.

Methodology

We define the cost of an FRM relative to an ARM at month *t*, $cost_t$, as,

(1) $$cost_t = \frac{PMT_t^{FRM} - PMT_t^{ARM}}{PMT_t^{FRM}}$$

where PMT_t^{FRM} is the monthly FRM payment and PMT_t^{ARM} is the monthly ARM payment[3]. Then the expected cost, *E(cost)*, is the average of $cost_t$ over the holding period. A relative payment shock on ARMs happens when the ARM payment becomes larger than the FRM payment ($PMT_t^{ARM} > PMT_t^{FRM}$) due to

[3] FRM and ARM monthly payment calculations are described in detail in Brueggeman and Fisher (2019, pp. 78–146).

increased interest rates. For those periods, we register the absolute value of $cost_t$ as a shock and register zero for other periods. So the shock, $shock_t$ is defined as,

(2) $$shock_t = \max\left[\frac{PMT_t^{ARM} - PMT_t^{FRM}}{PMT_t^{FRM}},\ 0\right].$$

Then the expected shock, *E(shock)*, is the average of $shock_t$ over the holding period.

In addition, we introduce a strategy to reduce the ARM payment shock if a borrower is not financially constrained. In this strategy, the borrower saves the payment differences between an FRM and an ARM whenever ARM payments are less than FRM payments. So, the savings balance at time *t* is: $saving_t = saving_{t-1} + \max[PMT_t^{FRM} - PMT_t^{ARM}, 0]$ with $saving_0 = 0$. Then, if there is a payment shock and the savings balance is positive, the borrower uses savings to make up for the payment shock. This strategy will reduce the risk of payment shocks in ARMs. $shock_t$ with the saving option is calculated by,

(3) $$shock_t^{saving} = \max\left[\frac{(PMT_t^{ARM} - PMT_t^{FRM}) - saving_t}{PMT_t^{FRM}},\ 0\right],$$

where savings reduce the size of the shock compared to the shock in equation (2).

To analyze mortgages that are broadly financed for US homebuyers, 30-year FRMs are used as a benchmark. On the counter side, we use 5/1 and 3/1 hybrid ARMs and 1/1 ARMs with a 30-year maturity. The FRM payment is a constant annuity that fully amortizes the principal over its 30-year life. N/1 ARMs offer an initial fixed rate for N years, after which the interest rate adjusts annually. We assume a $400,000 loan size[4] and 10-year holding period as a base case, which means borrowers fully pay back the mortgage balance at the end of year 10.[5] ARMs provide rate change caps to protect borrowers from interest rate hikes. The initial cap is the limit of the rate change for the initial year of rate adjustment. From the second year of rate

[4] As our measure is the relative payment ratio between FRMs and ARMs, our results are almost independent from the loan sizes even after considering interest rate adjustments for ARMs and refinancings for FRMs.
[5] Traditionally mortgage loans are held on average 7 years (Bible and Joiner, 2009).

adjustment, the annual cap is applied to limit the rate changes. In addition, ARMs limit cumulative rate changes within a lifetime cap throughout the loan term. We set the typical initial, annual and lifetime caps to 2%, 2% and 5% for 3/1 and 1/1 ARMs and 5%, 2% and 5% for 5/1 ARM, respectively, as found to be typical by Consumer Financial Protection Bureau (CFPB)[6]. Then, the indexed rate is determined for each year by adding a margin to a short rate. Finally, we calculate the ARM contract rate each year to calculate the ARM payment for that year. Refinancing of FRMs is also considered. We hypothesized that the FRM borrower will refinance whenever the market rate drops by 1% from the existing loan rate. We set a typically found $4,500 refinancing cost, and the maturity was reduced by the current holding period for every new contract to compare payments under the same conditions. We assume the borrowers keep the refinanced loan at least one year to recover their financing costs.

For *ex post* analysis, we use the realized 1-year Treasury rate as the short rate, and the 30-year FRM rate. For our *ex ante* analysis, we simulate future 1-year Treasury and 30-year FRM rates similarly to Tucker (1991) and Templeton et al. (1996). Detailed methodology and simulation results are documented in appendix A1.

Data

Historical 30-year fixed, 5/1 ARM and 1/1 ARM rates are collected from PMMS. The study period extends from January 2005 to January 2019. However, the latest loan origination date is January 2010 in the analysis since we estimate *ex post* outcomes over a 10-year holding period. The 1/1 ARM rate is provided only until December 2015. Therefore, the average spread between 5/1 and 1/1 ARM rates in year 2015 is subtracted from 5/1 ARM rates to calculate 1/1 ARM rates for year 2016 and onward. Similarly, the margin on the 1/1 ARM rate is a benchmark from the 5/1 ARM margin rate for year 2016 and onward. The 3/1 ARM is the

[6] https://www.consumerfinance.gov/ask-cfpb/with-an-adjustable-rate-mortgage-arm-what-are-rate-caps-and-how-do-they-work-en-1951/ (last reviewed in December 4, 2019).

average of 5/1 and 1/1 ARM rates. The 1-year Treasury rates (short-term rates) are from Federal Reserve Economic Data. The frequency of all data is monthly.

Table 1 presents summary statistics. The ARM initial (teaser) rate is lower than the FRM rate. The ARM initial rates are not necessarily the short-term rate plus margin rate (fully indexed rate) because lenders provide a lower than fully indexed rate during the initial period of an ARM loan.

[Table 1 here]

Empirical Results

In Figure 3, expected payment shocks are examined to depict ARM interest rate risk over time. If FRM holders are allowed to refinance their loans, they can lower their payments, increasing the probability of relative shocks to ARM holders. Accordingly, the expected shock varies cross-sectionally, with the lowest shock when refinancing is not allowed for FRM holders, and with the highest shock when refinancing is allowed. The range of shocks is displayed with non-saving (red) and saving (blue) options. In *ex post* results (upper row), the expected shock ranges from almost zero to 7.39% without a saving option. When the borrower adopts the saving strategy, the shocks decrease significantly with almost zero shocks in 3/1 and 1/1 ARMs. Interestingly, 5/1 ARM shows the highest level of expected shocks. This is due to the high initial rates applied to 5/1 ARMs during the fixed rate period relative to 3/1 or 1/1 ARMs (Figure 2). The longer term initial fixed rate period erodes the benefit of ARMs in terms of payment shocks. The *ex ante* (bottom row) results indicate a higher perceived risk in choosing an ARM than what actually happened during the study period. Without the saving option, the highest expected shock is 12.10% while the saving option reduces the shock to 7.89%.

[Figure 3 here]

Table 2 shows expected payment shocks over the market cycle. Panel A displays *ex post* expected payment shocks. The expected shock is highest for 5/1 ARM during the global financial crisis (GFC) at 4.96% while it is almost zero in other periods nearby. As the initial rate of 5/1 ARM inched up to the 30-year FRM rate, of which the spread is less than 0.36% between the two, 5/1 ARMs became riskier during that period. Over the full period, the expected shock ranges from 0.01% to 3.17%. The average expected shock level was 1.62%, 0.37% and 0.66% for 5/1, 3/1 and 1/1 ARM, respectively. As an alternative, we apply a saving option in the right columns. The saving option reduces the expected shocks significantly. The highest expected shock after applying the saving option is 2.00% for 5/1 ARM. The average expected shock drops to 0.35%, 0.01% and 0.17% for 5/1, 3/1 and 1/1 ARMs, respectively. Panel B shows *ex ante* results. Overall, *ex ante* expected shocks are higher than the *ex post* results with an average of 2.64%, 1.94% and 2.29% expected shocks without a saving option and 1.16%, 0.66% and 0.92% expected shocks with a saving option for 5/1, 3/1 and 1/1 ARMs, respectively. This higher *ex ante* perceived risk could be one of the reasons borrowers avoided ARMs.

[Table 2 here]

Figure 4 displays expected FRM costs. Similar to the expected payment shock, if an FRM borrower is allowed to refinance when rates are low, the borrower can lower the FRM cost. So, the lower bound of expected cost occurs when refinancing is allowed and the upper bound occurs when refinancing is not allowed. Upper rows of the figure show *ex post* results. The expected FRM cost reaches up to 25 – 40%, depending on the time period and ARM type. The expected FRM cost is the highest relative to the 1/1 ARMs, which means 1/1 ARMs are the least costly mortgage option. This is due to the lower initial rate on 1/1 ARMs and the relatively short fixed rate period. On the bottom row, *ex ante* results show lower but more volatile expected FRM costs than the *ex post* results. The expected cost is close to 46% at its highest value.

[Figure 4 here]

Table 3 reports the expected FRM cost over the market cycle. The realized *ex post* results are shown in Panel A. The relative cost of FRMs versus ARMs is almost always higher. It can be as high as over 32% if an FRM borrower does not refinance. One exception is during the GFC period when the expected FRM cost could be less than the 5/1 ARM. This is related to the high initial rate on 5/1 ARMs, as explained above. On average, the expected FRM cost is 12.28%, 20.55% and 23.46% relative to 5/1, 3/1 and 1/1 ARMs, respectively. Panel B reports *ex ante* results. Overall, the expected outcomes are similar to the *ex post* outcomes.

[Table 3 here]

The results in Table 3, together with Table 2, suggest that FRM borrowers paid 12.28% – 23.46% in costs to avoid 0.37% – 1.62% payment shock risks of ARMs, *ex post*. Payment shocks could have been reduced to 0.01% – 0.35% if the borrowers had adopted a saving option. The *ex ante* analysis implies that, at the time of origination, without a saving option, borrowers' perceived payment shock risk is 1.94% – 2.64%, which is higher than the realized shocks. The corresponding expected cost to avoid that perceived risk is 12.12% – 19.38%. The *ex ante* payment shock could have been reduced to 0.66% – 1.16% if the borrower chose to opt for the saving option.

ARMs were one of the factors assigned blame for the global financial crisis in 2007 – 2008. Table 4 summarizes recent ARM choices in 2018 and 2019 from the Home Mortgage Disclosure Act (HMDA) database[7]. Interestingly, ARM borrowers have higher income and borrow less relative to their income (Loan to income) and the property value (Loan to value), for both conforming limit loans (Panel A) and non-conforming limit loans (Panel B). This evidence suggests that recent ARM borrowers are not risky or less creditworthy, unlike ARM borrowers right before the GFC. Rather, they are financially less constrained compared to FRM borrowers, and less risk-averse. Thus, ARM borrowers in recent years should not be a concern to policymakers.

[7] ARM information is available since 2018 in the HMDA database.

[Table 4 here]

Conclusion

FRMs have been popular choices among US homebuyers in order to avoid the interest rate risk of ARMs. However, the cost of avoiding interest rate risk has not been analyzed thoroughly. In this research, we present a framework of evaluating the risks and costs of choosing an ARM versus an FRM. The results indicate that FRM borrowers make 12.28% – 23.46% higher monthly payments to avoid 0.37% – 1.62% possible payment shocks in ARM loans, *ex post*, and make 12.13 – 19.38% higher payments to avoid 1.94 – 2.63% shocks, *ex ante*. Our proposed saving strategy significantly reduces the expected payment shocks to 0.01 – 0.35% *ex post*, and 0.66 – 1.16% *ex ante*. Emerging data show that recent ARM borrowers are less financially constrained compared to FRM borrowers. ARM borrowers have higher income, and borrow less relative to their income and property value. Thus, unlike ARM borrowers before the GFC, recent ARM takers are creditworthy borrowers. Further research is encouraged to investigate changes in ARM borrower characteristics in recent years, and what is driving those changes. This will give more insights into borrowers' mortgage type preferences.

This study provides homebuyers with novel information to help in their home loan choices. Policymakers can use this study to evaluate the benefits and riskiness of ARM loans in recent years.

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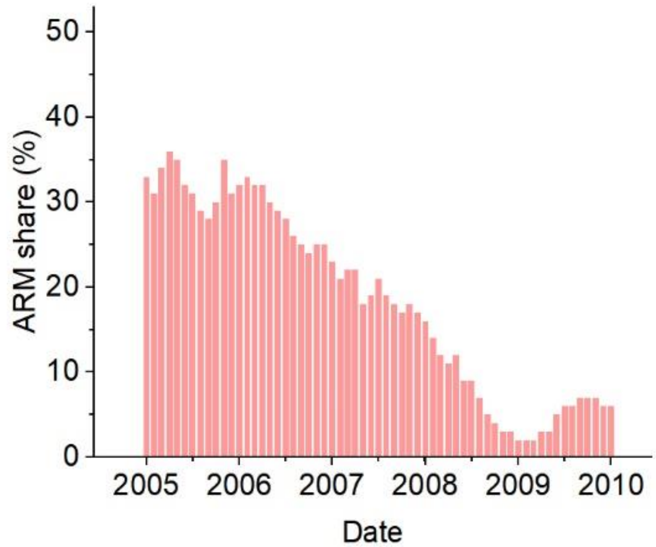
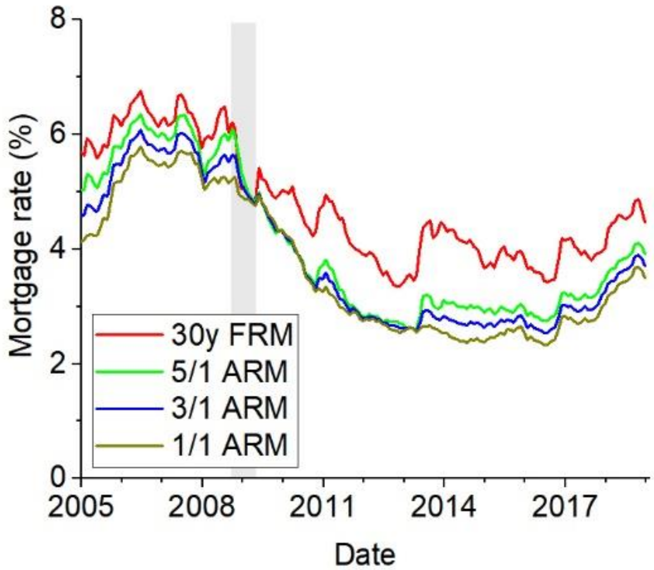
Figure 1: ARM Share (%)



Note: This figure displays the ARM share (%) among mortgage originations. Data runs from January 2005 thru January 2010.

Figure 2: Mortgage Rates



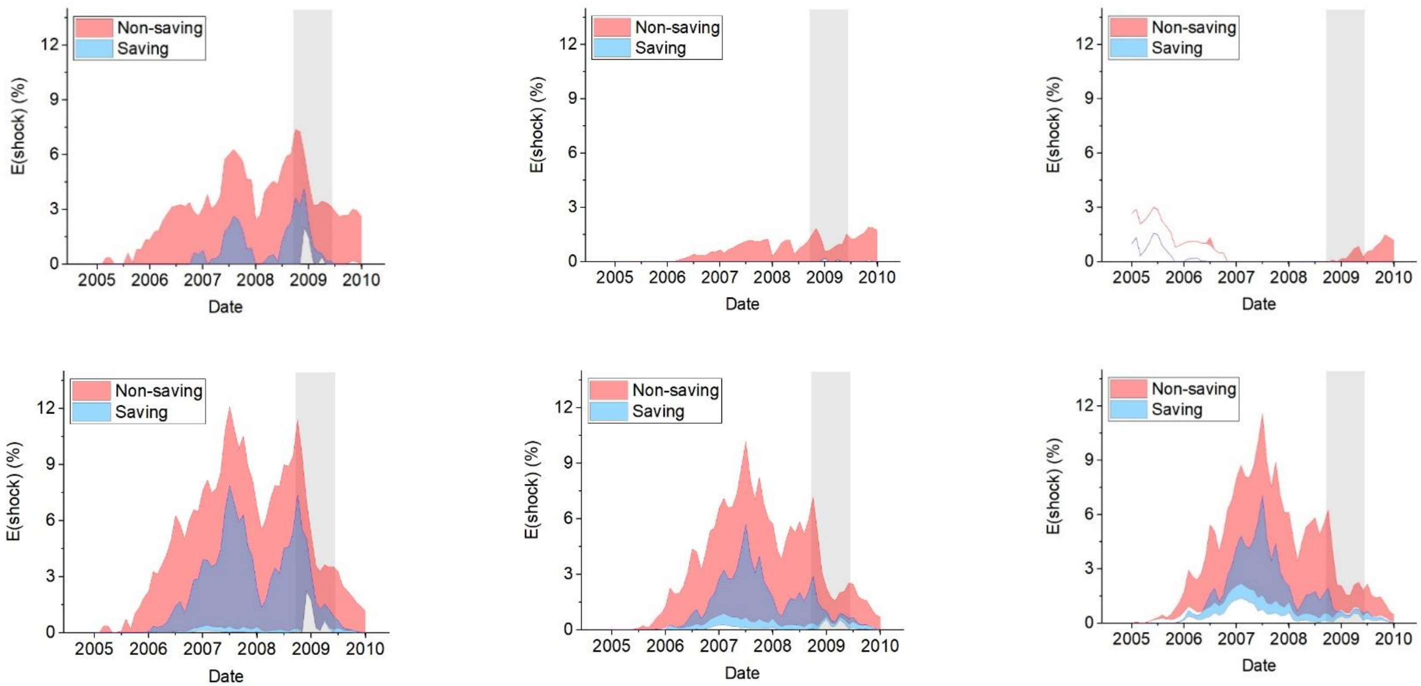
Note: This figure displays historical mortgage rates for 30-year FRM and 5/1, 3/1 and 1/1 ARMs. During January 2016 through January 2019, the 1/1 ARM rate is calculated by subtracting from the 5/1 ARM rate the average difference in the year 2015 of the 5/1 ARM rate and 1/1 ARM rate. The 3/1 ARM rate is calculated by averaging the 5/1 and 1/1 ARM rate. The data run from January 2005 thru January 2019. The shaded area covers the GFC from September 2008 to May 2009 (Hagen et al. 2011; Ji et al. 2020).

Figure 3: Expected Payment Shock

5/1 ARM | **3/1 ARM** | **1/1 ARM**

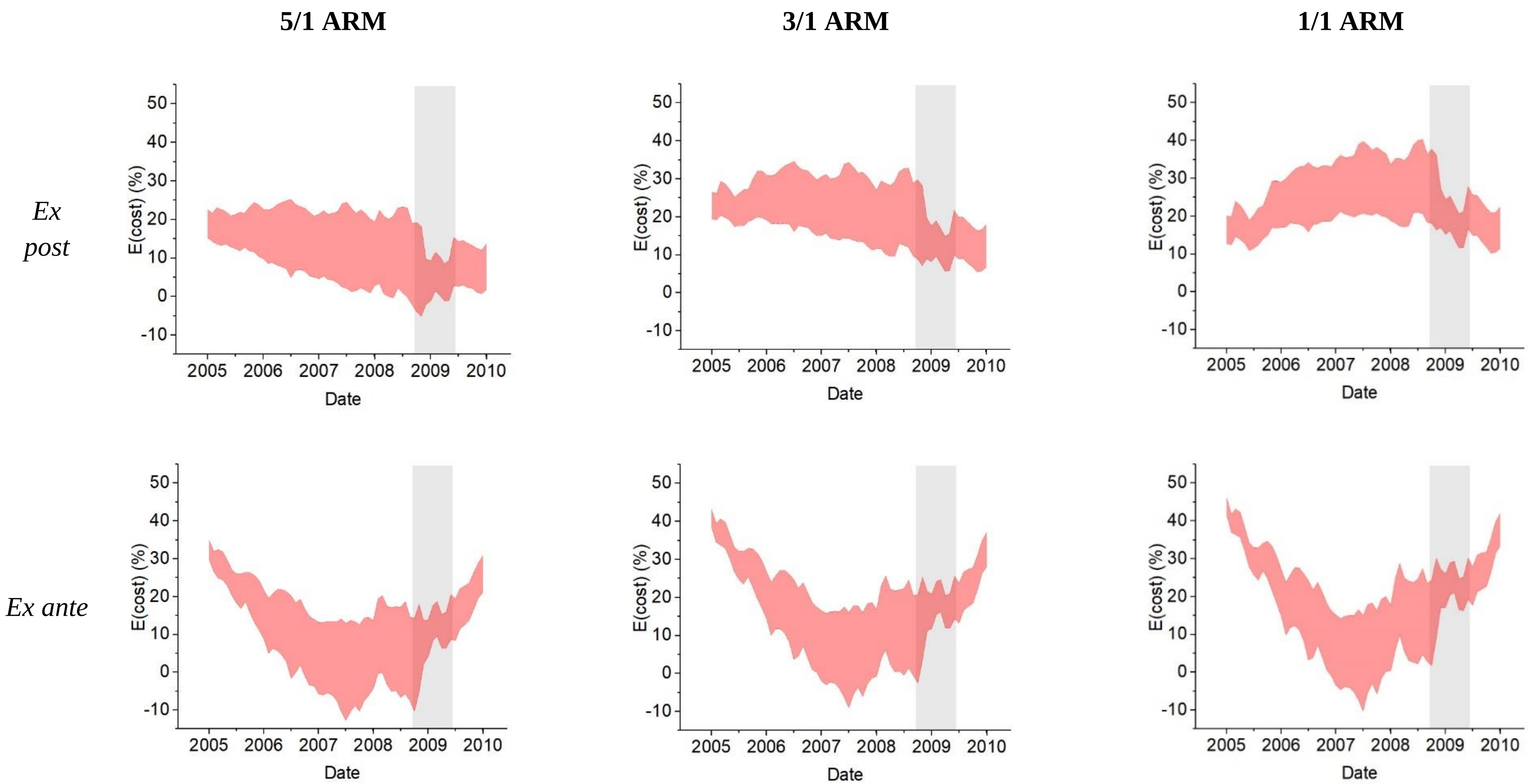
Ex post

Ex ante



Note: This figure reports the payment shocks of ARMs relative to an FRM. We use a hypothetical $400,000, 30-year FRM loan. The FRM loan is compared to 5/1 ARMs, 3/1 ARMs and 1/1 ARMs over a 10-year (120-month) holding period. Both *ex post* and *ex ante* results are presented. The Y-axis represents the expected payment shock, E(shock), as a percentage. The X-axis represents the origination time (month). E(shock) is the average of payment shocks during the holding period. The payment shocks are the ratio of the ARM payment in excess of the FRM payment to the FRM payment. The range of E(shock) is calculated with and without a refinancing option for FRMs. The lower bound of E(shock) occurs when refinancings are not allowed for FRMs and the upper bound occurs when refinancings are allowed for FRMs. With refinancing allowed, we assume an FRM borrower refinances whenever the market mortgage rate drops by 1% from the existing contract rate for the remaining term. For each refinancing, a $4,500 refinance cost will be charged. The borrower will not refinance within one year after the origination or refinancing to recover the refinance cost. The figure includes the non-saving (red) and saving (blue) options. With the saving option, an ARM borrower saves the difference between FRM payments and ARM payments when ARM payments are lower, then uses the savings to cover ARM payment shocks when ARM payments exceed FRM payments.

Figure 4: Expected FRM Cost



Note: This figure reports expected FRM costs. We use a hypothetical $400,000, 30-year FRM loan. The FRM loan is compared to 5/1 ARM, 3/1 ARM and 1/1 ARMs for over a 10-year (120-month) holding period. Both *ex post* and *ex ante* results are presented. The Y-axis represents expected FRM costs, E(cost), in percentage form. The X-axis represents the origination time (month). E(cost) is the average of extra FRM payments during the holding period. The extra FRM payments are the ratio of the difference between FRM and ARM payments to the FRM payment. The range of E(cost) is calculated with and without a refinancing option for FRMs. The lower bound of E(cost) occurs when refinancings are allowed for FRMs and the upper bound occurs when refinancings are not allowed for FRMs. With refinancing allowed, we assume an FRM borrower refinances whenever the market mortgage rate drops by 1% from the existing contract rate for the remaining term. For each refinancing, a $4,500 refinance cost is charged. The borrower will not refinance within one year after the origination or refinancing to recover the refinance cost.

Table 1: Summary Statistics

	Mean	Std.	Max	Min
Short-term rate (%)	2.613	2.194	7.050	0.100
5/1 ARM initial rate (%)	4.045	1.247	6.360	2.610
5/1 ARM margin rate (%)	2.749	0.015	2.790	2.710
3/1 ARM initial rate (%)	3.851	1.203	6.075	2.543
3/1 ARM margin rate (%)	2.751	0.013	2.786	2.724
1/1 ARM initial rate (%)	3.657	1.169	5.790	2.336
1/1 ARM margin rate (%)	2.752	0.014	2.790	2.708
30-year FRM rate (%)	4.762	0.999	6.760	3.350

Note: The study period extends from January 2005 to January 2019. Short-term rate is 1-year Treasury rate. The 1/1 ARM rate is provided only until December 2015. Therefore, we average the differences between 5/1 and 1/1 ARM rates during year 2015 and calculate the 1/1 ARM rate by subtracting the average from the 5/1 ARM rate during January 2016 through January 2019. We use 5/1 ARM margin rate as 1/1 ARM margin rate during January 2016 through January 2019. The 3/1 ARM rate is not provided by Freddie Mac. Therefore, we calculate it by averaging the 5/1 and 1/1 ARM rate. The 3/1 ARM margin rate is calculated by averaging the 5/1 and 1/1 ARM margin rates. The ARM initial rates are not necessarily short-term rate plus margin rate (fully indexed rate) because lenders provide lower than the fully indexed rate during the initial period of an ARM loan.

Table 2: ARM Risk Over the Market Cycle

Panel A: *Ex post* Results

	E(shock) (%) Non-saving option			**E(shock) (%) Saving option**		
ARMs	**5/1**	**3/1**	**1/1**	**5/1**	**3/1**	**1/1**
Pre-GFC	0.00 – 2.87	0.00 – 0.49	0.80 –0.81	0.00 – 0.46	0.00 – 0.00	0.22 – 0.23
GFC	0.45 – 4.96	0.05 – 1.08	0.00 –0.28	0.45 – 2.00	0.03 – 0.05	0.00 – 0.00
Post-GFC	0.05 – 2.84	0.02 –1.59	0.00 –0.94	0.00 – 0.03	0.00 – 0.00	0.00 – 0.00
Full Period	0.07 – 3.17	0.01 –0.72	0.58 –0.74	0.07 –0.63	0.01 – 0.01	0.16 – 0.17
Average	**1.62**	**0.37**	**0.66**	**0.35**	**0.01**	**0.17**

Panel B: *Ex ante* Results

	E(shock) (%) Non-saving option			**E(shock) (%) Saving option**		
ARMs	**5/1**	**3/1**	**1/1**	**5/1**	**3/1**	1/1
Pre-GFC	0.14 – 5.32	0.32 – 3.92	0.85 – 4.43	0.03 – 2.28	0.07 – 1.40	0.40 – 1.81
GFC	0.69 – 6.30	0.48 – 3.46	0.65 – 3.06	0.60 – 3.58	0.27 – 1.27	0.31 – 0.92
Post-GFC	0.13 – 2.23	0.25 – 1.61	0.38 – 1.33	0.01 – 0.30	0.05 – 0.31	0.15 – 0.33
Full Period	0.22 – 5.06	0.33 – 3.55	0.76 – 3.82	0.11 – 2.21	0.09 – 1.23	0.36 – 1.49
Average	**2.64**	**1.94**	**2.29**	**1.16**	**0.66**	**0.92**

Note: This table reports the expected payment shock, E(shock), with a non-saving and saving option during the study period (January 2005 to January 2010) by sub-periods. Panel A and B report *ex post* and *ex ante* results, respectively. Pre-GFC is from January 2005 through August 2008, GFC is from September 2008 through May 2009, and post-GFC is from June 2009 through January 2010. Full Period is for the full study period. The Average row provides the average of lower bound and upper bound of Full Period. With the saving option, an ARM borrower saves the difference between FRM payments and ARM payments when ARM payments are lower, then uses the savings to cover ARM payment shocks when ARM payments exceed FRM payments. The loans are assumed to have a 30-year term with a 10-year (120-month) holding period. E(shock) is the average of payment shocks during the holding period. The payment shocks are the ratio of ARM payment in excess of FRM payment to the FRM payment. The range of E(shock) is calculated with and without a refinance option for FRMs. In each period, the lower bound of E(shock) is calculated assuming refinancings are not allowed for FRMs and the upper bound assumes refinancings are allowed for FRMs. The averages of lower (upper) bound values are reported. With refinancing allowed, we assume an FRM borrower refinances whenever the market mortgage rate drops by 1% from the existing contract rate for the remaining term. For each refinancing, a $4,500 refinance cost is charged. The borrower will not refinance within one year after the origination or refinancing to recover the refinance cost.

Table 3: FRM Cost Relative to ARMs Over the Market Cycle

Panel A: Ex post Results

	E(cost) (%)		
ARMs	**5/1**	**3/1**	**1/1**
Pre-GFC	6.45 – 22.44	15.80 – 30.48	17.58 – 31.93
GFC	-1.65 – 12.82	7.97 – 21.20	15.37 – 28.04
Post-GFC	2.08 – 13.69	7.57 – 18.57	12.98 – 23.66
Full Period	4.68 – 19.87	13.56 – 27.55	16.65 – 30.27
Average	**12.28**	**20.55**	**23.46**

Panel B: Ex ante Results

	E(cost) (%)		
ARMs	**5/1**	**3/1**	**1/1**
Pre-GFC	3.17 – 19.92	8.73 – 24.81	9.49 – 25.49
GFC	1.51 – 15.79	8.79 – 22.18	13.57 – 26.63
Post-GFC	14.03 – 24.34	19.64 – 29.33	24.27 – 33.68
Full Period	4.35 – 19.89	10.17 – 25.02	12.03 – 26.73
Average	**12.12**	**17.59**	**19.38**

Note: This table reports the expected FRM cost, E(cost), during the study period (January 2005 to January 2010) by sub-periods. Panel A and B report *ex post* and *ex ante* results, respectively. Pre-GFC is from January 2005 through August 2008, GFC is from September 2008 through May 2009, and post-GFC is from June 2009 through January 2010. Full Period is for the full study period. The Average row provides the average of the lower bound and upper bound for Full Period. With the saving option, an ARM borrower saves the difference between FRM payments and ARM payments when ARM payments are lower, then uses the savings to cover ARM payment shocks when ARM payments exceed FRM payments. The loans are assumed to have a 30-year term with a 10-year (120-month) holding period. E(cost) is the average of extra FRM payments during the holding period. The extra FRM payments are the ratio of the difference between FRM and ARM payments to the FRM payment. The range of E(cost) is calculated with and without a refinance option for FRMs. In each period, the lower bound of E(cost) is calculated assuming refinancings are allowed for FRMs and the upper bound assumes refinancings are not allowed for FRMs. The averages of lower (upper) bound values are reported. With refinancing allowed, we assume an FRM borrower refinances whenever the market mortgage rate drops by 1% from the existing contract rate for the remaining term. For each refinancing, a $4,500 refinance cost is charged. The borrower will not refinance within one year after the origination or refinancing to recover the refinance cost.

Table 4: 5/1 ARM vs. FRM Origination Characteristics

Panel A: Conforming Loan Limit

	2018		**2019**	
	5/1 ARM	**FRM**	**5/1 ARM**	**FRM**
Number of loans	73,699	3,718,404	66,032	4,502,019
Loan Amount ($)	245,316	234,032	254,920	255,341
Income ($)	124.100	91,300	129,500	95,540
Income to area median income	1.68	1.25	1.69	1.24
Loan to income	2.50	2.91	2.72	3.24
Loan to value (%)	74.72	83.25	74.53	82.33

Panel B: Non-conforming Loan Limit

	2018		**2019**	
	5/1 ARM	**FRM**	**5/1 ARM**	**FRM**
Number of loans	20,910	156,954	20,765	257,618
Loan Amount ($)	955,775	760,949	1,037,655	757,091
Income ($)	473,700	287,200	532,400	277,600
Income to area median income	5.96	3.58	6.29	3.30
Loan to income	2.92	3.10	3.17	3.70
Loan to value (%)	71.49	78.05	69.92	77.55

Note: This table reports characteristics of 5/1 ARMs, and FRMs with a 30-year loan term at origination. Only single-family and non-commercial purpose loans are included. The data is from the HMDA database. Loans with a 60-month introductory interest period are classified as 5/1 ARMs. Panel A reports on loans within conforming loan limits, that meet the funding criteria of Fannie Mae and Freddie Mac. Panel B reports on loans above conforming loan limits. Number of loans, loan amount in dollars, and income in dollars are reported. Income to area median income is the ratio between borrower income and metropolitan statistical area (MSA) median income. Loan to income is the loan amount to income ratio. Loan to value is the loan amount divided by the property value, as a percentage.

Appendix A1: Interest rate simulation

We assume that rational home buyers form expectations about the trajectory of interest rates to make a loan type choice. For this, first using the Hodrick-Prescott filter (Hodrick and Edward 1997), we separate a historical 1-year Treasury constant maturity rate (short rate) r_t into a trend component T_t and a cyclical component C_t such that $r_t = T_t + C_t$. Then, we estimate the cyclical C_t using the Vasicek model (Vasicek 1977), which describes the evolution of interest rates driven by market risk[8]. The risk-neutral process for C_t at time t is defined by,

(A1) $$dC_t = k(\mu - C_t)dt + \sigma dW_t ,$$

where k , μ and σ are constants and represent the speed of adjustment, the mean reversion level and volatility, respectively, and W_t is a standard Wiener process.

To calibrate these cyclical parameters of the short rate model in equation (A1), we rewrite it in the following regression form (Hull and White 1996),

(A2) $$y_t = \alpha + \beta x_t + \varepsilon_t ,$$

where $y_t = dC_t$, $\alpha = k\mu dt$, $\beta = -kdt$, $x_t = C_t$ and $\varepsilon_t = \sigma dwt$. We estimate the parameters of equation (A2), i.e., α , β and σ , by the ordinary least squares method where volatility is proportional to the standard error of the residuals, i.e., $\sigma = \sqrt{\frac{\mathrm{var}(\varepsilon_t)}{dt}}$.

Finally, the estimated interest rate is,

(A3) $$\hat{r}_t = \hat{T}_t + \hat{C}_t \text{ for } t = 0 \text{ to } H ,$$

[8] The Vasicek model is a type of one-factor model describing a mean-revision process where interest rate movements are driven by market risk only (Ahn et al. 2018; Lee et al. 2020, for example).

where $\hat{C}_{t+1} = \hat{C}_t + d\hat{C}_t$ and $d\hat{C}_t = k(\mu - \hat{C}_t)dt + \sigma dW_t$. Then, $\hat{r}_t$ is the estimated historical interest rate using a trend $\hat{T}_t$ and cyclical component $\hat{C}_t$, where $\hat{T}_0$ and $\hat{C}_0$ are taken from the earliest historical interest rate.

The Vasicek model in equation (A1) is estimated for *ex ante* analysis. Table A1 summarizes the estimated parameters. We report three different time periods around the GFC from September 2008 through May 2009. It can be seen that the parameter for the speed of adjustment k is faster before the GFC and decreasing over time. The decline of mean reversion level μ, combined with the value of k, implies that the short-term interest rates are estimated to decline during and after the GFC. Indeed, the interest rate falls to the zero lower bound in September 2011. The volatility σ increase during the GFC is driven by turmoil in the financial markets. Overall, the parameters appear to properly incorporate the actual path of interest rates during the test periods.

Table A1: Vasicek Parameters

	k	μ	σ
Pre-GFC	0.541 (0.130)	0.001 (0.002)	0.012 (0.001)
GFC	0.532 (0.032)	-0.001 (0.000)	0.015 (0.000)
Post-GFC	0.460 (0.019)	-0.003 (0.001)	0.014 (0.001)
Full Period	0.529 (0.114)	0.000 (0.002)	0.013 (0.001)

Note: This table reports the average of parameter estimates of the Vasicek interest rate model. The mean and standard deviation (in parentheses) of each parameter are reported by time period. Pre-GFC period is from January 2005 through August 2008, GFC period is from September 2008 through May 2009, and post-GFC period is from June 2009 through January 2010.