J Real Estate Finan Econ (2020) 60:421–468
https://doi.org/10.1007/s11146-018-9682-z

Mortgage Risk Premiums during the Housing Bubble

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Published online: 24 January 2019

Abstract

How did pricing for mortgage credit risk change during the years prior to the 2008 financial crisis? Using a database from a major American bank that served as trustee for private-label mortgage-backed securitized (PLS) loans, this paper identifies a decline in credit spreads on mortgages conditioned on loan and borrower characteristics. We show that observable risk factors, FICO score and loan-to-value ratio, had less of an impact on mortgage pricing over time. As the volume of PLS mortgages expanded and lending terms eased, risk premiums failed to price the increase in risk.

Keywords Housing bubble · Risk premium · Securitization · Private-label

JEL G01 · G12 · G20 · G21

Introduction

In the years prior to the 2008 financial crisis, there was a well-documented rise in mortgage risk in multiple dimensions. Mayer et al. (2009) and Demyanyk and Hemert (2011), among others, show a shift to riskier mortgage products along with an increase in the volume of non-traditional mortgages. Private-label securitization (PLS) funded the major share of non-traditional mortgages issued in these years. While the role of PLS in funding non-traditional mortgages is well known and accepted (Mian and Sufi

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2014; Levitin and Wachter 2011), there is little consensus on how mortgage pricing evolved during this surge. Knowing how risk premiums on PLS mortgages changed with the shift to riskier product is important for understanding the source of the housing bubble and the subsequent financial crisis. Was the massive increase in the supply of credit and riskier product through PLS associated with a decline or increase in risk-adjusted mortgage interest rates?

The empirical literature provides conflicting findings on this question. Rajan et al. (2015) and Antinolfi et al. (2016) identify an increase in the size and explanatory power of credit risk factors in the pricing of securitized mortgages in this period. On the other hand, Demyanyk and Hemert (2011) and Justiniano et al. (2017) find a decrease in risk premiums.

We use a comprehensive loan level dataset of 4 million loans securitized in private-label pools, from 2001 to 2007, to examine this question. We organize the data, provided by a single large bank trustee, to identify the course of risk premiums during the years of the housing bubble. The data include mortgage and borrower risk characteristics, which allows an analysis of the changing composition of mortgage pools and the impact of these changes on risk premiums over time. By adjusting for changing characteristics and pricing of risk factors, we identify a residual vintage effect. We model credit spreads to incorporate borrower and mortgage risk characteristics and find that the residual vintage effect declines monotonically over time.

The decline in credit spreads in PLS, conditioned on mortgage characteristics, that we observe points to a rightward shift of the mortgage credit supply curve during the housing bubble, as posited by Levitin and Wachter (2011). A rightward shift indicates that PLS investor-led supply, rather than borrower demand, predominated in the expansion of credit in the years prior to the financial crisis. The finding is consistent with information asymmetries impeding investor analysis of the risk of securities.

The remainder of the paper is organized as follows. "Literature Review" section describes the relevant literature. "Data" section presents the data and summarizes key statistics. "Model and Results" section presents the model and reports results. "Discussion" section discusses and reconciles these results with those of prior studies. "Conclusion" section concludes.

Literature Review

The question of how the pricing of risk for private-label mortgage-backed securitized loans changed in the run-up to the financial crisis of 2008 relates to a literature on the pricing of mortgage risk as well as to a large finance literature on credit frictions in the business cycle. The trading and pricing of mortgage securities for credit risk is relatively new, hence the limited literature on the pricing of credit risk in mortgage securitization.[1] In an early study of the pricing of mortgage risk, Ambrose et al. (2004) identifies the differential pricing of conforming government-sponsored enterprise (GSE) loans (agency loans), which are insured against default risk, versus non-conforming (non-agency) loans. The findings confirm that markets differentially priced credit risk. Ambrose, LaCour-Little and Sanders show that observable credit risk characteristics, loan-to-value (LTV) ratio and FICO score, affect the mortgage yield spread between conforming and nonconforming loans in the

[1] For a history of PLS, see Levitin and Wachter (2011).

expected direction in the years 1995 through 1997, prior to the take-off of PLS, when agency loans still dominated the market for securitized lending.

Mian and Sufi (2009, 2014) document the rise of private-label securitization from the early 2000s through 2007, after which the private-label securitization (PLS) market shut down with the rise in mortgage defaults. PLS provided funding for purchase and refinance mortgages, for borrowers with prime and subprime credit, for adjustable rate and fixed rate mortgages, and increasingly over time, for non-traditional products, such as interest-only loans. As agency refinance securitization stalled in 2003, with the end of interest rate decreases, financial markets turned their efforts to the provision of this relatively new securitization product (Levitin and Wachter 2011). Mayer et al. (2009) show the increase in product complexity between 2003 and 2007 that accompanied this increase and the subsequent increase in default rate by vintage. Demyanyk and Hemert (2011) further identifies factors associated with this rise in delinquencies, including rising LTV ratios, declining FICO scores and rising debt-to-income ratios. While their focus is on delinquencies, they also show a decline in the risk-adjusted spread of the average subprime mortgage rate relative to the prevailing prime fixed mortgage rate from the early 2000s to 2006.

Rajan et al. (2015), Antinolfi et al. (2016) and Justiniano et al. (2017) directly test for how the pricing of risk changed as PLS issuance surged. Rajan, Seru and Vig (RSV) interpret their results as showing investors improved their pricing of risk over time by increasing their use of observable "hard" information in the pricing of securitized loans through 2006, as securitization took off. In support of this conclusion, they use CoreLogic data for purchase money loans in annual regressions with the mortgage rate as the dependent variable and show an increasing R-square, an unchanged coefficient on FICO score and an increasing coefficient on LTV over time.

Antinolfi, Brunetti and Im (ABI) come to a similar conclusion, using a database of purchase and refinance loans, by examining the differential effect of FICO score and LTV ratios on the mortgage rate minus the risk-free rate. They separately identify four groups of loans, private-label prime securitized loans, private-label subprime (from CoreLogic, including Alt-A) securitized loans, GSE-guaranteed loans and bank-portfolio-held loans and conduct monthly estimations of the marginal impacts of FICO and LTV on the mortgage rate spreads. Within these groups, they combine adjustable rate and fixed rate mortgages and focus only on 15- and 30-year maturity loans. They find that markets priced credit risk similarly across these mortgage groups with the exception of subprime. Like RSV, they find an increasing marginal impact of FICO and LTV from 2001 to 2007 for subprime loans. They interpret this result as showing that markets improved the pricing of risk over time.[2]

Justiniano, Primiceri and Tambalotti (JPT) also examines the pricing of risk over time in mortgage rates, using a somewhat different methodology and a dataset that includes purchase and refi loans, and identifies a decline in the pricing of risk, particularly in 2003, just as PLS issuance surged. JPT (mainly using CoreLogic data) pools mortgages originated from 2000 to 2007 and includes borrower and loan characteristics and vintage dummies to identify the changing effects of these terms on the mortgage rate over time, including term structure factors, since the sample includes fixed rate mortgages. JPT focuses on the residuals of regression equations, referring to these residuals as conditional mortgage rate spreads, as they provide a measure of what happened to the underlying cost of mortgage credit over the housing boom. These take account of changes in borrower and loan

[2] They also point to the salience of the subprime market in default outcomes.

characteristics. JPT, however, does not test for the impact of changes in the pricing of LTV and FICO score or for any impact of changes in pricing on these residuals. JPT finds a sharp decrease in mortgage rates and in conditional mortgage rate spreads, as measured by residuals in mid-2003. They refer to this finding as the mortgage rate conundrum, since it occurs when interest rates begin to rise, as the Federal Reserve reversed its formerly easy monetary policy put into place in response to the 2001 tech bubble collapse. As others, they ascribe this break to lenders starting to push harder into subprime securitization and other previously underserved segments of the mortgage market following the collapse of their refinancing business, in order to sustain their elevated level of activity. They did so by keeping mortgage rates low, in the face of an increase in Treasury rates, through a surge in PLS-funded non-agency mortgages, "especially for marginal borrowers that *ex post* appear to have contributed disproportionately to inflating the housing bubble."[3]

Securitization and, more generally, the development of financial trading vehicles to trade and price risk should enable, in principle, price discovery and the appropriate pricing of risk. Nonetheless, the finance literature points to a credit spread puzzle (Elton et al. 2001) over the cycle due to "frictions" (Gilchrist and Zakrajšek 2012). The empirical literature on mortgage finance points to an excessive *ex post* increase in mortgage risk premiums, conditional on borrower and loan characteristics, after the crisis (Stanton and Wallace 2011) and to sharply tighter mortgage lending standards as well (McCoy and Wachter 2017; Goodman 2017). What is lacking is a consensus around credit pricing in the run-up to the crisis. Unresolved in the empirical literature, as shown by the diverging results of recent studies, is the effect of observable risk characteristics, such as LTV, FICO scores and location, on the pricing of securitized mortgages and the residual vintage effect, that is, the pricing of risk over time. This relates to a broader question on the source of the financial crisis. Adelino et al. (2017) describe the common narrative of the crisis, as put forth by Mian and Sufi (2009), as the expansion of lending to subprime borrowers and offer a counter narrative pointing to excessive risk-taking by investors. We deploy the database used here for this purpose for the first time to identify the impact of the composition of PLS lending on risk-based pricing and, more broadly, to interpret the role of subprime and prime securitized lending in the evolution of housing finance and the pricing of securitized credit risk in the years prior to the financial crisis.

Data

Data Description

We use a loan-level database of more than 4 million loans derived from a major American bank that compiled the data in its role as trustee for approximately 10%, by dollar amount, of all private-label mortgage securitizations—securitizations not guaranteed by the federal government or by government-sponsored entities—during 2001–2007.[4] The trustee's role in private-label mortgage securitization includes providing reports on the securitized assets

[3] See Justiniano et al. (2017) for further discussion and references on this.

[4] PLS are mortgage securitizations, which are not guaranteed by government-sponsored entities (Fannie Mae and Freddie Mac) or the federal government (Ginnie Mae). This bank's share in the PLS trusteeship market, as measured by total deal dollar volume, was generally in the range of 10% during the years for which data are available (Inside Mortgage Finance 2012). The database is available from the authors and is from one of several major U.S. banks that served as trustees for private-label mortgage-backed securities (PLS).

and their performance to investors in the PLS. The data source is a file that contains monthly repeated loan-level cross-section data generated by the trustee for investor reporting on all of the PLS for which the bank served as trustee.

The database consists of mortgage pools containing hundreds of mortgages in each pool, with hundreds of pools issued each year and deal volume increasing over time, and includes detailed information on both the mortgagors and the mortgage contracts. We aggregate data by pools for each year.[5] The securitized mortgage pools are a mixture of mortgages by loan purpose (primary purchase, refinance with and without cash-out), credit quality (FICO scores and LTV ratios), documentation type (full, stated, limited) and product type (interest-only, negative amortization, balloon). The only exception to this combination of all types and purposes of loans in each mortgage pool is the separation of adjustable rate mortgage (ARM) and fixed rate mortgage (FRM) loans into different securitized pools. The database includes additional information on the mortgage loans, including origination date and location (by ZIP code) and whether the loan is currently delinquent. A smaller proportion of loans contains a detailed classification of product types, such as 2/28 ARM (discussed below), and distinguishes hybrid loans by index rate, the fixed rate period, interest rate adjustment frequency, loan term, etc.[6]

We exclude observations with missing information, which reduces the dataset of 4 million loans to 2.6 million loans.[7] We focus on the 2.2 of these 2.6 million loans which are adjustable rate loans. We use data on loans originated from 2001 to 2007. We choose this period to exclude origination from earlier years with fewer than 10,000 ARM loans per year, accounting for about 1% of the ARM observations.

Summary Statistics

The database shows a shifting composition of private-label securitized (PLS) mortgages toward ARMs and non-traditional loans over time. The changing composition of PLS mortgages in this database is representative of the broader shift in the PLS market (Mayer et al. 2009; Levitin and Wachter 2011).

Prior to 2004, both ARMs and FRMs were common, but beginning in 2004, a shift toward ARMs occurred at a time of rising short-term interest rates, as represented in the indexes frequently used as references for ARM loans.

Tables 1 and 2 report the number of loans and aggregate dollar volume respectively by product type and origination year. ARMs were approximately 50% of the number of loans and 60% of the dollar volume of loans originated in 2001 (remaining relatively constant until 2004) and then 70% of the number of originations and 80% of the dollar volume of originations in 2006. The shift to ARMs and away from FRMs is consistent with the aggregate data and with the shift to other more affordable products observed in this period of rising house prices (Mayer et al. 2009; Levitin and Wachter 2011).

Tables 1 and 2 also show the increasing share of more complex non-traditional products. These include interest-only (IO) mortgages, mortgages with negative amortization (meaning

[5] Our analysis collects data from all securitized mortgage pools originated from the same vintage into a single pool by year (vintage pools). Even if mortgage pools are homogeneous in borrower and loan characteristics, the analysis of risk pricing via the coefficients of key variables is unaffected.

[6] There are 103 detailed classification of product types. For more information, see Footnote 11.

[7] Observations missing FICO score, document type, appraisal value, original balance, origination date, or LTV (almost 40% of the overall data) are dropped from the dataset. Details are provided in the Appendix.

principal balances increase over time), and balloon mortgages (e.g. loans with a 30-year term but payments based on a 40-year amortization schedule), as well as hybrids that combine IO, negative amortization and balloon features. These products have lower monthly payments than traditional, fully-amortized loans. Therefore, a borrower with the same monthly payment capacity can borrow more with a non-traditional mortgage structure and purchase a more expensive property than with a traditional mortgage.

In the database, as shown in Table 1 (Table 2), non-traditional mortgages collectively accounted for 11% of the total number of loans originated (16% of dollar volume) in 2001 and 56% of the total number of originations (65% of dollar volume) in 2006.[8] Particular non-traditional mortgage types such as interest-only and negative amortization ARMs hardly existed in the early 2000s at 6% and 2% of all loans, respectively, and rose rapidly from their low base to 32% and 23% at their peaks, respectively.[9]

As shown in Table 3, 2/28 ARMs, or so-called "teaser rate" loans, are the most popular ARM product from 2001 to 2007, with the number of loans increasing from 252 in 2001 to almost 130,000 in 2006 at the peak in the sample.[10] Other variants of hybrid mortgages, such as 2/6 month ARMs and 5/1 ARMs[11] also proliferated as shown in Table 3 which lists the top 41 of 103 product types by descending frequency for all ARMs with more than 1000 observations.[12] At their peak share of the market, in 2006, 2/28 ARMs were 25% of PLS ARM loans. ARMs are more affordable than FRMs as they include a lower premium for interest rate risk; 2/28 ARMs start with a lower rate, used to qualify buyers of a given income to more easily borrow a mortgage of a given size, and, hence, are by design more affordable.

Table 4 reports summary statistics for major categorical features of mortgages in the ARM dataset in descending percentage shares for which we have data.[13] The composition of PLS by loan purpose (purchase, refi or refi cash-out) also shifted over time. Figure 1a, using quarterly data, shows the rapidity of these shifts.[14] There is a boom in refi loans refi loans without cash-out, driven by interest rate declines, through 2003q1. The share of

[8] To calculate the percentage shares of non-traditional mortgages, we sum up the share of ARM loans with balloon tag "B", interest-only tag "IO" or negative amortization tag "NegAm" and the share of FRM loans with balloon tag "B" in Table 1.

[9] To calculate the percentage share of interest-only (negative amortization) loans, we sum up the share of ARM loans with interest-only tag "IO" (negative amortization tag "NegAm") in Table 1.

[10] 2/28 ARMs are adjustable rate mortgages with the initial mortgage rate fixed for the first two years and adjusting for the next 28 years. The interest rate adjustment frequency is every 6 months and over 95% use 6-month London Interbank Offered Rate (LIBOR) as the index rate. The floating mortgage rate is the sum of the index rate and a margin that is specified at the beginning of the mortgage contract.

[11] 2/6 month ARMs are adjustable rate mortgages with the initial mortgage rate fixed for the first 2 years and adjusting every 6 months later on. 5/1 ARMs are adjustment rate mortgages with the initial mortgage rate fixed for the first 5 years and adjusting every year later on. Detailed mortgage product types provide more information but are only available to a subsample of ARM loans. We follow the coding of the product type in the database. It is possible that the product types are not mutually exclusive. For example, a fraction of "5-year ARMs" may fall in the category of "5/1 ARMs". There may be characteristics that distinguish those two groups, but they are unobservable to investors or researchers. Given the information provided by the database, we consider the loans within a product type defined by the database as homogeneous.

[12] The listed product types cover the vast majority (99%) of loans when data is available on detailed product types. However, we include all 103 variables in our regression results with detailed product types.

[13] We also report the frequency and percentage weighted by the original balance with the unweighted counterparts for comparison. The unweighted and weighted rankings generally coincide.

[14] We report the trends over time in Figure 1a and b respectively in ARMs by loan purpose and by documentation level. Using quarterly data instead of annual aggregated shares, we show how the shares of refi loans (with and without cash-out) change rapidly within a year.

Table 1 Mortgages by product type and origination year

	Origination year													
	2001		2002		2003		2004		2005		2006		2007	
	N	%	N	%	N	%	N	%	N	%	N	%	N	%
ARM														
!B, IO, NegAm	0	0.00	6	0.03	166	0.15	454	0.14	383	0.06	21,228	2.34	17,801	7.50
!B, IO,!NegAm	282	6.04	2649	12.41	21,620	19.30	101,265	31.56	202,668	31.32	195,635	21.55	44,745	18.85
!B,!IO, NegAm	93	1.99	361	1.69	1474	1.32	25,928	8.08	70,653	10.92	85,697	9.44	35,156	14.81
!B,!IO,!NegAm	2200	47.13	9286	43.49	33,878	30.24	103,634	32.29	180,586	27.90	172,347	18.98	39,129	16.48
B, IO, NegAm	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	5	0.00	90	0.04
B, IO,!NegAm	0	0.00	0	0.00	338	0.30	1202	0.37	2394	0.37	12,589	1.39	1679	0.71
B,!IO, NegAm	0	0.00	0	0.00	2	0.00	1	0.00	95	0.01	11,351	1.25	427	0.18
B,!IO,!NegAm	20	0.43	157	0.74	309	0.28	2599	0.81	14,836	2.29	102,189	11.25	23,596	9.94
Total	2595	55.59	12,459	58.35	57,787	51.58	235,083	73.26	471,615	72.88	601,041	66.19	162,623	68.50
FRM														
B	106	2.27	252	1.18	1189	1.06	6372	1.99	36,774	5.68	78,661	8.66	10,751	4.53
F	1967	42.14	8641	40.47	53,062	47.36	79,446	24.76	138,764	21.44	228,296	25.14	64,037	26.97
Total	2073	44.41	8893	41.65	54,251	48.42	85,818	26.74	175,538	27.12	306,957	33.81	74,788	31.50

The exclamation mark (!) refers to negation. ARM products are classified into eight types, because the classifications by balloon (B), interest-only (IO) and negative amortization (NegAm) are not mutually exclusive. FRM products are classified into two types: FRM with balloon payment (B) and FRM without balloon payment (F)

ARM, adjustable rate mortgage; *FRM*, fixed rate mortgage; *B*, Balloon; *IO*, Interest-Only; *NegAm*, Negative Amortization; *F*, Fixed Rate

Table 2 Mortgage dollar volume by product type and origination year

	Origination Year													
	2001		2002		2003		2004		2005		2006		2007	
	$	%	$	%	$	%	$	%	$	%	$	%	$	%
ARM														
!B, IO, NegAm	0	0.00	2.45	0.05	38.69	0.12	145.77	0.19	145.57	0.09	7954	3.24	6808	8.29
!B, IO,!NegAm	114.63	13.37	975	18.56	8249	25.45	33,100	43.54	75,212	44.21	77,118	31.39	22,009	26.80
!B,!IO, NegAm	10.69	1.25	57	1.08	287.01	0.89	5852	7.70	20,867	12.27	32,202	13.11	13,850	16.86
!B,!IO,!NegAm	377.36	44.03	1640	31.23	8755	27.02	21,581	28.39	39,476	23.21	37,824	15.40	10,867	13.23
B, IO, NegAm	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	1.8	0.00	34.82	0.04
B, IO,!NegAm	0	0.00	0	0.00	71.94	0.22	278.97	0.37	689.5	0.41	3810	1.55	530.56	0.65
B,!IO, NegAm	0	0.00	0	0.00	0.71	0.00	0.19	0.00	34.18	0.02	4404	1.79	179.66	0.22
B,!IO,!NegAm	3.19	0.37	17.86	0.34	71.8	0.22	359.2	0.47	4006	2.35	26,204	10.67	6791	8.27
Total	505.87	59.02	2691	51.26	17,474	53.92	61,318	80.66	140,431	82.55	189,519	77.14	61,070	74.35
FRM														
B	8.5	0.99	23.65	0.45	109.97	0.34	317.48	0.42	2450	1.44	7124	2.90	2027	2.47
F	343	39.99	2535	48.29	14,824	45.74	14,386	18.92	27,238	16.01	49,026	19.96	19,039	23.18
Total	351	40.98	2559	48.74	14,934	46.08	14,704	19.34	29,689	17.45	56,151	22.86	21,066	25.65

The exclamation mark (!) refers to negation. ARM products are classified into eight types, because the classifications by balloon (B), interest-only (IO) and negative amortization (NegAm) are not mutually exclusive. FRM products are classified into two types: FRM with balloon payment (B) and FRM without balloon payment (F). Dollar volume of each origination year is measured by the sum of original balance. Dollar volumes are in million dollars

ARM, adjustable rate mortgage; *FRM*, fixed rate mortgage; *B*, Balloon; *IO*, Interest-Only; *NegAm*, Negative Amortization; *F*, Fixed Rate

Table 3 Most popular ARM product types, by origination year

Product type	Origination year							
	2001 N	2002 N	2003 N	2004 N	2005 N	2006 N	2007 N	Total N
2/28 ARM	252	788	5625	27,066	84,701	128,927	21,559	268,918
2/6 Month ARM	12	665	1665	8888	56,103	84,505	11,997	163,835
Moving Treasury Average	88	278	1024	1751	28,973	42,583	12,108	86,805
5/25 ARM	10	99	1196	15,677	31,569	26,495	6245	81,291
5/6 Month LIBOR ARM	43	33	2144	14,374	17,101	32,552	13,603	79,850
5/1 ARM	46	221	2314	5325	18,988	19,292	14,218	60,404
5 Year ARM	11	155	2592	9064	11,954	19,369	10,861	54,006
3/27 ARM	136	83	1491	10,951	14,844	20,172	3583	51,260
3/6 Month ARM	5	110	698	5713	13,226	15,234	3512	38,498
5/25 ARM	13	165	2718	5255	15,305	12,120	134	35,710
30 Year Balloon	0	0	0	0	181	13,336	1001	14,518
10/1 ARM	8	79	2775	1830	14,762	7587	3880	30,921
30/40 Balloon	0	0	0	0	6993	14,362	2532	23,887
7/1 ARM	28	88	772	2480	10,027	7732	3140	24,267
5/1 IO ARM	1	18	3049	8608	7205	1640	0	20,521
10/20 ARM	1	36	50	392	4415	9875	901	15,670
5/10 ARM	3	16	201	2080	7999	1876	1108	13,283
1 Month ARM	25	0	36	83	751	8538	3380	12,813
7/23 ARM	1	79	375	1230	2406	6493	255	10,839
6 Month LIBOR	31	32	1539	4616	3655	294	38	10,205
2/1 ARM	1	3	49	20	269	9249	45	9636
10 Year ARM	11	5	2	148	2841	4952	783	8742
7 Year ARM	4	5	281	40	1675	3735	1387	7127
3 Year ARM	5	2	163	282	2133	3388	655	6628
7/6 Month ARM	15	36	274	632	2208	2600	704	6469
3/1 IO ARM	0	16	206	3167	2580	220	0	6189
6 Month LIBOR	1	23	406	1963	2694	641	23	5751
7/1 IO ARM	2	4	588	1958	2283	0	0	4835
1 Month LIBOR	67	43	125	1401	2551	134	1	4322
1 Year CMT	25	56	283	363	2565	654	0	3946
7/1 ARM	2	4	146	338	55	2598	682	3825
3/1 Year CMT	6	28	294	1532	1550	311	14	3735
10/1 IO ARM	2	7	495	1795	1347	0	0	3646
1 Year LIBOR	0	0	4	62	2794	506	3	3369
3/1 LIBOR	8	41	115	918	1411	682	39	3214
6 Month LIBOR 1 Year IO	0	16	1626	284	156	0	0	2082
3/12 ARM	0	6	92	634	692	254	289	1967
2/1 IO ARM	0	0	2	270	1279	0	0	1551
1 Year ARM	7	10	137	170	457	419	15	1215
7/2 ARM	1	0	5	472	465	146	32	1121
6 Month ARM	1	3	3	96	550	336	19	1008

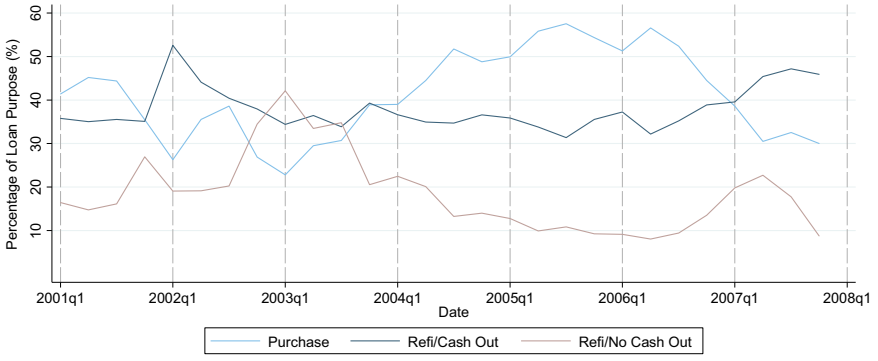
The list is ordered by the frequency of mortgage type. Product types with fewer than 1000 from 2001 to 2007 are omitted. See Footnote 11 in the paper for other details

Table 4 Summary statistics: Categorical variables, 2001–2007

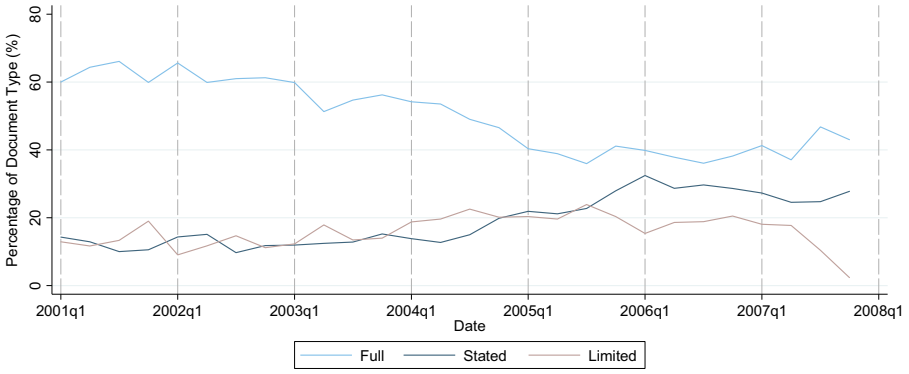
Variable	Weighted	Highest % Share			2nd Highest % Share			3rd Highest % Share		
		Description	N	%	Description	N	%	Description	N	%
Loan purpose	N	Purchase	763,010	49.44	Refi/Cash Out	551,125	35.71	No Cash Out	208,828	13.53
	Y	Purchase	737,798	47.81	Refi/Cash Out	538,895	34.92	No Cash Out	250,043	16.20
Document Type	N	Full	616,649	39.96	Stated	409,412	26.53	Limited	290,568	18.83
	Y	Full	540,893.4	35.05	Stated	420,071	27.22	Limited	332,120.69	21.52
ARM Index Rate	N	6 M LIBOR	658,673	42.75	1Y LIBOR	206,088	13.38	1Y CMT	176,926	11.48
	Y	6 M LIBOR	536,821	34.84	1Y LIBOR	312,043	20.25	1Y CMT	203,770	13.23
NegAm (Y/N)	N	N	1,271,832	82.42	Y	271,371	17.58			
	Y	N	1,240,193	80.36	Y	303,010	19.64			
Interest Only (Y/N)	N	N	916,004	59.36	Y	627,199	40.64			
	Y	Y	769,039	49.83	N	774,165	50.17			
Balloon (Y/N)	N	N	1,369,324	88.73	Y	173,879	11.27			
	Y	N	1,388,267	89.96	Y	154,936	10.04			

For each mortgage characteristic, categories with the highest shares are reported in descending order. Original balance is used as the weight

Loan Purpose: *Purchase*, purchase loan; *Refi/Cash Out*, refinance loan with cash-out; *No Cash Out*, refinance loan without cash-out; ARM Index Rate: *6 M LIBOR*, 6-month London Interbank Offered Rate; *1Y LIBOR*, 1-year London Interbank Offered Rate; *1Y CMT*, US 1-year Constant Maturity Treasury Rate; *NegAm*, negative amortization loans; *Interest Only*, interest-only loans; *Balloon*, loans with balloon payment at the end of a mortgage contract



(a) Share by loan purpose



(b) Share by documentation type

Fig. 1 Share of loan purpose and documentation type, 2001–2007. Data is aggregated quarterly

purchase loans decreases from 42% in 2001q1 to 23% in 2003q1, while the share of refi loans without cash-out increases from 17% to 41% in the same period. The shift is reversed and the share of purchase loans rises to 55%, remaining around this level until 2006q2. From 2006q2 to 2007q2, the share of purchase loans decreases from 57% to 31%, while refi loans with and without cash-out go up from 33% and 10% to 46% and 23% respectively.

There is also a shift toward low and no documentation (stated) loans over time.[15] Fig. 1b shows these trends by displaying the quarterly aggregated share of documentation types (full, stated, limited) in the ARM sample over time. The share of full documentation loans decreases from 60% in 2001q1 to 40% in 2005q1 and remains stable thereafter.

We focus on loans underlying ARM pools. As noted, ARMs and FRMs are generally securitized in separate pools.[16] This is unlike all other features of loans, such as loan purpose (whether for purchase or refinance), loan documentation, loan term, loan features (such as balloons) and various forms of amortization (including 2/28 s ARMs, hybrids, interest-only loans and option ARMs), all of which are included together in the same securitization pools.

[15] This and the preceding paragraph's description of an early increase in refis in the period of declining interest rates and then a decrease until 2006 are also consistent with market trends. See Justiniano et al. (2017) and Levitin and Wachter (2011).

[16] There are more than 1400 mortgage pools in the dataset. More than 95% of the pools have either ARMs or FRMs, but not both.

Tables 5 and 6 reports summary statistics for continuous variables in the ARM dataset. Table 5 reports the summary statistics of continuous variables including FICO and LTV from 2001 to 2007. Table 6 further reports the statistics by origination year. We show that the average FICO score in the ARM sample decreased by 20 points from 685 to 665 and the average LTV increased by 5.6 percentage points from 73.3% to 78.9% from 2003 to 2006.[17] As shown, the distributional statistics (Table 6) and the kernel density of FICO and LTV (Fig. 2a, b) also shifted: the FICO score distribution moved leftward starting from 2003 and, within the below average group, there was an increase in the proportion of low-score borrowers (measured by skewness), consistent with deterioration in borrowers' creditworthiness overall.[18]

Mortgage Risk

The database includes mortgage delinquency status for those loans that remain in the database. We examine loans that were not delinquent as of January 2007, only for their payment performance after this date through December 2008.[19] We show the strong associations of the FICO, LTV and loan purpose components of mortgage loans with *ex post* mortgage risk. While this association is not surprising, it confirms that the private-label loans in this dataset are similar in default outcomes to PLS outcomes more generally. Prior to 2007, PLS default rates remained low; they began their surge in 2007, as house prices began to fall and credit supply declined with the implosion of the PLS market.

Figure 3 shows the share of active loans that became delinquent in this period by origination year, loan purpose, FICO and LTV. Loans originated in the latter years of the housing bubble in 2004–2006 were more likely to become delinquent in 2007–2008. The increase in the likelihood of delinquency in those vintages is highest for purchase loans and refinance loans with cash-out and for loans with low FICO scores and high loan-to-value ratios. Figure 4 shows that the coefficient on FICO in the delinquency model was monotonically increasing in absolute value from 2004 and the coefficient on LTV was increasing by vintage year after 2003. These coefficients are statistically significant and in the expected direction of increasing mortgage risk.[20] These results for the database used here confirm those in the literature (Mayer et al. 2009; Gerardi et al. 2008; Demyanyk and Hemert 2011).

[17] We use LTV instead of combined LTV (CLTV), because about 40% of ARM loans do not report CLTV. Levitin and Wachter (2015), using data from INTEX, show that CLTV rose from 80% in 2003 to 89% in 2006.

[18] Table 21 replicates Table 6 using the original balance to weight observations instead. We find similar trends of FICO and LTV over time.

[19] Loan performance is recorded for the past 12 months for each loan in the database. A loan that was delinquent in 2006 that was cured and not delinquent in 2007 would not be included as delinquent in this analysis. The database lacks loans that are no longer reported due to foreclosure or prepayment that happened earlier than in the period we observe.

[20] We use the following model:

$$delinq_j = \gamma_0 + f(age_j) + \sum_{t=2002}^{2007} z_t \cdot \mathbf{1}\{t = orig\_year_j\} + \gamma_1 FICO_j + \gamma_2 LTV_j + \mathbf{X}_j' \Gamma_3 + e_j$$

where j indexes the individual mortgage and t indexes the origination year with 2001 chosen as the base level. $delinq_j$ is an indicator of mortgage delinquency in the period. $orig\_year_j$ is the origination year of loan j with z_t to be the corresponding coefficients. $f(age_j)$ includes high-order polynomials of loan age at delinquency if it happened or the loan age at the censoring point (December 2008). The summation term characterizes the vintage effect. $\mathbf{X}_j$ is a collection of the interaction terms of vintage and FICO/LTV and other controls on mortgage characteristics (including loan term, document type, state of origination and loan purpose, IO/NegAm/Balloon indicator), with vector $\mathbf{\Gamma}_3$ grouping the corresponding coefficients. e_j is the error term.

Table 5 ARM summary statistics: Continuous variables, 2001–2007

	Mean	sd	p25	p50	p75
ARM					
Margin	4.13	1.87	2.25	3.53	5.99
Original interest rate spread	1.89	2.49	1.28	2.27	3.45
FICO	673.55	72.37	623.00	677.00	729.00
LTV	77.69	12.63	75.00	80.00	80.00

Original interest rate refers to the initial rate of ARM loans. The spread is defined as the difference between the original interest rate and US 7-year Constant Maturity Treasury Rate. Both the margin and the original interest rate spread are measured in percentage points

ARM, adjustable rate mortgage; *LTV*, loan-to-value ratio

Mortgage Rate Spreads

As noted, we focus on ARMs, which predominated in the database, accounting for 70% of the number and 80% of the dollar volume by 2007 (Tables 1 and 2). We use two mortgage risk measures in the following analysis: the margin and the original interest rate spread.[21] The margin is defined as the spread of an ARM loan between the mortgage interest rate and the index rate.[22] The margin on ARMs is the compensation to the investor for bearing the risk of the loan, relative to underlying yields. We also perform regressions using the original interest rate spread defined as the gap between the original interest rate and US 7-year Constant Maturity Treasury Rate on the origination date.[23]

The aggregated spread that would be available to securitization investors in these loans underlying the ARM pools would be the weighted average spread on both purchase money and refinance mortgages.[24] Because it is likely that the change in the term structure affects the risk premium of ARMs, for robustness, we separately test for results on 2/28 ARM loans in the next section.

We show the time trend in the margin and original interest rate spread weighted by the original balance, in Figs. 5 and 6 (weighted and unweighted), using quarterly aggregate averages. The risk measures are aggregates unconditional on borrowers and loan characteristics. The unweighted margin decreased from 5% in 2001q1 to 3.2% in 2003q3, followed by a gradual increase to 4.5% in 2006q1 and a decrease to 3.7% in 2007q2 thereafter. Similarly, the unweighted original interest rate spread decreased from 4% in 2001q1 to 0.8%

[21] Original interest rate in the data is the initial rate for an ARM that is in effect either for a limited period of a so-called teaser rate or for the full term of the loan.

[22] The margin used here, as in prior papers referenced, is thus the gross margin, rather than the net margin, which is reduced by servicing fees and trustee fees, which are relatively constant over time. Mortgage brokers offer these rates to borrowers off the rate sheets that show the available pricing and terms from suppliers of mortgage funds. Mortgage brokers also charge mortgage fees and, if they are able to extract higher rates than the prevailing rates from borrowers, they will gain yield spread premiums. Neither appear to affect mortgage rates investors receive from PLS (Berndt et al. 2014).

[23] We include the regression results of original interest rate spread to produce comparable results with the literature. When the sample includes fixed rate mortgages, the studies cited use a risk-free interest rate with similar duration to calculate the risk price (Antinolfi et al. 2016; Justiniano et al. 2017), as we do here.

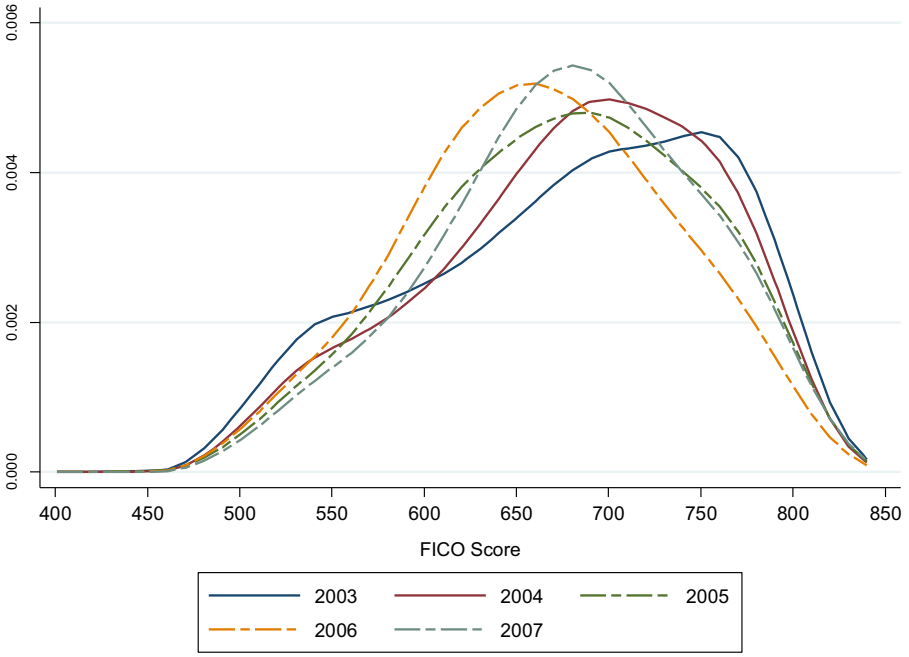
[24] We also analyze purchase money and refinance mortgages separately for comparisons to the studies cited in the literature.

Table 6 ARM summary statistics: Continuous variables by origination Year, 2001–2007

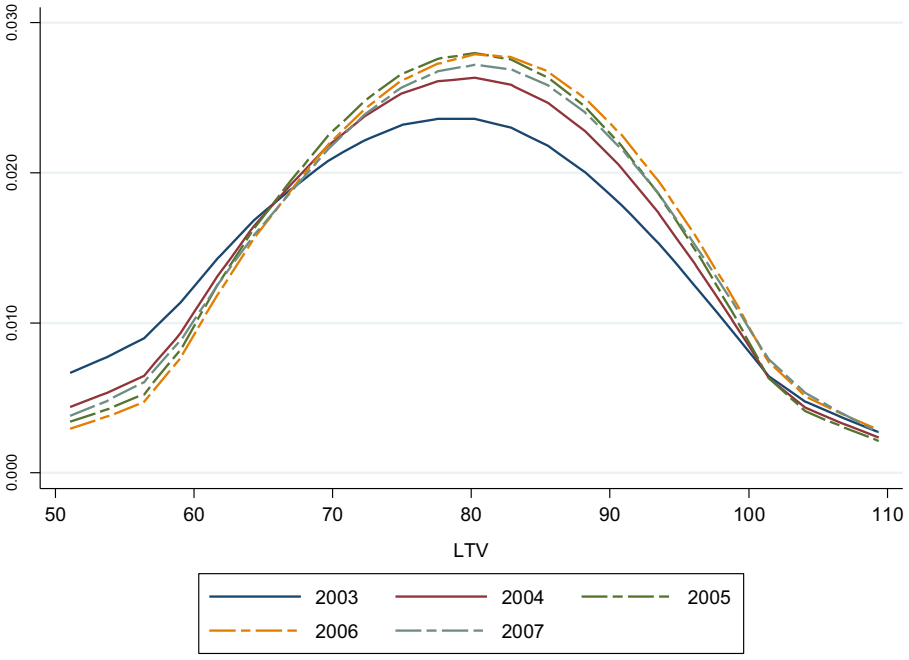
	Mean	sd	p25	p50	p75
2001, ARM					
Margin	5.07	2.51	2.75	5.88	6.99
Original Interest Rate Spread	3.86	2.76	2.07	4.58	5.76
FICO	626.81	85.18	559.00	611.00	686.00
LTV	78.14	14.78	74.70	80.00	90.00
Loan Term	354.70	27.33	360.00	360.00	360.00
2002, ARM					
Margin	4.59	2.26	2.25	5.00	6.45
Original Interest Rate Spread	3.05	2.46	1.42	3.47	4.99
FICO	644.03	88.92	567.00	635.00	721.00
LTV	75.13	15.72	69.80	80.00	85.00
Loan Term	348.82	30.09	360.00	360.00	360.00
2003, ARM					
Margin	3.51	1.98	2.25	2.75	5.25
Original Interest Rate Spread	1.88	2.46	0.49	1.77	3.68
FICO	684.55	80.46	628.00	698.00	752.00
LTV	73.29	16.22	65.90	79.30	80.00
Loan Term	352.04	26.37	360.00	360.00	360.00
2004, ARM					
Margin	3.61	1.85	2.25	2.75	5.40
Original Interest Rate Spread	1.39	2.37	0.53	1.64	2.90
FICO	682.17	73.89	634.00	691.00	741.00
LTV	75.81	15.38	72.90	80.00	80.00
Loan Term	358.15	17.89	360.00	360.00	360.00
2005, ARM					
Margin	4.10	1.87	2.25	3.50	5.95
Original Interest Rate Spread	1.77	2.27	1.30	2.05	3.13
FICO	677.47	72.68	626.00	682.00	734.00
LTV	77.58	11.97	75.00	80.00	80.00
Loan Term	361.90	21.46	360.00	360.00	360.00
2006, ARM					
Margin	4.46	1.82	2.75	4.70	6.05
Original Interest Rate Spread	2.17	2.55	1.61	2.68	3.70
FICO	665.32	70.13	617.00	666.00	717.00
LTV	78.85	11.45	77.10	80.00	80.00
Loan Term	366.53	32.27	360.00	360.00	360.00
2007, ARM					
Margin	3.96	1.72	2.25	3.40	5.95
Original Interest Rate Spread	1.87	2.85	1.40	2.43	3.56
FICO	679.20	68.63	634.00	683.00	730.00
LTV	78.15	11.74	75.00	80.00	84.20
Loan Term	366.65	39.74	360.00	360.00	360.00

Original interest rate refers to the initial rate of ARM loans. The spread is defined as the difference between the original interest rate and US 7-year Constant Maturity Treasury Rate. Both the margin and the original interest rate spread are measured in percentage points. Loan Term is calculated by month

ARM, adjustable rate mortgage; *LTV*, loan-to-value ratio

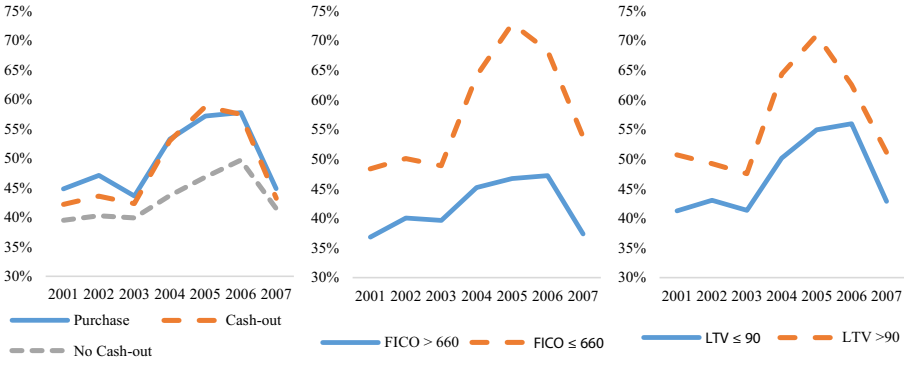


(a) FICO Score



(b) LTV

Fig. 2 Kernel density of FICO (panel **a**) and LTV (panel **b**), by vintage. The bandwidth is 20 percentage points and 10 percentage points for FICO and LTV, respectively. The sample is ARM loans



(a) loan purpose (b) FICO (c) LTV

Fig. 3 Share of the current loans in January 2007 that became delinquent between January 2007 and December 2008, by mortgage vintage and borrower/loan characteristics

in 2004q2, followed by a gradual increase to 2.3% in 2006q4 and a decrease to 1.2% in 2007q2 thereafter. The margin and original interest rate spread weighted by original balance closely follow the trend of the unweighted counterparts but are uniformly smaller in value.

Model and Results

The empirical specification takes the following form:

$$risk\quad price_j = \beta_0 + \beta_1 FICO_j + \beta_2 LTV_j + \sum_{t=2002}^{2007} d_t \cdot \mathbf{1}\{t = orig\_year_j\} + \mathbf{X}_j' \mathbf{B}_3 + e_j \quad (1)$$

Where j indexes the individual mortgage and t indexes the origination year, with 2001 chosen as the base level. *Risk price*$_j$ can be one of the two measures of mortgage credit

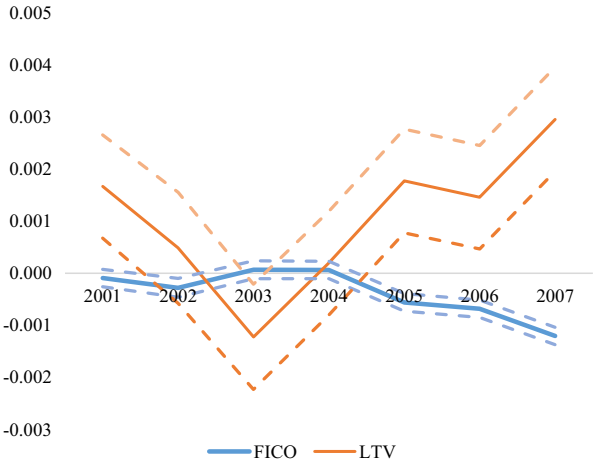


Fig. 4 Regression coefficients on FICO (blue) and LTV (orange) in delinquency regression by vintage. The sample includes loans that were current in January 2007. The dependent variable is the indicator of loan delinquency from January 2007 to December 2008. The dashed bands represent 95% confidence intervals

Fig. 5 Weighted and unweighted margin of ARM loans, 2001–2007. Data is aggregated quarterly. Original balance is used as the weight in the weighted margin

risks, margin or original interest rate spread. $orig\_year_j$ is the origination year of loan j with d_t to be the corresponding coefficients. The summation term characterizes the vintage effect. $\mathbf{X_j}$ is a collection of non-linear terms, interaction terms or other controls on mortgage characteristics, with vector $\mathbf{B_3}$ grouping the corresponding coefficients. e_j is the error term.

Mortgage characteristics controlled across all regressions (unless otherwise indicated) include loan term (for example, 15-year or 30-year), document type (full, stated or limited documentation), state of origination, and loan purpose (purchase, refi or refi cash out) as well as vintage. In addition, we include indicators of different product types; either a coarse or detailed classification by product type is applied to the models. The coarse classification includes a fully amortized ARM flag, a negative amortization flag, an IO flag and a balloon flag. The detailed classification further differentiates each class of products by index rate, fixed rate period, loan term, etc.[25]

Main Results

Table 7 reports the main regression results focusing on FICO, LTV and year dummies. Table 8 reports coefficients of other control variables used in these regressions, including product types, document types and loan purposes.[26] The dependent variables, credit risk prices, both the margin and the original interest rate spread, are measured in percentage points. Models 1–4 use the margin as the dependent variable with mortgage characteristics including credit score and loan-to-value ratio and models 5–8 use the interest rate spread. Significant coefficients on credit score and LTV indicate that both risk characteristics are priced in the mortgage risk, with expected signs. On average, as is shown by Model 1, a 100-point increase in FICO score decreases the margin by 120

[25] Not all loans carry detailed information on product types. About 78% of loans include detailed classification of product types.

[26] In general, riskier product types should have higher coefficients, indicating that they are accompanied by a higher credit margin for the higher risk, but the reverse holds in the data. For example, limited information loans have a lower coefficient than fully documented loans and negative amortization loans and IO loans have lower coefficients than fully amortizing loans, indicating they were priced as less risky.

Fig. 6 Weighted and unweighted original Interest Rate Spread of ARM loans, 2001–2007. Data is aggregated quarterly. Original balance is used as the weight in the weighted original interest rate spread

basis points, while a 10-percentage point decrease in loan-to-value ratio decreases the margin by 20 basis points.

The coefficients on mortgage vintage (conditioned on mortgage and borrower characteristics) are informative about the cyclical behavior of the credit spread. As seen in Model 1, the margin significantly changes over time and is year-dependent. There is a decrease of the margin from 2001 to 2003/04, followed by an increase through 2007, back to the level of 2001. All else being equal, the margin in 2003–2004 is on average 50–60 basis points lower than that in 2001, as shown in Fig. 7.[27]

We further investigate effects over time by testing whether the coefficients on FICO and LTV are time-varying in Model 2. We include FICO score and a time dummy interact term and, similarly, LTV ratios and a time interact dummy. We find evidence that the absolute value of the partial effect of FICO on the margin is decreasing over time through 2007, implying less responsiveness of risk pricing to the change of credit scores and declining mortgage underwriting standards, as shown in Fig. 8. The absolute value of the marginal effect of FICO in 2007 is 0.6 basis points lower than that in 2001, which translates to a 37% decrease in the absolute value of the marginal effect. In other words, for two mortgagors with a 100-point difference in FICO scores, this implies that the difference in the margin of two loans decreases by 60 basis points, which is equivalent to a 37% decrease in the margin gap. The partial effect of LTV on the margin shows a weaker response of the margin to LTV over time. The margin gap between two loans with a difference in LTV of 10 percentage points is 28 basis points in 2001, which narrows to 11 basis points in 2004, rising thereafter until 2006, although still remaining below the level of 2001.

The residual vintage effect in this model, which includes time-varying coefficients on FICO score and LTV, is also reported in Model 2 and shown in Fig. 9a. The coefficient on the vintage dummy in this model is monotonically decreasing. This

[27] We also run a regression of the risk price on mortgage vintage only. The coefficients on the vintage are effectively the average mortgage margin and have the pattern shown in Figure 5.

[0] From 2003 to 2007, the coefficients of FICO and LTV of 2/28 ARMs both decreased in absolute value, consistent with the finding in the ARM sample. We report the regression results in Table 9. We also graphically show similar decreasing coefficients of FICO and LTV in absolute value for loans with FICO less than or equal to 660 in the discussion of Demyanyk and Hemert (2011) in Appendix.

Table 7 Regression Table: Margin and original interest rate spread

	(1) Margin	(2) Margin	(3) Margin	(4) Margin	(5) Spread	(6) Spread	(7) Spread	(8) Spread
FICO	−0.0120***	−0.0158***	−0.00648***	−0.0119***	−0.0109***	−0.0150***	−0.00842***	−0.00901***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)
LTV	0.0203***	0.0273***	0.0131***	0.0188***	0.0161***	0.0181***	0.0147***	0.00668*
	(0.000)	(0.002)	(0.000)	(0.002)	(0.000)	(0.002)	(0.000)	(0.003)
year = 2002	−0.148***	−0.707*	−0.369***	−2.840***	−0.604***	−0.519	−0.321***	−0.789
	(0.028)	(0.299)	(0.042)	(0.441)	(0.035)	(0.378)	(0.050)	(0.521)
year = 2003	−0.570***	−0.804**	−0.398***	−2.102***	−1.216***	0.0616	−1.066***	1.051*
	(0.026)	(0.280)	(0.038)	(0.403)	(0.033)	(0.354)	(0.046)	(0.477)
year = 2004	−0.458***	−1.306***	−0.549***	−2.538***	−1.587***	−2.639***	−1.553***	−1.363**
	(0.025)	(0.275)	(0.038)	(0.400)	(0.032)	(0.348)	(0.045)	(0.473)
year = 2005	−0.0862***	−1.957***	−0.382***	−3.592***	−1.366***	−3.762***	−1.352***	−2.856***
	(0.025)	(0.274)	(0.038)	(0.399)	(0.032)	(0.347)	(0.045)	(0.472)
year = 2006	0.00493	−2.514***	−0.322***	−3.707***	−0.906***	−3.871***	−1.173***	−2.271***
	(0.025)	(0.274)	(0.038)	(0.399)	(0.032)	(0.347)	(0.045)	(0.472)
year = 2007	−0.0878***	−3.078***	−0.281***	−4.019***	−0.260***	−4.939***	−0.846***	−2.660***
	(0.025)	(0.276)	(0.038)	(0.400)	(0.032)	(0.350)	(0.045)	(0.473)
2002*FICO		0.00179***		0.00513***		−0.000345		0.000755
		(0.000)		(0.000)		(0.000)		(0.001)
2003*FICO		0.00185***		0.00391***		−0.00102*		−0.00328***
		(0.000)		(0.000)		(0.000)		(0.001)
2004*FICO		0.00348***		0.00387***		0.00231***		−0.000760
		(0.000)		(0.000)		(0.000)		(0.001)
2005*FICO		0.00349***		0.00573***		0.00413***		0.00186***
		(0.000)		(0.000)		(0.000)		(0.001)
2006*FICO		0.00441***		0.00567***		0.00451***		−0.0000082
		(0.000)		(0.000)		(0.000)		(0.001)

Table 7 (continued)

	(1) Margin	(2) Margin	(3) Margin	(4) Margin	(5) Spread	(6) Spread	(7) Spread	(8) Spread
2007*FICO		0.00564***		0.00658***		0.00897***		0.00196***
		(0.000)		(0.000)		(0.000)		(0.001)
2002*LTV		−0.00687***		−0.0114***		0.00228		−0.000369
		(0.002)		(0.003)		(0.002)		(0.003)
2003*LTV		−0.0106***		−0.0106***		−0.00495*		0.00143
		(0.002)		(0.002)		(0.002)		(0.003)
2004* LTV		−0.0168***		−0.00635**		−0.00374		0.00444
		(0.002)		(0.002)		(0.002)		(0.003)
2005*LTV		−0.00356*		−0.00679**		−0.00225		0.00347
		(0.002)		(0.002)		(0.002)		(0.003)
2006*LTV		−0.00320		−0.00405		0.00165		0.0141***
		(0.002)		(0.002)		(0.002)		(0.003)
2007*LTV		−0.00785***		−0.00735**		−0.0150***		0.00648*
		(0.002)		(0.002)		(0.002)		(0.003)
Constant	11.84***	13.74***	5.509***	8.695***	10.88***	13.32***	5.357***	6.537***
	(0.414)	(0.494)	(0.432)	(0.586)	(0.525)	(0.625)	(0.512)	(0.693)
Adjusted R^2	0.6152	0.6174	0.7511	0.7519	0.6418	0.6460	0.7329	0.7354
N	1,254,381	1,254,381	973,480	973,480	1,254,381	1,254,381	973,480	973,480

Year 2001 is chosen as the base level. Both the margin and the spread are measured in percentage points. Unreported controlled variables: loan term, documentation types, state dummies and loan purpose. Models 1–4 and Models 5–8 use margin and original interest rate spread respectively as the dependent variables. Models 1–2, 5–6 control product types, including negative amortization flag, interest-only flag and balloon flag. Models 3–4 and 7–8 instead control more detailed product types but rely on a smaller sample due to data availability. We control 103 detailed product types in Models 3–4 and 7–8; we don't include the dummies of balloon, interest-only and negative amortization in these models to prevent multicollinearity in regressions

Standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Margin, margin; *Spread*, original interest rate spread (with respect to 7-year Constant Maturity Treasury Rate)

Table 8 Coefficients on document type, product types, and loan purpose

	(1) Margin	(2) Margin	(3) Margin	(4) Margin	(5) Spread	(6) Spread	(7) Spread	(8) Spread
Doc: Full	0	0	0	0	0	0	0	0
	(.)	(.)	(.)	(.)	(.)	(.)	(.)	(.)
Doc: Stated	0.252***	0.248***	0.163***	0.157***	0.599***	0.585***	0.525***	0.528***
	(0.0026)	(0.0026)	(0.0024)	(0.0024)	(0.0032)	(0.0032)	(0.0028)	(0.0028)
Doc: Limited	−0.222***	−0.223***	−0.0481***	−0.0495***	0.345***	0.348***	0.428***	0.426***
	(0.0029)	(0.0029)	(0.0028)	(0.0028)	(0.0037)	(0.0036)	(0.0033)	(0.0033)
!NegAm	0	0			0	0		
	(.)	(.)			(.)	(.)		
NegAm	−1.076***	−1.102***			−3.629***	−3.669***		
	(0.0034)	(0.0034)			(0.0044)	(0.0044)		
!IO	0	0			0	0		
	(.)	(.)			(.)	(.)		
IO	−1.026***	−1.028***			−0.0554***	−0.0687***		
	(0.0026)	(0.0026)			(0.0033)	(0.0033)		
!Balloon	0	0			0	0		
	(.)	(.)			(.)	(.)		
Balloon	0.422***	0.442***			−0.0710***	−0.0186***		
	(0.0036)	(0.0036)			(0.0045)	(0.0046)		
Purchase	0	0	0	0	0	0	0	0
	(.)	(.)	(.)	(.)	(.)	(.)	(.)	(.)
Cash Out	0.0168***	0.0231***	0.0810***	0.0806***	−0.0829***	−0.0834***	−0.0546***	−0.0532***
	(0.0025)	(0.0025)	(0.0023)	(0.0023)	(0.0031)	(0.0031)	(0.0027)	(0.0027)

Table 8 (continued)

	(1) Margin	(2) Margin	(3) Margin	(4) Margin	(5) Spread	(6) Spread	(7) Spread	(8) Spread
No Cash Out	−0.261***	−0.256***	−0.0815***	−0.0833***	−0.337***	−0.324***	−0.206***	−0.206***
	(0.0033)	(0.0033)	(0.0032)	(0.0032)	(0.0042)	(0.0042)	(0.0038)	(0.0038)
Observations	1,254,381	1,254,381	973,480	973,480	1,254,381	1,254,381	973,480	973,480

The exclamation mark (!) refers to negation. The coefficients are unreported coefficients of Models 1–8 in Table 7. Both the margin and the spread are measured in percentage points. Rows with zero values are chosen as the base levels (full documentation, not negative amortization, not interest only, not balloon, primary purchase)

Standard errors in parentheses * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Margin, margin; *Spread*, original interest rate spread (with respect to 7-year Constant Maturity Treasury Rate)

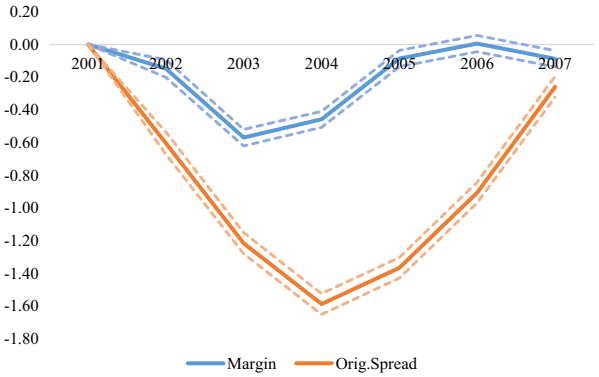


Fig. 7 Regression coefficients on vintage year from margin regression (Model 1) and original rate spread regression (Model 5) by vintage (from Table 7). Margin and Original interest rate spread are measured by percentage point. 2001 is the base level and normalized to 0. The dashed bands represent 95% confidence intervals

shows a decreasing trend in risk price conditional on borrower characteristics and time-varying response to FICO and LTV. We observe the vintage effect assuming constant LTV and FICO score coefficients in Model 1 and Fig. 7. Time-varying FICO and LTV coefficients, along with the changing composition of the mortgages, give rise to the monotonic decline in the residual vintage effect shown by the estimated coefficients of the vintage years through 2007 in Fig. 9a.

The residual vintage effect includes the change of risk premiums and macro factors including the term structure of interest rates; hence we also separately examine the residual vintage effect for 2/28 ARMs whose margin adjusts with the 6-month LIBOR, which is less likely to be greatly impacted by changes in the term structure. Results for 2/28 ARMs are similar to those for ARMs in general, as shown in Table 9 and Fig. 9b.[28]

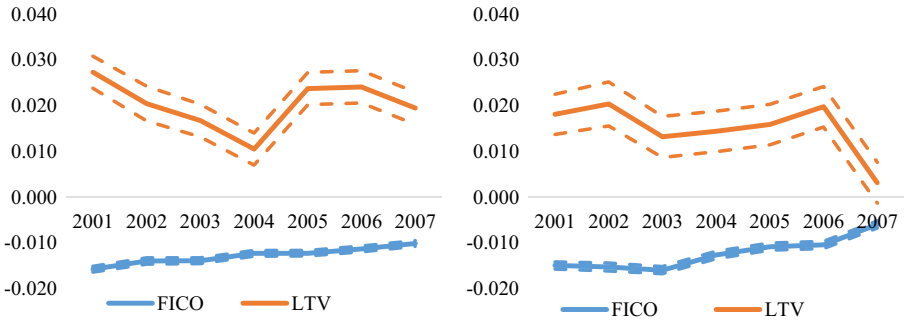
To further explore the source of this trend, we decompose the residual vintage effect by running separate regressions by loan purpose (primary purchase, refi with and without cash-out), respectively in Tables 10, 11 and 12. In the vintage decomposition by loan purpose (Fig. 10), we find that the residual vintage effect of primary purchase loans is statistically constant from 2001 to 2005. The monotonic decline of the residual vintage effect in Fig. 9a is associated with refinance loans both with and without cash-out.

We also examine ARM loans with FICO score below 660 and above 660 separately (Table 13). The residual vintage effects in both groups follow a downward trend for low FICO group after 2003 and high FICO group after 2005 (Fig. 11). This has direct implications for the issue of whether subprime or prime loans underpriced credit risks, as discussed further below.

We further explore the impact of risk-related characteristics on the risk premium by including the location of the loans by state. We report in Fig. 12 the histograms of

[28] From 2003 to 2007, the coefficients of FICO and LTV of 2/28 ARMs both decreased in absolute value, consistent with the finding in the ARM sample. We report the regression results in Table 9. We also graphically show similar decreasing coefficients of FICO and LTV in absolute value for loans with FICO less than or equal to 660 in the discussion of Demyanyk and Hemert (2011) in Appendix.

[0] We don't include the dummies of balloon, interest-only and negative amortization in Model 3–4 to prevent multicollinearity issues in the regressions. See Table 3 for a list of detailed product types as the additional variables and Footnote 11 for information on the details.



(a) Margin regression (b) Original rate spread regression

Fig. 8 Regression coefficients on FICO (blue) and LTV (orange) from margin regression (Model 2) and original rate spread regression (Model 6) by vintage (in Table 7). Margin and Original interest rate spread are dependent variables and measured by percentage point. The dashed bands represent 95% confidence intervals

coefficients on the origination state. Panels a-d in Fig. 12 rank the coefficients on the state dummies in ascending order from Models 1–4 in Table 7 (Alaska is chosen as the reference point whose coefficient is normalized to 0). We show that the "sand states" (Arizona, California, Florida and Nevada), where homeowners experienced the most extreme run-up in housing prices before the crisis and greatest decline in the collapse, have coefficients lower than the median, which is robustly detected in all model specifications.

Additional Results

In Models 3–4 of Table 7, we apply a detailed product type classification, instead of basic product types as in Models 1–2, by including 103 additional variables.[29] Coefficients of FICO and LTV still decrease in absolute value and remain statistically significant, as the adjusted R-square goes from 0.60 in Model 1 to 0.75 in Model 3.

Models 5–8 of Table 7 use original interest spread as the measure of mortgage risk. They replicate qualitatively the findings in Models 1–4. The partial effects of both FICO and LTV on the original interest rate spread are similar. The time trend of the coefficients of the vintage dummies are also similar.

For completeness and robustness, in the Appendix, we show results for testing for Models 1–8 in Table 7 for whether the vintage effect and the response to FICO and LTV are statistically different from their counterparts in the previous year. We report the *p*-values from a set of Wald tests, using no time-varying effect in two consecutive years as the null hypothesis. We find that the time-varying effects discussed above are statistically significant.

[29] We don't include the dummies of balloon, interest-only and negative amortization in Model 3–4 to prevent multicollinearity issues in the regressions. See Table 3 for a list of detailed product types as the additional variables and Footnote 11 for information on the details.

[0] If the survival process follows our assumption in the Appendix, we see as much as a 7% downward bias in FICO coefficient and 7% upward bias in LTV coefficient. The scale of the bias is small relative to the time-varying trend of FICO (37% decrease in absolute value from 2001 to 2007) and LTV (more than 50% decrease in absolute value from 2001 to 2004).

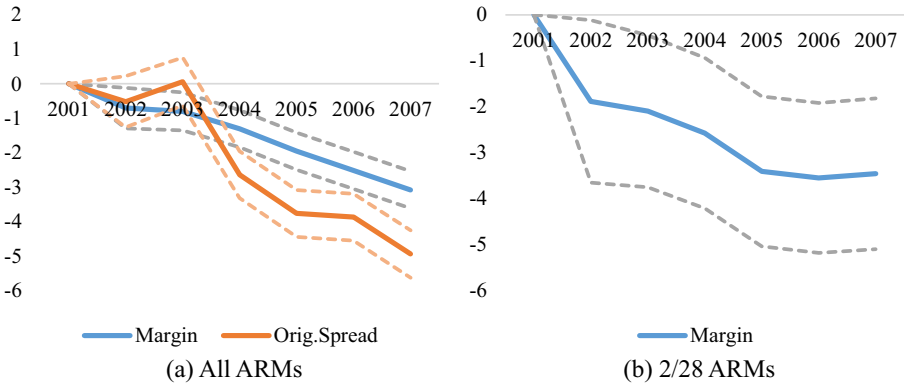


Fig. 9 Regression coefficients on vintage year. Panel (**a**): from Models 2 and 6 in Table 7 with the ARM sample. Panel (**b**): from Model 2 in Table 9 with the 2/28 ARM sample. The margin and the original interest rate spread are measured in percentage points. 2001 is the base level and normalized to 0. The dashed bands represent 95% confidence intervals

We also test the possibility of sample selection survival bias. In the Appendix, we construct an experimental data set and use Heckman models to test potential biases of our estimates and find limited potential of survival bias. Comparing with the significant time-varying effect in vintage, FICO and LTV from 2001 to 2007, the potential bias is too small to reverse our conclusion.[30]

Discussion

Was the increase in composition of riskier loans reflected in higher mortgage risk premiums during the housing bubble? Loans with risky features, such as low FICO scores and high LTVs would have been at greater risk of default. Did the increasingly risky features of loans result in higher risk premiums attributable to these features? We estimate the coefficients of LTV and FICO score over time to show their contribution to risk premiums, which would be expected to increase in absolute terms to reflect the growing risk. We find by estimating coefficients over time that these variables were less influential in the pricing of risk.

Our results differ from that of Rajan, Seru and Vig (RSV), which finds an increase in absolute value for the coefficient of LTV and an unchanged coefficient on FICO score. RSV uses a different dataset, estimating results only for subprime purchase money securitized loans (rather than for all loans as typically combined in PLS). When we replicate their regressions (shown in the Appendix) we find results similar to theirs. This finding is consistent with lenders originating mortgages at higher costs for higher LTV loans over time for purchase money mortgages, as borrowers became more constrained by down payments with soaring housing prices.[31] Nonetheless, the pricing of risk for PLS mortgage pools

[30] If the survival process follows our assumption in the Appendix, we see as much as a 7% downward bias in FICO coefficient and 7% upward bias in LTV coefficient. The scale of the bias is small relative to the time-varying trend of FICO (37% decrease in absolute value from 2001 to 2007) and LTV (more than 50% decrease in absolute value from 2001 to 2004).

[31] Barakova et al. (2014) find that income and credit borrowing constraints decreased in this period but that wealth constraints increased. See also Acolin et al. (2016).

Table 9 Regression Table: Margin and mortgage rate

	(1) 2/28, margin	(2) 2/28, margin	(3) 2/28, rate	(4) ARM, rate
FICO	−0.00520***	−0.00781***	−0.00849***	−0.0152***
	(0.000)	(0.001)	(0.001)	(0.000)
LTV	0.0101***	0.00515	−0.000832	0.0172***
	(0.000)	(0.006)	(0.006)	(0.002)
year = 2002	−0.795***	−1.885*	−0.861	−0.289
	(0.064)	(0.903)	(1.009)	(0.374)
year = 2003	−1.205***	−2.098*	−1.235	−0.832*
	(0.058)	(0.843)	(0.942)	(0.351)
year = 2004	−1.280***	−2.574**	−2.013*	−3.376***
	(0.057)	(0.835)	(0.933)	(0.345)
year = 2005	−1.445***	−3.407***	−3.588***	−4.817***
	(0.057)	(0.833)	(0.932)	(0.344)
year = 2006	−1.341***	−3.550***	−2.549**	−4.831***
	(0.057)	(0.833)	(0.931)	(0.343)
year = 2007	−1.407***	−3.459***	−2.489**	−6.149***
	(0.057)	(0.836)	(0.934)	(0.346)
CMT1			0.376***	0.405***
			(0.006)	(0.005)
CMT7				−0.0966***
				(0.007)
2002*FICO		0.00133	−0.000212	−0.00130**
		(0.001)	(0.001)	(0.000)
2003*FICO		−0.000726	−0.00177	−0.000683
		(0.001)	(0.001)	(0.000)
2004*FICO		−0.0000902	−0.00278*	0.00259***
		(0.001)	(0.001)	(0.000)
2005*FICO		0.00236*	−0.000869	0.00433***
		(0.001)	(0.001)	(0.000)
2006*FICO		0.00338**	−0.00211	0.00475***
		(0.001)	(0.001)	(0.000)
2007*FICO		0.00355**	−0.00257*	0.00950***
		(0.001)	(0.001)	(0.000)
2002*LTV		0.00352	0.00473	0.00420
		(0.006)	(0.007)	(0.002)
2003*LTV		0.0163**	0.0149*	−0.00332
		(0.006)	(0.007)	(0.002)
2004* LTV		0.0167**	0.0238***	−0.00326
		(0.006)	(0.006)	(0.002)
2005*LTV		0.00695	0.0245***	−0.00180
		(0.006)	(0.006)	(0.002)
2006*LTV		0.00240	0.0275***	0.00253

Table 9 (continued)

	(1) 2/28, margin	(2) 2/28, margin	(3) 2/28, rate	(4) ARM, rate
		(0.006)	(0.006)	(0.002)
2007*LTV		−0.000818	0.0310***	−0.0146***
		(0.006)	(0.006)	(0.002)
Adjusted R^2	0.1426	0.1493	0.4892	0.6678
N	235,012	235,012	235,012	1,254,381

Standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

CMT, Constant Maturity Treasury rate (1-year or 7-year)

The dependent variables are the margin (percentage) in Models 1–2 and original interest rate (percentage) in Model 3–4, respectively. Year 2001 is chosen as the base level. The samples in the regressions are 2/28 ARM (Models 1–3) and all ARM (Model 4) loans, respectively. Unreported controlled variables: loan term, documentation types, loan purpose, state dummies, negative amortization flag, interest-only flag and balloon flag

declined, showing that the supply of purchase money and refinance loans combined, as they generally are in mortgage securitizations, increased, fueling this demand for more affordable product. This is also consistent with our decomposition of the vintage effect by loan purpose.

Our results also differ from those of Antinolfi, Brunetti and Im (ABI). They conduct monthly cross-sectional regressions. Conditional on loan term and loan amount, they find increasing importance of FICO and LTV on the pricing of risk in subprime mortgages over time. When we apply our model to FRMs in our database, we also find an increasing marginal impact of FICO and LTV from 2001 to 2007 (in the Appendix), opposite to our finding on ARMs. Our results differ from their findings, because we examine ARMs separately from FRM loans to allow for differential factor impacts across the two separately securitized pools. Our results also differ from their finding in that when we separate our sample by credit score, we find similar results.

We explicitly test for risk premiums over time. We do so both including and excluding time-varying coefficients and estimating coefficients for vintage year. While Justiniano et al. (2017) test for this as well using regression residuals, with mortgage rates as dependent variables and term structure factors included as controls, we directly test for risk by using the margin of mortgage rates over the index rate for adjustable rate mortgages. Without controlling for time-varying effects on FICO and LTV, the time dummies in the JPT regressions exhibit a U-shape pattern similar to the trend of vintage effects in our results, with a decreasing impact on gross margin over time until 2003 followed by an increase back to 2001 levels in 2006 and 2007. JPT finds a sudden decrease in the conditional mortgage spread and persistently cheaper mortgage credit starting from mid-2003, the so-called mortgage rate conundrum. However, JPT does not include time-varying effects on the coefficients of LTV and FICO. We also find a sharp decline in risk premiums starting in 2003, but we also show, when taking into account time-variant coefficients on FICO and LTV, residual vintage effects are monotonically decreasing from 2001 through 2007. The U-shaped vintage effect in our result shows a similar pattern of time dummies in JPT when we do not allow coefficients on FICO and LTV to vary.

As the housing price bubble inflated over the years 2003 to 2007, mortgage characteristics became increasingly risky. At the same time as observable risk

Table 10 Regression Table: Purchase loans

	(1) Margin	(2) Margin	(3) Margin	(4) Margin
FICO	−0.0126***	−0.0147***	−0.00572***	−0.00979***
	(0.000)	(0.000)	(0.000)	(0.001)
LTV	0.0266***	0.0435***	0.0202***	0.0263***
	(0.000)	(0.003)	(0.000)	(0.004)
year = 2002	−0.0517	0.503	−0.131*	−1.672*
	(0.043)	(0.530)	(0.066)	(0.752)
year = 2003	−0.442***	0.0126	−0.0772	−1.009
	(0.039)	(0.485)	(0.060)	(0.671)
year = 2004	−0.327***	0.639	−0.211***	−1.570*
	(0.038)	(0.471)	(0.059)	(0.662)
year = 2005	0.0987**	0.348	−0.0122	−2.086**
	(0.038)	(0.470)	(0.059)	(0.661)
year = 2006	0.146***	−0.677	0.0256	−2.736***
	(0.038)	(0.470)	(0.059)	(0.660)
year = 2007	−0.0254	−1.650***	0.0553	−2.908***
	(0.038)	(0.477)	(0.059)	(0.665)
2002*FICO		0.000452		0.00388***
		(0.001)		(0.001)
2003*FICO		0.000614		0.00210**
		(0.001)		(0.001)
2004*FICO		0.00228***		0.00301***
		(0.001)		(0.001)
2005*FICO		0.00165***		0.00420***
		(0.000)		(0.001)
2006*FICO		0.00255***		0.00430***
		(0.000)		(0.001)
2007*FICO		0.00388***		0.00522***
		(0.001)		(0.001)
2002*LTV		−0.0100**		−0.0137**
		(0.004)		(0.005)
2003*LTV		−0.00914**		−0.00591
		(0.003)		(0.004)
2004* LTV		−0.0299***		−0.00835*
		(0.003)		(0.004)
2005*LTV		−0.0154***		−0.00970*
		(0.003)		(0.004)
2006*LTV		−0.00984**		−0.00208
		(0.003)		(0.004)
2007*LTV		−0.0114***		−0.00741
		(0.003)		(0.004)
Constant	11.44***	11.38***	3.873***	6.248***
	(0.862)	(0.978)	(0.681)	(0.945)
Adjusted R^2	0.5833	0.5856	0.7534	0.7540
Observations	629,930	629,930	511,736	511,736

The margin is measured in percentage points. The sample is ARM loans whose loan purpose is primary purchase. Year 2001 is chosen as the base level. Unreported controlled variables: loan term, documentation types, state dummies and loan purpose. Models 1–2 control product types, including negative amortization flag, interest-only flag and balloon flag. Models 3–4 instead control more detailed product types but rely on a smaller sample due to data availability

Standard errors in parentheses * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 11 Regression Table: Refinance loan with cash-out

	(1) Margin	(2) Margin	(3) Margin	(4) Margin
FICO	−0.0114***	−0.0160***	−0.00735***	−0.0115***
	(0.000)	(0.001)	(0.000)	(0.001)
LTV	0.0189***	0.0269***	0.0113***	0.0306***
	(0.000)	(0.003)	(0.000)	(0.004)
year = 2002	−0.360***	−1.372**	−0.732***	−1.556*
	(0.043)	(0.476)	(0.067)	(0.769)
year = 2003	−0.791***	−0.661	−0.813***	−0.280
	(0.041)	(0.452)	(0.062)	(0.720)
year = 2004	−0.707***	−1.787***	−0.887***	−0.744
	(0.040)	(0.445)	(0.062)	(0.715)
year = 2005	−0.404***	−2.773***	−0.784***	−2.042**
	(0.040)	(0.444)	(0.061)	(0.714)
year = 2006	−0.275***	−3.048***	−0.690***	−2.085**
	(0.040)	(0.443)	(0.061)	(0.714)
year = 2007	−0.362***	−3.223***	−0.690***	−2.154**
	(0.040)	(0.446)	(0.062)	(0.715)
2002*FICO		0.00214***		0.00349***
		(0.001)		(0.001)
2003*FICO		0.00124*		0.00171*
		(0.001)		(0.001)
2004*FICO		0.00389***		0.00166*
		(0.001)		(0.001)
2005*FICO		0.00438***		0.00434***
		(0.001)		(0.001)
2006*FICO		0.00546***		0.00464***
		(0.001)		(0.001)
2007*FICO		0.00593***		0.00501***
		(0.001)		(0.001)
2002*LTV		−0.00372		−0.0181***
		(0.003)		(0.004)
2003*LTV		−0.0101***		−0.0208***
		(0.003)		(0.004)
2004* LTV		−0.0166***		−0.0152***
		(0.003)		(0.004)
2005*LTV		−0.00347		−0.0193***
		(0.003)		(0.004)
2006*LTV		−0.00739**		−0.0200***
		(0.003)		(0.004)
2007*LTV		−0.0104***		−0.0223***
		(0.003)		(0.004)
Constant	11.84***	14.11***	6.616***	7.887***
	(0.462)	(0.637)	(0.564)	(0.905)
Adjusted R^2	0.6322	0.6351	0.7320	0.7339
Observations	455,184	455,184	344,386	344,386

The margin is measured in percentage points. The sample is ARM loans whose loan purpose is refinance with cash-out. Year 2001 is chosen as the base level. Unreported controlled variables: loan term, documentation types, state dummies and loan purpose. Models 1–2 control product types, including negative amortization flag, interest-only flag and balloon flag. Models 3–4 instead control more detailed product types but rely on a smaller sample due to data availability

Standard errors in parentheses * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 12 Regression Table: Refinance loan without cash-out

	(1) Margin	(2) Margin	(3) Margin	(4) Margin
FICO	−0.0112***	−0.0153***	−0.00602***	−0.0129***
	(0.000)	(0.001)	(0.000)	(0.001)
LTV	0.0131***	0.0132***	0.00752***	−0.000789
	(0.000)	(0.004)	(0.000)	(0.005)
year = 2002	−0.0511	−0.0951	−0.286***	−4.621***
	(0.060)	(0.633)	(0.084)	(0.859)
year = 2003	−0.450***	−2.402***	−0.468***	−4.984***
	(0.057)	(0.595)	(0.076)	(0.761)
year = 2004	−0.203***	−1.628**	−0.597***	−4.448***
	(0.056)	(0.587)	(0.076)	(0.755)
year = 2005	0.0882	−2.150***	−0.508***	−5.575***
	(0.056)	(0.587)	(0.076)	(0.753)
year = 2006	0.235***	−3.079***	−0.424***	−5.462***
	(0.056)	(0.586)	(0.076)	(0.752)
year = 2007	0.285***	−4.571***	−0.365***	−7.112***
	(0.057)	(0.589)	(0.076)	(0.755)
2002*FICO		0.000872		0.00627***
		(0.001)		(0.001)
2003*FICO		0.00376***		0.00655***
		(0.001)		(0.001)
2004*FICO		0.00310***		0.00556***
		(0.001)		(0.001)
2005*FICO		0.00362***		0.00721***
		(0.001)		(0.001)
2006*FICO		0.00448***		0.00643***
		(0.001)		(0.001)
2007*FICO		0.00662***		0.00863***
		(0.001)		(0.001)
2002*LTV		−0.00534		0.00374
		(0.004)		(0.005)
2003*LTV		−0.00624		0.00369
		(0.004)		(0.005)
2004* LTV		−0.00692		0.00401
		(0.004)		(0.005)
2005*LTV		−0.000483		0.00523
		(0.004)		(0.005)
2006*LTV		0.00594		0.0119**
		(0.004)		(0.005)
2007*LTV		0.00672		0.0143**
		(0.004)		(0.005)
Constant	9.863***	12.51***	7.334***	12.35***
	(0.310)	(0.665)	(0.855)	(1.132)
Adjusted R^2	0.6216	0.6254	0.7535	0.7556
Observations	169,267	169,267	117,358	117,358

The sample is ARM loans whose loan purpose is refinance without cash-out. Year 2001 is chosen as the base level. Unreported controlled variables: loan term, documentation types, state dummies and loan purpose. Models 1–2 control product types, including negative amortization flag, interest-only flag and balloon flag. Models 3–4 instead control more detailed product types but rely on a smaller sample due to data availability

Standard errors in parentheses * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ The margin is measured in percentage points

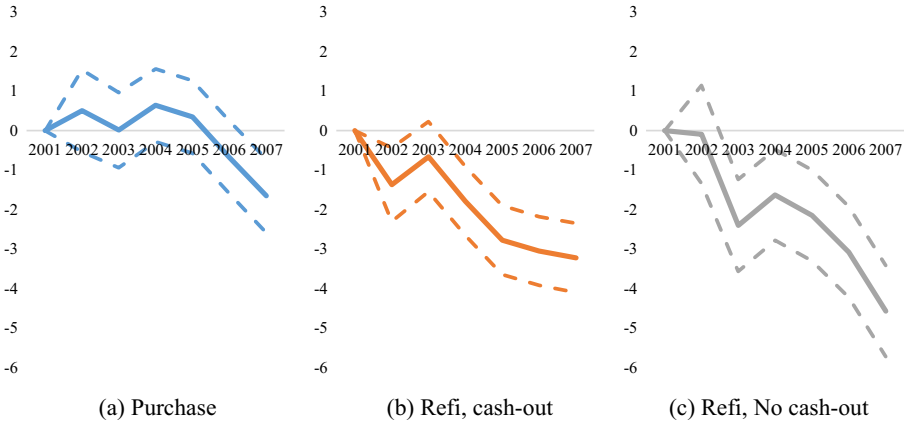


Fig. 10 Regression coefficients on vintage year from margin regression (Model 2) in Tables 10, 11, 12, decomposed by loan purpose (purchase, refi/cash-out, refi/no cash-out). Margin is measured by percentage points. 2001 is the base level and normalized to 0. The dashed bands represent 95% confidence intervals

increased, risk premiums decreased, especially in so-called sand states that had particularly sharp price increases during the bubble.

If credit pricing in the various sources of credit supply had indicated growing risk, borrowers might have been discouraged from borrowing, thereby limiting housing demand and the housing bubble itself.[32] Our findings, however, show that even as the volume of mortgages expanded and lending terms eased, the pricing of credit risk did not rise.[33] Similarly, our findings are consistent with not only subprime PLS mispricing credit; prime PLS was also mispriced. Although we do not directly test for the pricing differences between investors and owner occupants, our findings are consistent with property investors increasingly taking advantage of the underpriced put option through their use of PLS. New home buyers and existing homeowners, through purchase money and cash-out refi loans, also increased their use of PLS. Nonetheless, homeownership rates reached their highs in 2004 and stalled as marginal borrowers became increasingly constrained by higher prices (Barakova et al. 2014; Acolin et al. 2016). In the aftermath, homeownership rates precipitously declined, disproportionately for young, low- and moderate-income, and minority households, as default risk became incorporated into mortgage rates.[34]

Post-crisis, mortgage securitization is again the domain of the Agencies – with the taxpayer-backed GSEs and Ginnie Mae providing housing finance in near entirety. The GSEs are under conservatorship with Congress considering their reform. Financial stability should be a key concern, both for the sustainability of homeownership and to extent of U.S. taxpayer exposure to the credit risk.[35]

[32] Frame finds securitization itself may not have been the problem to the recent financial crisis, but rather the origination and distribution of observably riskier loans, by both portfolio lenders and PLS investors. This is not inconsistent with our results.

[33] Glaeser et al. (2012) show that 20% of the rise in housing prices in this period can be attributed to a decline in mortgage rates over time. However, they use only prime mortgage rates in their analysis.

[34] For the discussion on endowments and minority homeownership, see Acolin et al. (2018). Risks premiums were raised, when credit quality requirements substantially increased. See Acolin et al. (2016) and McCoy and Wachter (2017).

[35] For discussions on policies, see Wachter (2018) and Levitin and Wachter (forthcoming).

Table 13 Regression Table: Margin by FICO

	(1) FICO ≤ 660 Margin	(2) FICO ≤ 660 Margin	(3) FICO > 660 Margin	(4) FICO > 660 Margin
FICO	−0.00909***	−0.0135***	−0.00710***	−0.00940***
	(0.000)	(0.001)	(0.000)	(0.001)
LTV	0.0188***	0.0296***	0.0197***	0.0218***
	(0.000)	(0.003)	(0.000)	(0.002)
year = 2002	−0.191***	−0.774	0.105*	−1.623
	(0.032)	(0.459)	(0.048)	(0.853)
year = 2003	−0.546***	0.303	−0.151***	−2.836***
	(0.030)	(0.433)	(0.045)	(0.790)
year = 2004	−0.652***	−0.179	0.101*	−1.668*
	(0.029)	(0.422)	(0.045)	(0.782)
year = 2005	−0.290***	−2.473***	0.424***	−0.266
	(0.029)	(0.420)	(0.045)	(0.781)
year = 2006	−0.197***	−2.559***	0.499***	−1.634*
	(0.029)	(0.419)	(0.045)	(0.781)
year = 2007	−0.301***	−2.289***	0.457***	−2.696***
	(0.030)	(0.425)	(0.045)	(0.784)
2002*FICO		0.00111		0.00294**
		(0.001)		(0.001)
2003*FICO		−0.00228**		0.00463***
		(0.001)		(0.001)
2004*FICO		0.00114		0.00366***
		(0.001)		(0.001)
2005*FICO		0.00499***		0.000690
		(0.001)		(0.001)
2006*FICO		0.00582***		0.00236*
		(0.001)		(0.001)
2007*FICO		0.00555***		0.00428***
		(0.001)		(0.001)
2002*LTV		−0.000569		−0.00610*
		(0.003)		(0.003)
2003*LTV		0.00696**		−0.0101***
		(0.003)		(0.002)
2004* LTV		−0.0131***		−0.0124***
		(0.003)		(0.002)
2005*LTV		−0.00875***		0.00215
		(0.003)		(0.002)
2006*LTV		−0.0127***		0.00510*
		(0.003)		(0.002)
2007*LTV		−0.0155***		0.000367
		(0.003)		(0.002)
Constant	10.57***	12.21***	7.247***	8.760***
	(0.508)	(0.655)	(0.649)	(1.011)
Adjusted R^2	0.3832	0.3879	0.3696	0.3757
Observations	543,294	543,294	711,087	711,087

Year 2001 is chosen as the base level. Both the margin and the spread are measured in percentage points. Unreported controlled variables: loan term, documentation types, state dummies and loan purpose. Models 1–4 control product types, including negative amortization flag, interest-only flag and balloon flag. Models 1–2 restrict sample to FICO ≤ 660, while Model 3–4 restrict sample to FICO > 660

Standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Margin, margin

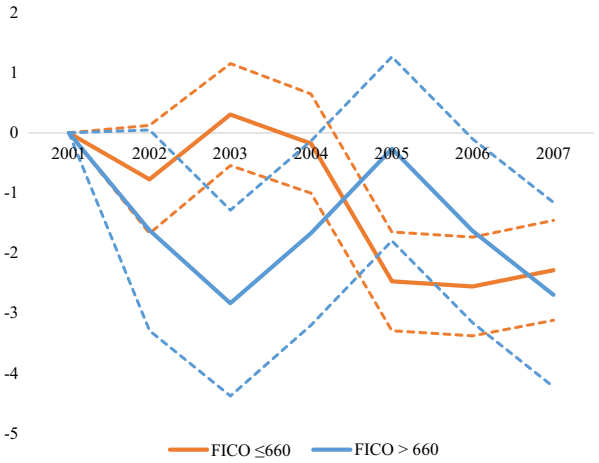


Fig. 11 Regression coefficients on vintage year from Model 2 (FICO ≤ 660) and Model 4 (FICO > 660) in Table 13 with the ARM sample. The margin is measured in percentage points. 2001 is the base level and normalized to 0. The dashed bands represent 95% confidence intervals

This paper shows that PLS investors *ex ante* underpriced mortgage risk. Many investors may not have recognized the mortgage credit risk, because information on mortgages was not available in a timely way, mortgage products were complex, mortgage-backed securities were non-standardized, and the extent of correlated risks, including counterparty and second lien risks, was not known. The rightward shift of the supply curve occurred after the surge in refi loans ended with the increase in interest rates. This left a large underutilized installed securitization capacity which was repurposed to private-label securitization. In this environment, financial innovation outpaced financial regulation.[36] Price rises, due to the increase in mortgage supply and irrational exuberance, prevented a rise in default.[37] Going forward, a self-enforcing market-informing mechanism that increases transparency and enhances price discovery needs to be in place.[38]

Conclusion

We measure the credit spread or margin, defined as the difference between the ARM mortgage rate and the index rate, in a database of securitized ARM mortgages included in private-label mortgage pools in the run-up to the financial crisis of 2008. We also calculate the difference between the stated interest rate at origination and the 7-year Treasury rate for these loans. Both unconditional risk

[36] See McCoy and Wachter (2016).
[37] As we know, delinquency and foreclosure rates remained low through 2006. See Shiller (2000) on irrational exuberance, and see Levitin and Wachter (2011, forthcoming) on alternative discussion.
[38] Credit risk transfer programs (CRTs) implemented by Fannie Mae and Freddie Mac in 2013 are moves toward a market-informing mechanism. See Wachter (2016, 2018, forthcoming) for a discussion of the role.

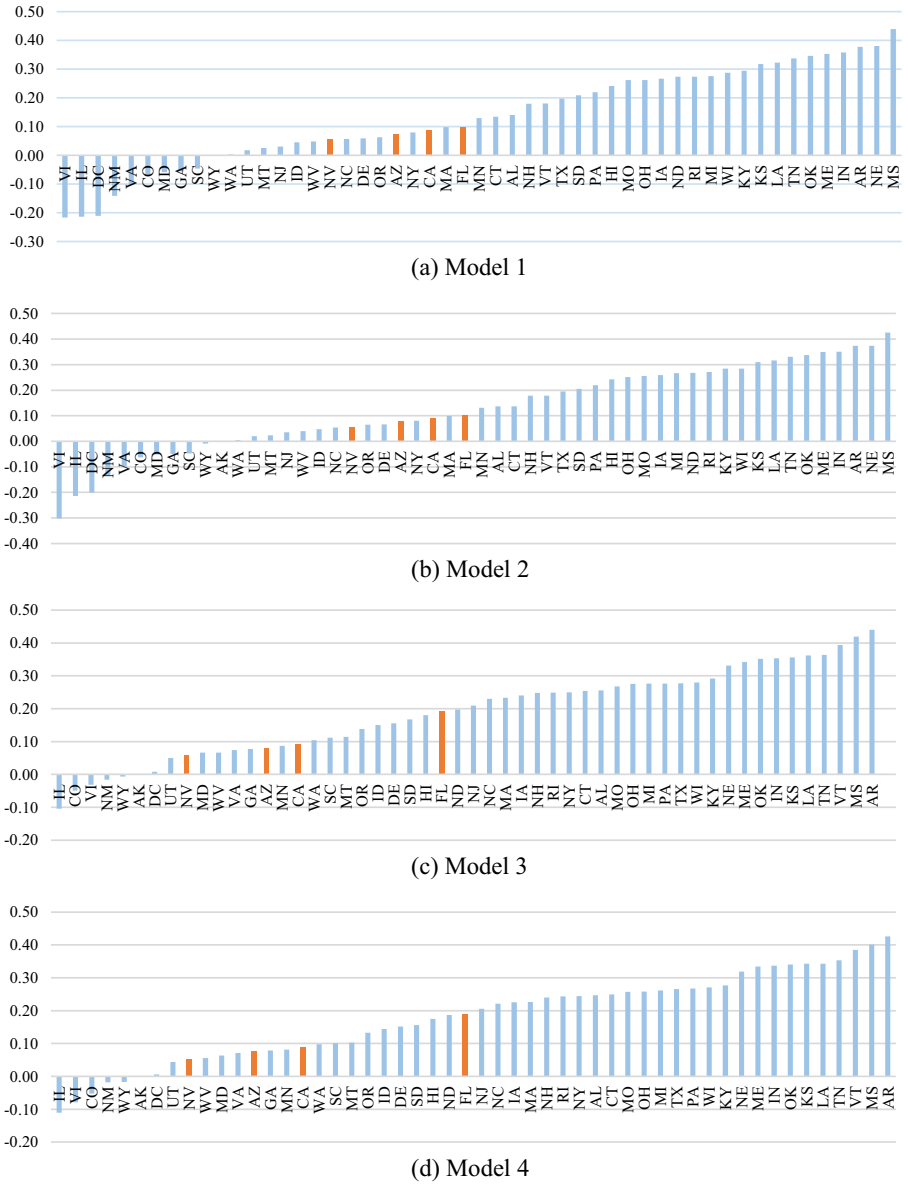


Fig. 12 Regression coefficients on the state dummies from margin regression (Model 1–4) in Table 7, respectively. Sand States (AZ, CA FL, NV) are highlighted. Margin is measured by percentage point. States are sorted by the coefficient in ascending order

spreads decrease by more than 100 basis points from 2001 to 2003–2004 and then increase somewhat until 2007 but still remain below 2001 levels.

We also estimate time-varying coefficients on the key risk variables, FICO score and LTV ratio, and find that the time-varying coefficients on FICO score decline in absolute value over time. The absolute values of the time-varying coefficients on LTV decrease from 2001 to 2004, followed by a weak increase until 2006.

Finally, we examine vintage pricing conditional on time-varying marginal effects of FICO and LTV. The vintage effect, taking account of these and other borrower and loan characteristics, is found to decline monotonically from 2001 to 2007. These findings are consistent with the mortgage finance supply curve shifting rightward during the housing bubble more than any rightward shift of the mortgage finance demand curve, which indicates that the bubble was driven primarily by an increase in the supply of credit rather than a growth in demand.

Acknowledgements We thank Ben Keys, Michael LaCour-Little, Laurie Goodman, and Jing Yang as well as seminar participants at the 2018 AREUEA National Meeting for their helpful comments and discussion. Susan Wachter acknowledges financial support from the Zell Lurie Real Estate Center at the Wharton School of the University of Pennsylvania.

Appendix

Data Cleaning

The data are subject to missing values. There are in total 4,080,770 observations in the cross section of January 2008 and 2,196,117 loans fall in the category of ARM. The origination window, 2001–2007, is selected by the number of observations; we focus on origination years with more than 10,000 observations in ARM loans. Table 14 lists the distribution of missing data on ARM and the operation to produce the clean sample for analysis. 2,576,175 loans meet our criteria, and 1,543,203 of them are ARM. 30% of the data are not usable due to missing values. Figure 13 compares the distribution of observations by origination year, before and after the data cleaning operation, while Fig. 14 compares the quarterly-aggregated margin of ARM loans of the clean sample and the dropped sample. Both figures provide evidence that the sample we work on is representative. Table 15 reports the counts and the shares of missing values by vintage, from 2001 to 2007.

Table 14 Operation on raw data, ARM

Description of operations	Missing Data	Percentage	No. of obs Survived
(delete obs with)			2,196,117
missing origination date	342,442	15.59	1,853,675
origination outside 2001–2007	23,461	1.07	1830,214
missing FICO score	66,831	3.04	1,763,383
missing document type	53,167	2.42	1,710,216
missing original balance	346	0.02	1,709,870
missing appraisal value	148,078	6.74	1,561,792
missing LTV	18,589	0.85	1,543,203
Total	652,914	29.73	1,543,203

The percentage is calculated as the share of the total observations before cleaning

Table 15 Survival rate by vintage, ARM

	Origination year							
Missing	2001	2002	2003	2004	2005	2006	2007	Total
N	2595	12,459	57,787	235,083	471,615	601,041	162,623	1,543,203
	25.77	60.84	78.68	89.18	85.76	84.05	82.29	84.32
Y	7473	8019	15,655	28,536	78,290	114,030	35,008	287,011
	74.23	39.16	21.32	10.82	14.24	15.95	17.71	15.68
Total	10,068	20,478	73,442	263,619	549,905	715,071	197,631	1830,214
	100	100	100	100	100	100	100	100

Numbers in each cell are counts and column shares (percentage), respectively

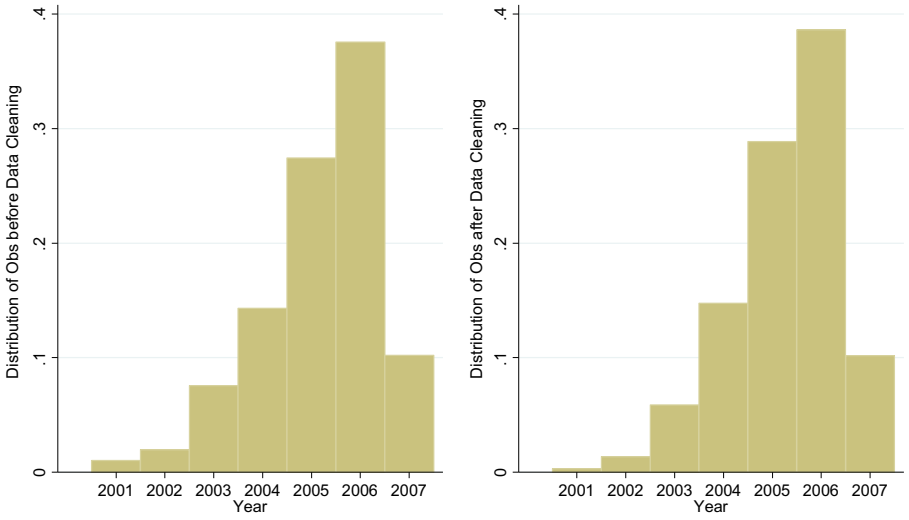


Fig. 13 Distribution of observations by origination year, raw data vs. clean sample

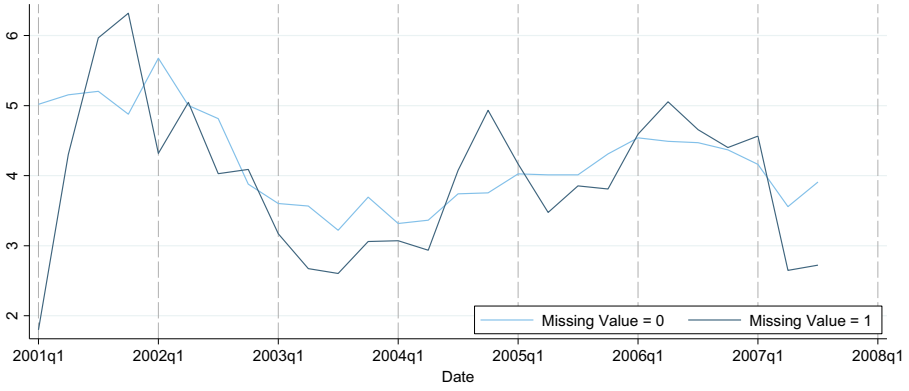


Fig. 14 Margin of clean sample (Missing Value = 0) and dropped sample (Missing Value = 1) 2001–2007. Data is aggregated quarterly

Robustness Test for Survival Bias

The observations may be subject to survival bias. The earlier the loan origination is, or the riskier a loan is, the less likely a loan will exist in the data we observe. Moreover, loans might be subject to service transfer and disappear in the data. We may overweigh the importance of young and surviving loans. A loan can vanish from the database record either voluntarily or involuntarily. A mortgagor can make payment in full and terminate the contract early or can become delinquent on the loan due to bankruptcy, business failure, illness or death, etc. The lender/servicer will monitor its payment, label any delinquent behavior by 30 days, 60 days or 90+ days past due (dpd), and consider foreclosure of the collateral property. The property is either successfully auctioned or is Real-Estate-Owned (REO) by the lender and ceases to be part of the database.

We use the information on delinquency to test potential survival bias by considering an incidental truncation model. Specifically, we define a binary variable survival in the following way. If a loan in the cross-section carries the delinquency code "no action", *Survival = 1*. Otherwise, *Survival = 0*.[39] Loans with *Survival = 0* will be removed from or not survive in the next cross-section (let's call it experimental data). Heckman's two-step procedure is implemented to test the sample selection problem of the experimental data (Heckman 1976, 1979).

$$\begin{aligned} survival_j &= \mathbf{1}\left\{\mathbf{Z}_j'\gamma + e_{1j} > 0\right\} \\ risk\quad price_j &= \beta_0 + \beta_1 FICO_j + \beta_2 LTV_j + \sum_{t=2002}^{2007} d_t \cdot \mathbf{1}\left\{t = orig\_year_j\right\} + \mathbf{X}_j'\mathbf{B}_3 + e_{2j} \end{aligned} \tag{2}$$

where loan j is observable in the experimental data only if *Survival = 0*. Incidental truncation leads to the regression with a correction term

$$\begin{aligned} risk\quad price_j = \beta_0 + \beta_1 FICO_j + \beta_2 LTV_j + \sum_{t=2002}^{2007} d_t \cdot \mathbf{1}\left\{t = orig\_year_j\right\} + \mathbf{X}_j'\mathbf{B}_3 \\ +\sigma_{12}\lambda\left(\mathbf{Z}_j'\gamma\right) + e_j \end{aligned} \tag{3}$$

where the first is the selection equation and the second is the outcome equation. λ is the inverse Mills ratio and σ is the covariance between e_{1j} and e_{2j} under the assumption of joint normality.

In Table 16, we summarize the test results of survival bias. Three models reported are bias adjustment versions of Model (1) and (5) in Table 7, respectively. To mitigate the concern of violating the joint normality assumption, we use the logarithmic variables instead of their levels to extend the domain from positivity to the entire real line. In addition to FICO and LTV, we include the current loan rate in the selection equation as one driving force of the delinquency decision, especially to ARM loans. We further control loan term, documentation types, loan purpose and mortgage vintage as determinants of sample selection. The coefficients of the inverse Mills ratio using experimental data are statistically significant, providing evidence for survival bias.

[39] Loans with survival = 0 are off the record due to bankruptcy, decision for foreclosure, loan paid in full, REO.

Since the coefficients of the correction terms are positive, there is an upward bias in estimations without correction. In other words, we tend to bias the marginal effect of FICO downward and bias the marginal effect of LTV upward without a correction procedure. As to the cross-section data we actually observe, there is no way to test how much survival bias our estimates will suffer, but conservatively speaking, our estimates do provide a lower and upper bound for FICO and LTV, respectively. Moreover, if we assume the actual loan survival process is isomorphic to that in the experiment we conduct, we find the selection impact doesn't drastically change the estimates. Using the experimental data, the coefficient gap (or elasticity gap in the logarithmic setting) between OLS and Heckman estimates in the log margin regression is 0.16 to FICO (7% downward bias) and 0.01 to LTV (7% upward bias).

Table 16 Test of Survival Bias, Heckman Model vs. OLS

	Model (1)		OLS	Model (2)		OLS
	Log.Margin	Survival	Log.Margin	Log.Spread	Survival	Log.Spread
Log.FICO	−2.253***	1.413***	−2.409***	−2.325***	−0.358***	−2.575***
	(0.006)	(0.017)	(0.00609)	(0.005)	(0.017)	(0.00504)
Log.LTV	0.161***	−0.385***	0.172***	0.243***	−0.291***	0.281***
	(0.002)	(0.008)	(0.00189)	(0.002)	(0.008)	(0.00221)
year = 2002	0.010	−0.127***	0.0120	−0.102***	−0.118***	−0.0893***
	(0.015)	(0.034)	(0.0152)	(0.012)	(0.034)	(0.0122)
year = 2003	−0.193***	−0.193***	−0.199***	−0.268***	−0.304***	−0.277***
	(0.014)	(0.032)	(0.0142)	(0.012)	(0.032)	(0.0113)
year = 2004	−0.045**	−0.296***	−0.0482***	−0.379***	−0.441***	−0.377***
	(0.014)	(0.031)	(0.0140)	(0.011)	(0.031)	(0.0111)
year = 2005	0.047***	−0.284***	0.0432**	−0.201***	−0.509***	−0.200***
	(0.014)	(0.031)	(0.0140)	(0.011)	(0.031)	(0.0110)
year = 2006	0.103***	−0.208***	0.0948***	−0.058***	−0.525***	−0.0701***
	(0.014)	(0.031)	(0.0140)	(0.011)	(0.031)	(0.0110)
year = 2007	0.123***	0.341***	0.0968***	0.036**	−0.000	−0.0176
	(0.014)	(0.032)	(0.0140)	(0.011)	(0.032)	(0.0111)
Log.Curr.Rate		−1.830***			−2.735***	
		(0.009)			(0.009)	
cons	15.162***	−2.536***	16.19***	15.314***	10.571***	16.89***
	(0.249)	(0.128)	(0.249)	(0.189)	(0.133)	(0.193)
InvMills	0.139			0.265		
	(0.001)			(0.001)		
N	1,253,066			1,065,543		

Both the margin and the spread are measured in percentage points. Year 2001 is chosen as the base level. OLS models use the subsample selected by delinquency code with "no action," which is used as the indicator of surviving loans in the experimental data. Unreported controlled variables in outcome equations: loan term, documentation types, loan purpose, state dummies, negative amortization flag, interest-only flag and balloon flag. Unreported controlled variables in selection equations: loan purpose, state dummies

Standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Margin, margin; *Spread*, original interest rate spread (with respect to 7-year Constant Maturity Treasury Rate); *InvMills*, inverse mills ratio

Rajan et al. (2015) Revisited

We revisit the benchmark regression results from Rajan et al. (2015) with the model specification

$$orig\ rate_{jt} = \beta_{0,t} + \beta_{LTV,t} LTV_{jt} + \beta_{FICO,t} FICO_{jt} + e_{jt} \quad (4)$$

Where t is the vintage year and *orig rate* refers to the original interest rate in the data. We look at both FRM and ARM loans originated from 2001 in 2007. For ARM loans, original interest rate refers to the initial rate, while for the FRM loans, it refers to the fixed interest rate. There is no variable in the dataset indicating whether a borrower is a first-time buyer, but we do observe the loan purpose of each observation. We report regression results in Tables 17, 18 and 19 based on loan purposes: primary loan, refinance with cash-out, or refinance without cash-out.

Table 17 is comparable to Table 4 in Rajan et al. (2015) (RSV), and we find consistent results. RSV's main results focus on the subprime primary purchase loans (both ARM and FRM included); we confirm RSV's results with the subprime pools (FICO ≤660) but include both prime and subprime shares in our report. For primary purchase loans, the reliance of FICO, measured by the absolute value of the coefficient, is relatively constant, while the reliance of LTV witnesses an increase from 2001 to 2007. The adjusted R-square increases from 0.09 in 2001 to 0.33 in 2006, following a similar trend as RSV quantitatively. Moreover, both FICO and LTV coefficients estimated using our data have similar scales. As to refinance loans with and without cash-out, the reliance on FICO or LTV is increasing over time from 2001 to 2004 and becomes relatively steady from then on. We find that the adjusted R-squares of the refinance pool (with and without cash-out) do not show a similar increasing trend from 2001 to 2006 as the primary purchase pool. Instead, the adjusted R-squares of the refinance pool in 2001 were as high as 0.3 and had ever decreased since 2002. For robustness, we additionally control other loan characteristics similar to the implementation by RSV: whether a loan is ARM and whether it has low documentation. Consistent with their results, we find our previous results on FICO, LTV and R-squares are preserved in the enhanced models. For brevity, they are not reported but available upon request.

To relate our results to RSV's, we focus on mortgage risk pricing for the ARM sample. Figure 15 compares the trend of R-squares in the mortgage rate regression with the trend in the margin regression by loan purpose, with FICO and LTV as the explanatory variables. Similar to our benchmark results, we cannot find evidence supporting increasing reliance of FICO or LTV from 2001 to 2007 in the margin regressions. In addition, adjusted R-square is relatively flat over time for all loan purposes. The difference in the mortgage rate and margin regressions implies that term structures and other unobserved factors explain the variation in the mortgage rate but not the variation in the risk pricing in terms of gross margin. As year 2001/02 was in the regime of high interest rate, controlling term structures using short- and long-term interest rates (1-year and 7-year constant maturity treasuries) can flatten but cannot reject the increasing trend of R-squares in the mortgage rate regressions within the primary purchase pool. However, part of the increasing trend in R-squares for purchase money loans still remained unexplained due to other unobservable factors.

Table 17 Regression Table: Original Interest Rate (Primary Purchase)

	2001	2002	2003	2004	2005	2006	2007
FICO	−0.00713***	−0.00865***	−0.0116***	−0.0117***	−0.0115***	−0.0125***	−0.0122***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
LTV	−0.0274***	0.0381***	0.0387***	0.0747***	0.0934***	0.0969***	0.0512***
	(0.004)	(0.002)	(0.001)	(0.000)	(0.000)	(0.000)	(0.001)
Constant	15.21***	10.13***	11.06***	8.007***	6.748***	8.069***	11.74***
	(0.505)	(0.276)	(0.127)	(0.071)	(0.054)	(0.051)	(0.125)
Adjusted R^2	0.0851	0.2209	0.2958	0.3612	0.3496	0.3316	0.1901
Observations	2756	8511	34,706	135,554	296,259	363,069	72,234

The regression for each vintage year uses loans whose purpose is primary purchase. The dependent variable is original interest rate measured in percentage points. The sample includes both ARM and FRM loans

Standard errors in parentheses * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 18 Regression Table: Original interest rate (Refinance with Cash-out)

	2001	2002	2003	2004	2005	2006	2007
FICO	−0.0134***	−0.0143***	−0.0136***	−0.0153***	−0.0154***	−0.0174***	−0.0144***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
LTV	0.00637*	0.0272***	0.0279***	0.0451***	0.0390***	0.0426***	0.0136***
	(0.003)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)	(0.001)
Constant	17.18***	15.06***	13.61***	12.81***	13.46***	15.17***	15.83***
	(0.391)	(0.152)	(0.079)	(0.067)	(0.057)	(0.050)	(0.089)
Adjusted R^2	0.3142	0.4613	0.4464	0.3869	0.3159	0.2947	0.2109
Observations	2241	11,375	39,313	101,005	184,625	270,333	81,031

The regression for each vintage year uses loans whose purpose is refinance with cash-out. The dependent variable is original interest rate measured in percentage points. The sample includes both ARM and FRM loans

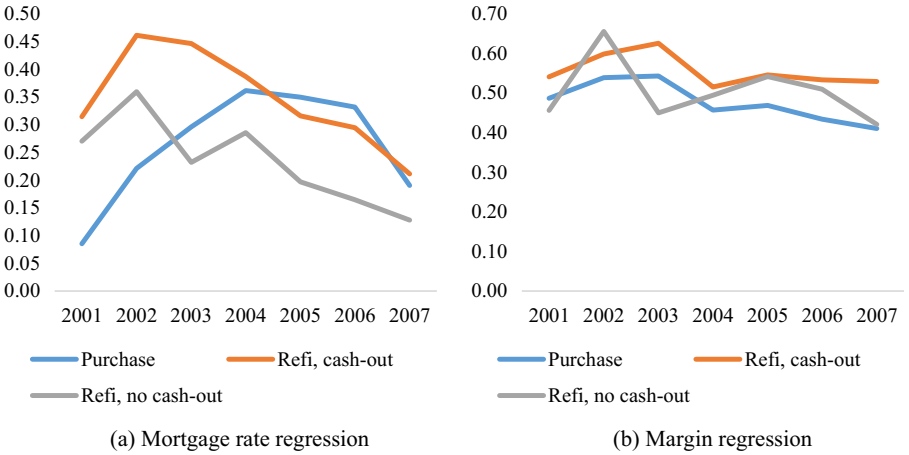
Standard errors in parentheses * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 19 Regression Table: Original interest rate (Refinance without Cash-out)

	2001	2002	2003	2004	2005	2006	2007
FICO	−0.0110***	−0.0108***	−0.00903***	−0.0129***	−0.0121***	−0.0150***	−0.0152***
	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
LTV	−0.00361	0.0129***	0.0149***	0.0295***	0.0235***	0.0233***	−0.0112***
	(0.004)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Constant	15.50***	13.18***	11.06***	12.17***	12.23***	14.72***	17.38***
	(0.538)	(0.224)	(0.108)	(0.116)	(0.124)	(0.133)	(0.190)
Adjusted R^2	0.2701	0.3596	0.2318	0.2854	0.1970	0.1644	0.1279
Observations	1246	6411	30,715	44,625	57,736	78,855	39,590

The regression for each vintage year uses loans whose purpose is refinance without cash-out. The dependent variable is original interest rate measured in percentage points. The sample includes both ARM and FRM loans

Standard errors in parentheses * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$



(a) Mortgage rate regression (b) Margin regression

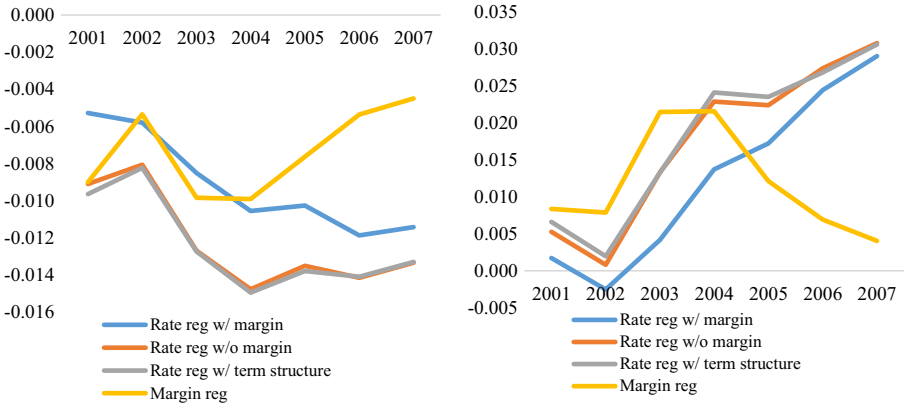
Fig. 15 Adjusted R-squares of mortgage rate regression (panel a) and margin regression (panel b) by vintage and loan purposes (primary purchase, refinance with cash-out, refinance without cash-out). The regressions control FICO and LTV. The sample universe in the mortgage rate regression is ARM and FRM loans, while the sample in the margin regression includes ARM loans

Demyanyk and Hemert (2011) Revisited

Demyanyk and Hemert (2011) (DvH) find that securitizers were aware of increasing riskiness of borrowers by examining the determinants of the mortgage rate of subprime 2/28 ARMs. They find the normalized LTV coefficient scaled by the standard deviation has been increasing over time (see DvH Fig. 2). We use our data to confirm and augment the finding. Figure 15 shows the time-varying coefficients on FICO and LTV. The mortgage rate regression with gross margin as one explanatory variable replicates increasing riskiness awareness in DvH's regression. Alternatively, we consider two alternative variations in specification: one without gross margin and the other with term structures consideration (by controlling 1-year and 7-year constant maturity treasury rates). Similarly, both show more pronounced effects of FICO and LTV over time. To bridge our results with DvH's, we report the FICO and LTV coefficients in gross margin regression with a sample restricted to subprime 2/28 ARM, defined as loans with FICO scores lower than 660 (Demyanyk and Hemert 2011). Consistent with our benchmark result, we show that there is decreasing reliance on FICO and LTV starting from 2004 (Fig. 16).

Coefficients on FICO/LTV and Residual Vintage Effect of FRMs

We use the FRM sample in the database and report the time-varying coefficients on FICO and LTV and the residual vintage effect over time. Different from the diminishing impact of hard information in ARMs, we find that the marginal impact of FICO and LTV in FRMs followed an increasing trend. The residual vintage effect of FRMs was relatively constant from 2002 to 2006, compared to a monotonically decreasing trend of ARMs (Fig. 17).



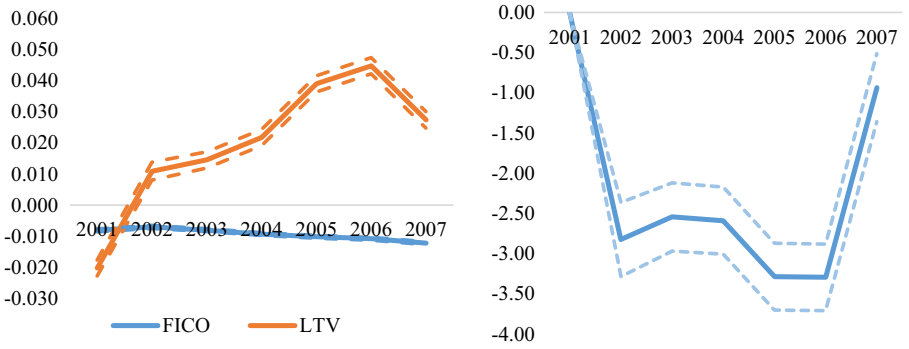
(a) FICO, 2/28 ARMs (b) LTV, 2/28 ARMs

Fig. 16 Regression coefficients on FICO (panel a) and LTV (panel b) for subprime section of 2/28 ARM loans (FICO ≤ 660). The dependent variables in percentage points are original interest rate (model 1–3) and the margin (model 4), respectively. Models 1–3 are specifications with margin, without margin, and with term structures in the control variables, respectively. Controlled variables include loan term, documentation types, loan purpose, state dummies, negative amortization flag, interest-only flag and balloon flag. Term structure includes constant maturity treasury rates

Justiniano et al. (2017) Revisited and Residuals of Main Regressions

We report the average residuals of the regressions in Table 7. By the Gauss-Markov Theorem, the model errors should be zero in expectation conditional on observable factors. In estimation, the time average of loan-level residuals weighted by the number of loans in each time window, by construction, should be equal to zero. We aggregate the loan-level residuals by taking the monthly average from 2001 to 2007. Figs. 18 and 19 plots the time series of average residuals from Model4 1–4 and Model 5–8, respectively.

Justiniano et al. (2017) (JPT) finds that there was a sudden decrease in mortgage rate and persistently cheaper mortgage credit starting from mid-2003 (the so-called



(a) FICO and LTV Coefficients, FRMs (b) Residual vintages, FRMs

Fig. 17 Panel (**a**): Regression coefficients on FICO (blue) and LTV (orange) from original interest rate spread regression by vintage with FRM sample. Panel (**b**): Regression coefficients on vintage year from original interest rate spread regression. The dependent variables are measured in percentage points. The dashed bands represent 95% confidence intervals

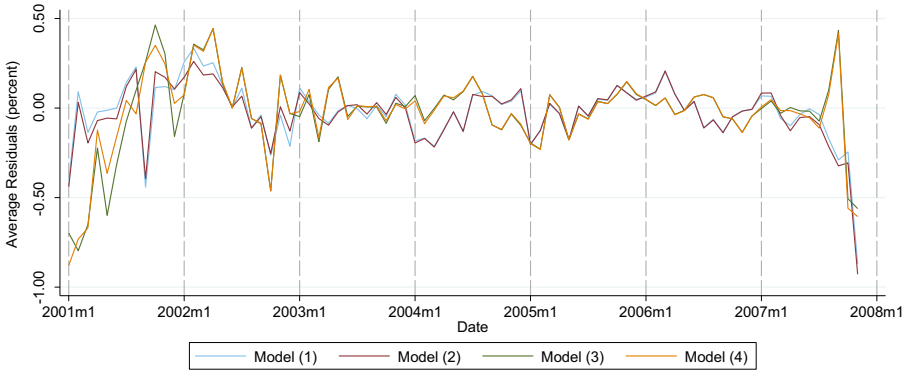


Fig. 18 Time series of average residuals of Model (1–4) in Table 7 with margin as the dependent variable. Data is aggregated by month

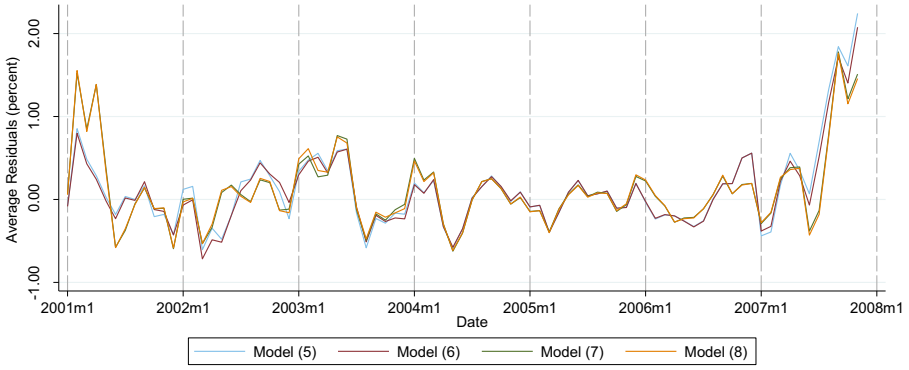


Fig. 19 Time series of average residuals of Model (5–8) in Table 7 with original interest rate spread as the dependent variable. Data is aggregated by month

mortgage rate conundrum). JPT shows that the average residuals suddenly plummeted in mid-2003 and stayed low persistently (see JPT Fig. 4.1). Using our ARM samples, we find the average residuals in the original interest rate spread regression did experience a sudden decrease in mid-2003, but the drop was not as persistent as what JPT found. In our margin regression, the average residuals exhibit a less persistent "white noise" pattern, compared to the trend of the average residuals in the original rate spread regressions and in JPT's models. This suggests that the model controls are able to explain cross-vintage variation of the gross margin, in addition to cross-section variation of the gross margin.

Additional Tables

We show the number of 2/28 ARMs and the dollar volume by origination year in Table 20.

Table 20 Mortgage Frequency and Dollar Volume of 2/28 ARMs by Origination Year

Year	Count		Dollar volume	
	N	%	Million	%
2001	252	28.67	23	9.20
2002	788	23.66	83	11.20
2003	5625	15.47	688	6.25
2004	27,066	18.96	3980	10.66
2005	84,701	21.96	17,000	14.78
2006	128,927	25.48	28,400	18.02
2007	21,559	18.05	5540	12.10

A 2/28 ARM is an adjustable rate mortgage with the initial mortgage rate fixed for the first two years and starting to adjust for the next 28 years. The percentage shares of 2/28 ARMs are relative to the total number or dollar volume of ARM loans with information on detailed product types. In the sample, not all observations report detailed product type

In Table 21, we report the weighted version of Table 6, using original balance to weigh the observations.

Table 21 Summary statistics: Continuous Variables by Origination Year (Weighted by Original Balance), 2001–2007

	Mean	sd	p25	p50	p75
2001, ARM					
Margin	3.37	2.39	1.88	2.75	5.50
Original interest rate spread	2.15	2.75	0.62	1.89	4.22
FICO	682.16	89.12	611.00	697.00	760.00
LTV	71.17	18.00	60.70	75.00	80.00
Loan term	352.31	32.09	360.00	360.00	360.00
2002, ARM					
Margin	3.32	1.98	2.00	2.60	4.88
Original interest rate spread	1.81	2.23	−0.15	1.74	3.30
FICO	688.47	83.30	630.00	705.00	760.00
LTV	70.52	17.02	61.30	75.00	80.00
Loan term	341.80	36.99	300.00	360.00	360.00
2003, ARM					
Margin	2.70	1.46	2.13	2.25	2.75
Original interest rate spread	1.01	2.16	0.01	1.30	2.07
FICO	714.17	65.21	680.00	726.00	765.00
LTV	68.58	16.42	59.90	72.70	80.00
Loan term	352.09	25.83	360.00	360.00	360.00
2004, ARM					
Margin	3.05	1.57	2.25	2.25	3.05
Original interest rate spread	0.90	2.12	0.11	1.30	2.03
FICO	703.25	65.61	666.00	712.00	755.00

Table 21 (continued)

	Mean	sd	p25	p50	p75
LTV	72.84	16.05	67.90	79.80	80.00
Loan term	358.47	16.97	360.00	360.00	360.00
2005, ARM					
Margin	3.55	1.74	2.25	2.75	5.30
Original interest rate spread	1.34	2.14	1.10	1.69	2.51
FICO	697.10	67.73	653.00	704.00	751.00
LTV	75.52	12.12	71.40	80.00	80.00
Loan Term	362.63	21.83	360.00	360.00	360.00
2006, ARM					
Margin	3.92	1.78	2.25	3.30	5.78
Original interest rate spread	1.61	2.55	1.26	2.14	3.20
FICO	684.17	67.50	639.00	687.00	735.00
LTV	77.23	11.34	75.00	80.00	80.00
Loan Term	368.99	34.43	360.00	360.00	360.00
2007, ARM					
Margin	3.50	1.59	2.25	2.75	4.85
Original interest rate spread	1.59	2.61	1.29	2.07	3.09
FICO	695.50	64.45	656.00	699.00	745.00
LTV	76.64	11.59	72.60	80.00	80.00
Loan term	367.78	38.23	360.00	360.00	360.00

Original balance is used as the weight. Original interest rate refers to the initial rate of ARM loans. The spread is defined as the difference between the original interest rate and US 7-year Constant Maturity Treasury Rate. Both the margin and the original interest rate spread are measured in percentage points. Loan terms are in calculated by month

ARM, adjustable rate mortgage; *LTV*, loan-to-value ratio

We report hypothesis testing results for Models 1–8 in Table 7 regarding whether the vintage effect and the response to FICO and LTV are statistically different from their counterparts in the previous year. We report the *p*-values from a set of Wald tests, using no time-varying effect in two consecutive years as the null hypothesis in Tables 22, 23 and 24.

Table 22 Wald test of time-varying coefficients, vintage

H_0	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
2001 = 2002	0.00	0.02	0.00	0.00	0.00	0.17	0.00	0.13
2002 = 2003	0.00	0.48	0.11	0.00	0.00	0.00	0.00	0.00
2003 = 2004	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2004 = 2005	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005 = 2006	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
2006 = 2007	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

p-values of the Wald tests from Table 7 are reported. Each row shows the null hypothesis of the test

Table 23 Wald test of time-varying coefficients, FICO

H_0	Model 2	Model 4	Model 6	Model 8
2001*FICO = 2002*FICO	0.00	0.00	0.43	0.19
2002*FICO = 2003*FICO	0.69	0.00	0.00	0.00
2003*FICO = 2004*FICO	0.00	0.60	0.00	0.00
2004*FICO = 2005*FICO	0.76	0.00	0.00	0.00
2005*FICO = 2006*FICO	0.00	0.11	0.00	0.00
2006*FICO = 2007*FICO	0.00	0.00	0.00	0.00

p-values of the Wald tests from Table 7 are reported. Each row shows the null hypothesis of the test

Table 24 Wald test of time-varying coefficients, LTV

H_0	Model 2	Model 4	Model 6	Model 8
2001*LTV = 2002*LTV	0.00	0.00	0.35	0.91
2002*LTV = 2003*LTV	0.00	0.55	0.00	0.27
2003*LTV = 2004*LTV	0.00	0.00	0.02	0.00
2004*LTV = 2005*LTV	0.00	0.13	0.00	0.00
2005*LTV = 2006*LTV	0.10	0.00	0.00	0.00
2006*LTV = 2007*LTV	0.00	0.00	0.00	0.00

p-values of the Wald tests from Table 7 are reported. Each row shows the null hypothesis of the test

Additional Results on Residual Vintage Effects

We report additional results on decomposition of the residual vintage effects by specific types of non-traditional mortgage product. As shown in Fig. 20, we compare the residual vintage effects for loans including interest-only (IO), negative amortization (NegAm) and balloon mortgages. From 2004 to 2007, the residual vintage dummies are uniformly higher for the affordable products (IO, NegAm, balloon) than their counterparts (non-IO, non-NegAm, non-balloon) and are declining for the more traditional product.

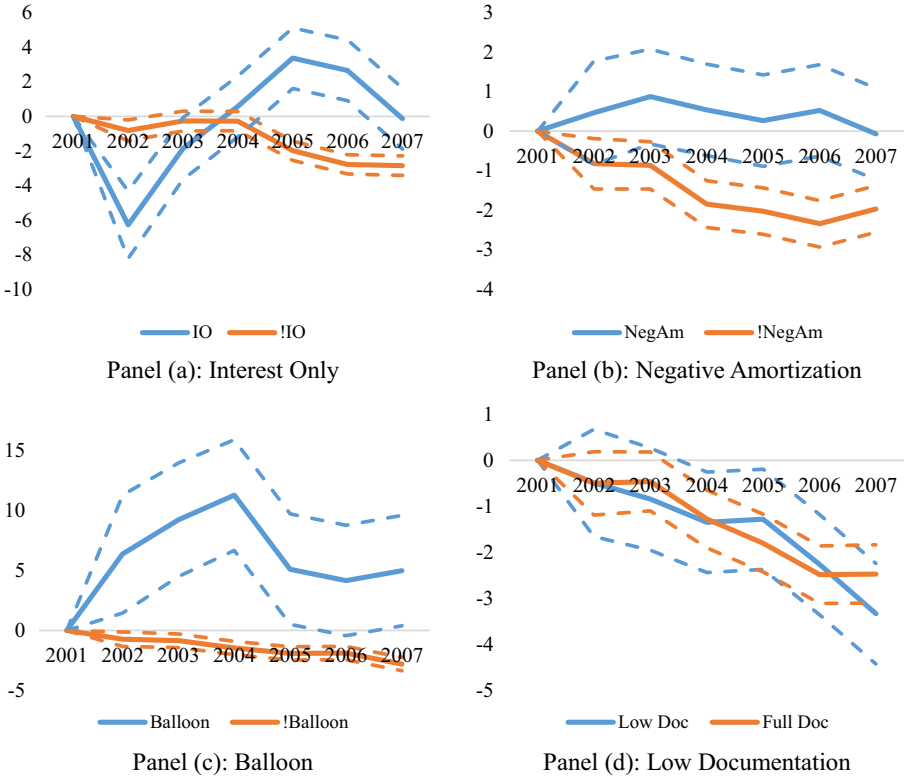


Fig. 20 Regression coefficients on vintage year from margin regression (Model 2) in Table 7, decomposed by loan characteristics (interest only, negative amortization, balloon, low documentation). Margin is measured by percentage point. Exclamation mark (!) refers to negation. 2001 is the base level and normalized to 0 for two comparison groups. The dashed bands represent 95% confidence intervals

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