



Federal Reserve Bank of Chicago

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the U.S. housing boom**

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REVISED
October 5, 2018

WP 2010-12

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Abstract

Borrowers in cities where house prices boomed in the 2000s relied heavily on back-loaded interest-only (IO) mortgages that require borrowers only to pay interest initially. We develop a theory that encompasses common explanations for IO use and show that while they can largely account for the regional variation in IOs, they cannot fully explain the concentration of IOs in booming cities. We propose a new explanation. In our model, uncertain price appreciation and no-recourse lending can lead to speculation financed with backloaded mortgages. We find evidence that IO borrowers behaved in ways consistent with such speculation.

JEL Classification Numbers: E0, O4, R0

Keywords: Housing, house prices, interest-only mortgages, speculation, bubble

*This is a substantial revision to a paper previously circulated under the title “Mortgage choices and housing speculation.” We thank several referees, Sumit Agarwal, Gene Amromin, David Andolfatto, Marco Bassetto, Martin Eichenbaum, Huberto Ennis, Simon Gilchrist, Lars Hansen, Benoit Mojon, Alex Monge, Erwan Quintin, Monika Piazzesi, Ned Prescott, Amit Seru, Amir Sufi, and Randy Wright for helpful comments. We are grateful to Albert Saiz for sharing his geographical data. We also thank Keyoung Lee, Ryan Peters, Shani Schechter and Trevor Serrao for their excellent research assistance. The views expressed herein are the authors’ and do not necessarily represent the views of the Federal Reserve Bank of Chicago or the Federal Reserve System.

1. Introduction

Following the 2000s boom and bust in U.S. housing prices, a large literature emerged which exploited the fact that rapid house price growth was not widespread but rather was concentrated among particular cities. This paper uses the same variation to explore differences in mortgage choices across cities during the housing boom. We are interested in whether cities where house prices surged relied on different types of mortgages than cities where house prices did not surge, and what we can learn from such differences about housing and mortgage markets.

We find that cities with a rapid rise in house prices differ sharply in their use of mortgages with backloaded payments, especially interest-only (IO) mortgages. An IO mortgage obliges borrowers to pay only the interest on their loan for a predetermined period, typically 3, 5, or 10 years. After this period, borrowers must begin to pay both interest and principal, at which point the required monthly payment jumps. We show that the share of IOs among first-lien for-purchase mortgages is a strikingly good predictor of how fast house prices grew in a city. The share of IOs remains highly correlated with rapid house price growth even after we control for other differences in mortgage characteristics across cities, such as the share of subprime loans, the share of mortgages that were privately securitized, or the share of mortgages with high leverage.

To understand this pattern, we develop a theoretical framework that can encompass the various explanations for IO usage that have been proposed in previous work. We show that these explanations indeed can account for why IO mortgages were more popular in some cities than others. However, we also present empirical evidence that shows these factors alone cannot explain why IOs were more common in cities with rapid house price appreciation. After accounting for the variation in IOs due to these factors, we find that the residual variation in the share of IOs remains an economically and statistically significant predictor of rapid appreciation.

In view of this evidence, we use our theoretical framework to develop a novel explanation for the concentration of IOs in cities with rapid price appreciation. We show that if mortgages are not subject to recourse, meaning the lender cannot seize the borrower's income if the

borrower defaults, then agents have an incentive to gamble on house prices by buying a house and defaulting if its price falls. Demand from these speculators pushes house prices above the expected present value of the housing services derived from the marginal house. This overvaluation encourages the use of IOs. These mortgages reward speculators with low initial payments in exchange for encouraging them to sell earlier than they would otherwise, to the benefit of both borrowers and lenders.

Consistent with this explanation, we show that among cities with rapid house price growth, IOs were far more popular in non-recourse states. We also find evidence of individual behavior that is consistent with a speculative motive: Borrowers who used IOs were more likely to sell their houses when prices appreciated and to default when prices fell, than borrowers who took out traditional mortgages. While other explanations for the popularity of IOs cannot fully account for their correlation with house price growth, our explanation offers a possible resolution for why the two are so strongly related. We conclude that the strong correlation of IOs with house price growth could reflect indirect evidence of overvaluation in certain markets, especially in states where regulation encouraged borrowers to speculate.

Our analysis offers some insights for public policy. First, it suggests that policymakers worried about overvalued assets should look not only at whether the growth in their prices is accompanied by a growth in total credit, as [Borio and Lowe \(2002\)](#) and [Schularick and Taylor \(2002\)](#) argue, but also at the type of credit arrangements that accompany this growth. In addition, our model implies that banning IOs would not have eliminated speculation. Overvaluation in our theory encourages the use of IOs rather than emerging as a result of the introduction of IOs. This suggests that allowing for full-recourse mortgages may be more effective at limiting speculation, something we find some support for in the data. We discuss these points further at the conclusion of this paper.

The literature on the boom in U.S. house prices during the 2000s is vast and cannot be easily summarized. We refer to key papers as we present our findings below. The most closely related papers are those that specifically examine IOs, both in the U.S. and elsewhere. [Amromin, Huang, Sialm, and Zhong \(2018\)](#) look at the characteristics of borrowers who took out mortgages with backloaded payments during the housing boom and how these loans performed. We confirm their findings that IOs were more common in cities with rapid house

price growth and more likely to default when prices fell. Several other papers analyze the popularity of IOs both in the U.S. and elsewhere. [Cocco \(2013\)](#) studies the use of IOs in the United Kingdom between 1991 and 2008. He shows that after financial reforms that reduced the use of IOs, these loans were primarily used by borrowers whose income was likely to grow. [Dokko, Keys, and Relihan \(2015\)](#) argue that the widespread use of IOs and other non-traditional mortgages facilitated home purchases in areas where housing became expensive, and [Bäckman and Lutz \(2017\)](#) similarly argue affordability was behind the use of IOs in Denmark. [LaCour-Little and Yang \(2010\)](#) and [Brueckner, Calem, and Nakamura \(2016\)](#) argue that expected future house price growth promoted the use of IOs by borrowers who would otherwise not have borrowed or would have relied on different types of financing. We show that while these various hypotheses can explain why IOs were more popular in some cities than others, they cannot fully explain why IOs were so concentrated in cities with rapid house price growth. In addition, we present theory and evidence to argue that speculation may have also played a role in the appeal of these loans.

2. Evidence on mortgage choices across cities

In this section we document how mortgage choices and house price dynamics varied across cities during the housing boom. As others have already noted, the general rise in house prices was associated with a growing share of so-called alternative mortgage products, specifically those that feature backloaded payments. This includes IOs that only obligate borrowers to pay interest for a predetermined period before they must repay principal, but also a type of adjustable rate mortgage called Option-ARMs that give borrowers the option to pay less than the required interest and thus borrow even more against their house. We document that the use of IOs is strongly and robustly correlated with rapid house price appreciation and that the use of IOs seems to be a better indicator of rapid house price appreciation than other mortgage attributes.

Table 1 reports summary statistics for different types of first-lien mortgages originated for purchase in 2003 and 2006, just before the surge in house prices and around when house prices peaked. Our data come from Black Knight Inc., previously known as the McDash dataset. This dataset is compiled by mortgage servicers and covers 9 out of the top 10 servicers and

Table 1: Mortgages originated for purchase in 2003 and 2006

Type	Year	Share of total	Mean Amount	Share of Mortgage Type			
				Sub- Prime	Private Securitized	Pre Pay Penalty	Investor
IO	2003	2.2	339.2	12.2	71.0	11.9	7.2
	2006	19.0	328.4	9.5	61.4	17.6	11.3
Option ARM	2003	3.1	280.9	10.1	24.0	41.5	3.3
	2006	5.0	341.5	24.5	69.6	65.7	13.5
Fixed (Not backloaded)	2003	73.0	157.0	1.9	12.8	4.9	5.2
	2006	56.0	184.5	2.9	15.7	2.7	7.4
ARM (Not backloaded)	2003	13.1	219.0	11.3	22.4	17.1	5.6
	2006	11.3	230.6	28.5	67.3	28.9	9.1
Other	2003	8.6	146.8	1.0	7.2	1.4	13.5
	2006	8.6	191.3	14.1	35.1	18.8	14.3
All	2003	100.0	172.1	3.5	15.2	7.7	6.1
	2006	100.0	225.5	9.1	35.0	12.8	9.3

Note: Shares are in percentage points and mean amount is in thousands of current dollars.

about 60% of the total mortgage market during the period we study. Our mortgage data is described in more detail in Appendix A.1. Given our interest in backloading, we report statistics for IOs and Option-ARMs and then divide the remaining mortgages into fixed rate, adjustable rate (ARM), and a remaining catch-all “other” category that accounts for less than 9% of the sample.

Table 1 highlights the rapid growth in backloading during this period. In 2003, IOs represented 2.2% of mortgages in our dataset, compared with 19% in 2006. Option-ARMs also grew, but not nearly as dramatically.¹ Although both mortgages featured backloaded payments, they differed in several ways. First, borrowers who took out IOs were primarily prime borrowers with high credit ratings; fewer than 10% were subprime in 2006, compared with 24% of borrowers with Option-ARMs. The two kinds of mortgage also differed in terms of the frequency with which they featured prepayment penalties. Less than 20% of IOs in 2006 featured prepayment penalties, compared with nearly two thirds of Option-ARMs. Option-ARMs were much less likely to be privately securitized than IOs in 2003 but more likely in 2006. Option-ARMs thus seem to have involved borrowers with higher credit risk, more restrictions, and featured a growing tendency toward securitization over time.²

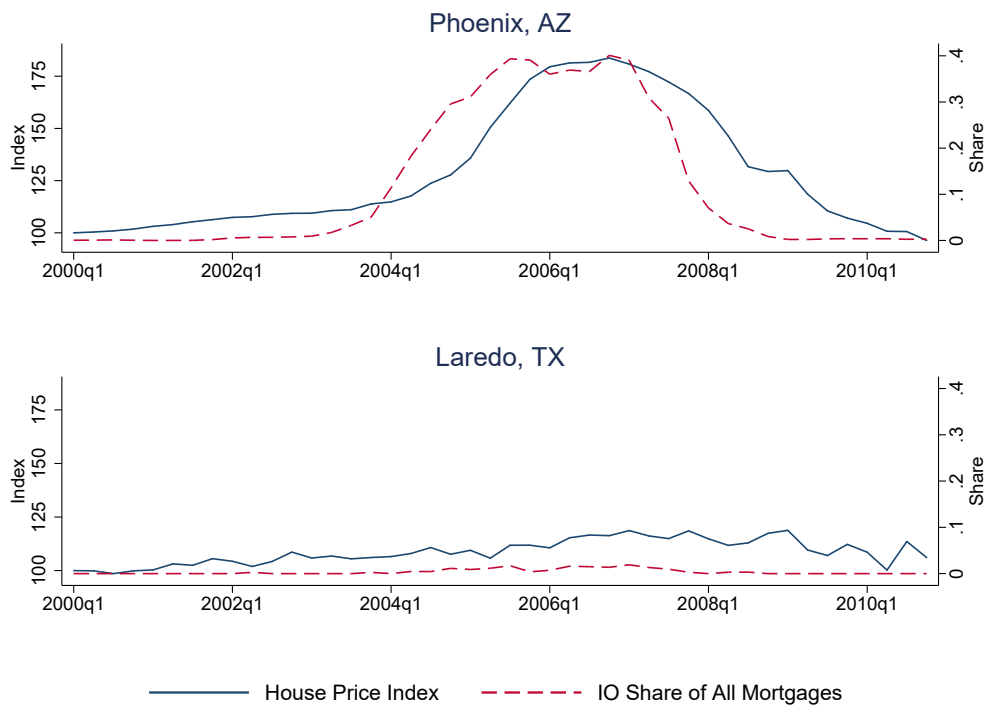
To motivate the connection between IOs and house price growth, consider the two extreme cases of Phoenix, AZ and Laredo, TX. Phoenix ranks relatively high on the index of housing regulation compiled by Gyourko, Saiz, and Summers (2008), and was one of the cities where house prices surged during the boom. Laredo, by contrast, had little regulation and ample space for additional housing. Figure 1 shows for each city and quarter from 2000 to 2010 the share of IOs among all first-lien for-purchase mortgages, along with the Federal Housing Finance Agency price index deflated by the national Consumer Price Index. Our results are similar for other house price indices. Appendix A.2 describes our house price data in more detail. The figure conveys several patterns. First, the share of IOs could be quite high, reaching over 40% of all new mortgages in Phoenix. Second, in Phoenix where house prices grew rapidly, the share of IOs grew with house prices, albeit with a slight lead. Finally, in

¹The fact that some IOs and Option-ARMs were offered in 2003 underscores the fact that, while rare, neither was a novel product that emerged during the housing boom. As an example, Golden West Financial in California began to offer option-ARM mortgages back in 1981.

²See Amromin et al. (2018) for additional comparisons of borrowers with IOs and option-ARMs.

Laredo where house prices never much took off, IOs were essentially non-existent.

Figure 1: House prices and IO mortgages in Phoenix, AZ and Laredo, TX



To document these patterns more broadly, we need to summarize house price growth and IO usage for many cities. For house prices, we identified in each city the quarter between 2003q1 and 2008q4 when real house prices peaked. We then computed the maximum 4-quarter log real price growth between 2003q1 and when house prices peaked in each city. This measure identifies cities where house price growth was both large and concentrated in time. If two cities had the same average growth rate, our measure would rank the one where house prices grew slowly and then surged higher. As such, this measure seems to identify the cities commonly associated with a property boom better than a simple average.³ To measure IO use, we used the maximum IO share among all first-lien for-purchase mortgages per quarter between 2003q1 and 2008q4.⁴

³For example, the two cities with the highest maximum 4-quarter price growth in our data are Las Vegas and Phoenix, respectively, yet these cities rank only 56th and 60th in terms of their average price appreciation from 2003 to their peak, respectively. Although our measure reflects how fast house prices grew during the boom, it is closely correlated with the decline in house prices during the bust as well. The correlation between our measure and the largest 4-quarter price decline between when prices peaked and the end of 2010 is .75.

⁴We also considered the share of IOs weighted by loan size, but the results were similar. Even though the average IO loan in Table 1 is larger, IOs were more common in more expensive cities. Within cities, IOs do not appear to be systematically larger or smaller.

Figure 2: House prices and IO shares in cities with elastic and in-elastic housing supply

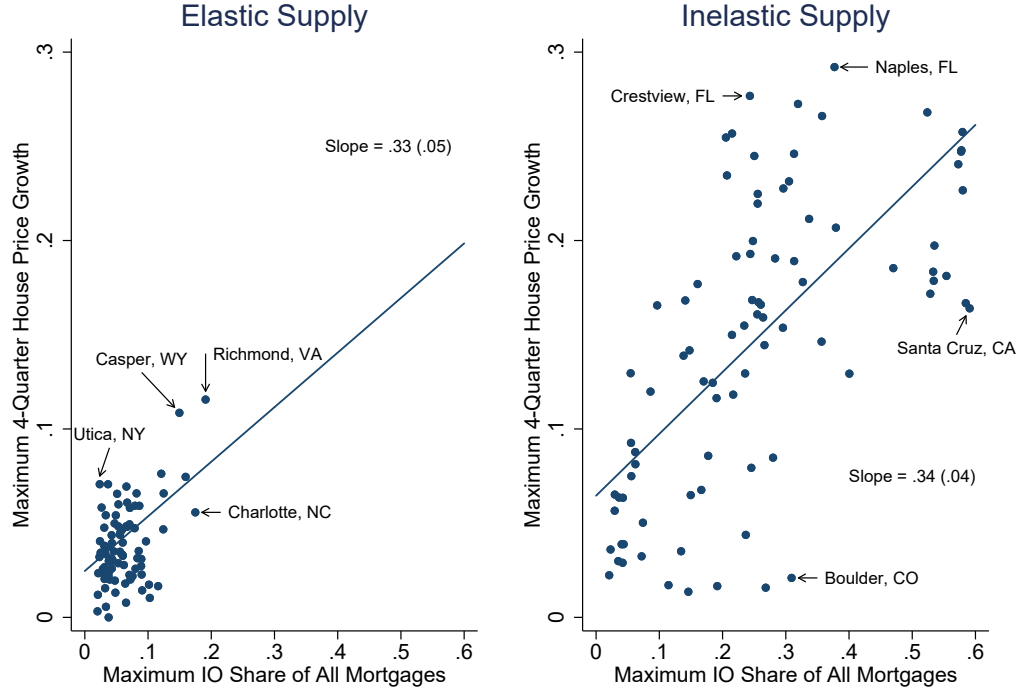


Figure 2 plots our measures of peak house price growth and peak IO use. We divide the sample into cities with relatively elastic housing supply and those with relatively inelastic house supply. The left panel includes only cities that rank in the bottom half of all cities according to the share of undevelopable land compiled by [Saiz \(2010\)](#) and the housing regulation index compiled by [Gyourko et al. \(2008\)](#). The right panel includes only cities that rank in the top half of all cities according to these two rankings. Unsurprisingly, cities with relatively elastic housing supply exhibit low rates of house price appreciation. These cities also tended to avoid IOs; in most, their share did not exceed 10%, and in all, it was below 20%. By contrast, cities with relatively inelastic housing supply exhibit wide variation in both house price appreciation and IO usage, and the two go hand-in-hand. IOs were used mainly where housing supply was inelastic, and then only where prices actually surged.

To assess the relationship between the two variables more rigorously, we regressed the maximum 4-quarter house price appreciation on the maximum share of IOs, both with and without controls. Our data consists of 240 cities for which we have a full set of controls. We stress that our regression is not meant to be interpreted causally. It merely captures

Table 2: IOs are correlated with rapid price appreciation

Independent Variable	Dependent variable	
	House price growth (1)	(2)
IO	0.43*** (0.04)	0.45*** (0.04)
Controls	No	Yes
Adjusted R^2	0.59	0.77
Observations	240	240

Note: OLS regressions of Maximum 4 quarter price appreciation on peak IO share with and without control variables, weighted by number of mortgages. See the text for a description of the variables included in the regressions. Robust standard errors are in parenthesis. The superscripts ***, **, and * denote statistical significance at the .1, 1 and 5 percent levels respectively.

the extent to which knowing the peak share of IO mortgages in a city helps predict what happened to house prices in that city. Our results are in Table 2. The first column uses only data on the peak IO share. The coefficient on the IO share is statistically significant at the 0.1% level. The adjusted R^2 shows that IO usage alone can account for 59% of the variation in house price appreciation. The coefficient of .43 on the IO share implies that the maximum 4-quarter house price appreciation in the city with the largest share of IO mortgages (.59) should exceed house price appreciation in the city with the smallest share (.016) by 28 percentage points. This is comparable to the difference in the maximum 4-quarter house price growth between Phoenix (36%) and Laredo (7.8%) in Figure 1. In the second column, we add various controls that could potentially explain house price growth. Following previous studies, we include log levels and growth rates of population and per capita income, levels and changes of the unemployment rate and the median property tax rate, and the two housing supply variables mentioned above. We describe these and other control variables discussed here in more detail in Appendix A.3. Adding the controls improves the overall fit in terms of adjusted R^2 but hardly affects the coefficient on IO share.⁵ We will refer to the regression in this second column as our *baseline regression*.

We next examine whether it is the share of IOs that helps to predict house price growth

⁵We also added as a control the city-specific house price growth between 1985 and 1989, which has no effect on the coefficient on the peak IO share.

or some other mortgage attribute that is correlated with the use of IOs. We consider the share of loans in each city that were designated as subprime, that were privately securitized one year after origination, that featured a combined loan-to-value ratio (CLTV) in excess of 80%, that had a maturity of more than 30 years, and that were used for investment purposes, meaning the borrower reports they do not plan to reside in the house they buy. For each category, we use the maximum share of each type of mortgage between 2003q1 and 2008q4, except for the share of mortgages with CLTV above 80% where we use the average over the sample period. Table 1 suggests IOs were more likely to be privately securitized or used to finance investment properties than traditional mortgages, and so our measure might be proxying for those attributes. Although IOs were mainly used by prime borrowers, the use of IOs and subprime mortgages could still be correlated across cities, for instance if the IOs in cities with rapid house price growth were disproportionately subprime. We also include the CLTV variable because high leverage is often cited as a driving force of the housing boom. Finally, we include loans with long maturity to make sure that backloading rather than a longer maturity is the relevant feature of the mortgages that were most popular in cities with rapid house price growth.

As is evident from Table 3, none of these other mortgage variables by itself has much of an impact on the ability of the IO share to predict rapid house price growth. The coefficient on IOs remains statistically indistinguishable from our baseline regression in each case and remains highly statistically significant. When we control for all the mortgage variables together in the final column, the coefficient on the share of IOs falls. However, it remains statistically significant at the 5% level. Since the standard error more than doubles when we include all the mortgage variables, we cannot reject the hypothesis that the IO coefficient is the same as in our benchmark regression.

Our key takeaway from Table 3 is that data on IO use can help predict price growth in a city, even conditional on other attributes of mortgages in that city. However, the table offers other insights that are worth noting. The first is that once we control for the IO share in a city, information on the share of subprime mortgages is not statistically significant in predicting house price growth, and its sign is negative. Hence, knowing that a city had a high share of subprime mortgages, all else being equal, tells us its peak rate of house price appreciation

Table 3: Controlling for Other Mortgage Attributes

Independent Variable	Dependent variable: House price growth						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
IO	0.45*** (0.04)	0.46*** (0.04)	0.38*** (0.08)	0.38*** (0.06)	0.35*** (0.08)	0.45*** (0.04)	0.24* (0.11)
Sub prime		-0.14 (0.13)					-0.33 (0.27)
Securitized			0.08 (0.08)				0.08 (0.13)
High CLTV				-0.51* (0.20)			-0.27 (0.28)
Long term					0.40 (0.21)		0.52* (0.22)
Investor						0.44*** (0.13)	0.36** (0.12)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Adjusted R^2	0.77	0.77	0.77	0.78	0.78	0.79	0.81
Observations	240	240	240	240	240	240	240

Note: OLS regressions of Maximum 4 quarter price appreciation on indicated variables, weighted by number of mortgages. See the text for a description of the variables included in the regressions. Robust standard errors are in parenthesis. The superscripts ***, **, and * denote statistical significance at the .1, 1 and 5 percent levels respectively.

was relatively low.⁶ Since our analysis compares house price growth *across* cities, this finding does not contradict previous work that showed that *within* cities, poorer areas with more subprime borrowers tended to be those with the fastest house price appreciation.⁷ We also find that, other things being equal, faster house price appreciation is associated with more private securitization, longer maturities, and more purchases of investment properties. However, these features cannot explain why IOs were so concentrated in cities with house price booms. Interestingly, house price growth was lower in cities where borrowers were highly leveraged, i.e., where a larger share of first-liens involved a CLTV of over 80%. One

⁶We find similar results when we use two alternative measures of subprime mortgages, one based on the share of mortgages in subprime mortgage pools and another based on the share of mortgages issued by lenders identified as subprime lenders. See Appendix A for more details.

⁷See, for example, Mian and Sufi (2009), Landvoigt, Piazzesi, and Schneider (2015) and Guerrieri, Hartley, and Hurst (2013). Beyond prices, work by Chambers, Garriga, and Schlagenhauf (2009) and Corbae and Quintin (2016) finds that subprime lending played an important role in the rise in home ownership and the foreclosure rate when house prices fell.

possibility is that lenders sought to protect themselves in markets with rapid house price growth. We will return to this point in Section 8.

3. Theoretical framework

Now that we have documented a robust association between the use of IOs and rapid house price growth, we turn to developing a theoretical framework that can help us interpret this pattern. In particular, we develop a framework in which house prices are endogenous and agents can choose their mortgages. We then use this framework in subsequent sections to sort through different potential explanations for why backloaded mortgages might be concentrated in cities with sustained house price appreciation. We begin by analyzing a housing market where agents do not need to borrow, in order to focus on house price appreciation, and then introduce borrowing and mortgage choice.

3.1. Setup

Consider a city with a fixed stock of identical houses normalized to 1.⁸ We assume the mass of potential residents in the city exceeds the housing stock. Agents who do not reside in the city must reside in a catch-all outside location. All potential residents are infinitely-lived and discount the future at the same rate β . They derive utility from housing services and from a consumption good. Agents can differ in how they value housing relative to consumption. We further assume agents value housing services differently depending on whether they own or rent their housing, reflecting the benefits of ownership, such as the ability to customize one's dwelling. Regardless of how many houses an agent owns, she can occupy at most one house per period and derives housing services only from that house. As a starting point, we assume all agents have deep pockets and each can afford to buy a house. This allows us to temporarily abstract from mortgages.

Each agent i 's utility is given by

$$\sum_{t=1}^{\infty} \beta^t (c_{it} + v_i h_{it}), \quad (1)$$

⁸Assuming a fixed housing stock is convenient but not essential; we could have allowed for some construction as long as capacity constraints would bind eventually.

where c_{it} denotes agent i 's consumption at date t and h_{it} is an indicator equal to 1 if i resides in the city at date t and zero otherwise. The first thing to note about this specification is that it assumes agents are risk-neutral. We invoke this assumption for its tractability, but comment below on the consequences of allowing for risk-aversion. Second, this specification implies each agent i is willing to trade v_i consumption goods in order to reside in the city for one period. We assume all agents are willing to give up the same amount of consumption goods per period to rent a house, $v_i = (\beta^{-1} - 1) d$, but differ in how much they value owning the house. *Low types* value owning the same as renting, i.e., $v_i = (\beta^{-1} - 1) d$. *High types* value owning their house at $v_i = (\beta^{-1} - 1) D$, with $D > d > 0$.

If the population of potential residents in the city were fixed over time, house prices would be constant over time as well. In particular, if the mass of high types was less than the stock of houses, all high types would own houses in the city. All of the remaining units would be occupied by low types, either as owners or renters. The price of a house would be d , the value of buying a house and then renting it out indefinitely. If the price were lower, demand for housing would exceed its supply. If the price exceeded d , no agent would hold a house not occupied by a high type unless they expected to gain by selling it at an even higher price after discounting. In this case, house prices would have to grow indefinitely at a rate of at least $\beta^{-1} - 1$, which violates the transversality condition that the value of any asset at date t discounted to the present tends to 0 as $t \rightarrow \infty$. If the mass of high types instead exceeded the stock of houses, all housing would be owned and occupied by high types. By the same logic as above, the price of a house would be D . When the population of potential residents is fixed, then, house prices equal the expected present discounted value of the housing services derived from the last house built. We refer to this valuation as the *fundamental value* of a house.

3.2. House Price Appreciation

To generate dynamics in house prices and in particular rising house prices, the population of potential residents must increase over time. This could reflect migration into the city. Alternatively, once we introduce mortgages, it could reflect demand from those previously shut out of credit markets who can now buy homes because of an increase in credit supply,

in line with evidence in [Mian and Sufi \(2009\)](#) and, more recently, [Mian and Sufi \(2018\)](#). For convenience, we focus on the migration analogy.

Suppose that at date 0 the mass of high types is $1 - \phi_0 < 1$, so that there are fewer high types than houses. Migration is modeled as a steady flow of newcomers that continues for a potentially random length of time. A mass $n < \phi_0$ of new potential residents begins to arrive at date 0. As long as n migrants keep arriving, there is a constant probability q per period that the migration wave will end and no more migrants will arrive as of the following period. Among each cohort of arrivals, a fraction $1 - \phi$ are high types and ϕ are low types. When $q = 1$, the migration wave only lasts for one period, and agents know with certainty that the mass of high types will fall short of the housing stock. When $q = 0$, the migration wave will last indefinitely and agents know with certainty that the mass of high types will exceed the mass of houses after $\phi_0 / [(1 - \phi) n]$ periods. For $0 < q < 1$, agents cannot be sure whether the mass of high types will exceed the stock of houses or not. With each new cohort of arrivals, the odds that high types will ultimately exceed the housing stock rises, given that fewer additional periods of migration are needed for high types to outnumber houses. If new buyers stop arriving before $\phi_0 / [(1 - \phi) n]$ periods pass, the mass of high types will forever fall short of the housing stock, and from that point on, house prices would equal d . [Zeira \(1999\)](#) previously showed that this type of uncertainty can generate sustained price booms (or a crash if arrivals stop), an insight [Burnside, Eichenbaum, and Rebelo \(2016\)](#) applied to the housing market.

We assume $\phi_0 / [(1 - \phi) n]$ is not an integer, and define t^* as the smallest integer that exceeds $\phi_0 / [(1 - \phi) n]$. Since at date t^* we know whether or not the mass of high types will exceed the mass of housing, the price of housing from date t^* on equals D if agents arrive through this date and d otherwise. Let p_t denote the price of a house for $t < t^*$, assuming that migrants have kept arriving through date t . At this date, the housing stock still exceeds the number of high types, so some houses must be occupied by low types. Agents always have the option to buy a house at date t , rent it out for $(\beta^{-1} - 1) d$ at date $t + 1$, and then sell it. To prevent excess demand, this strategy cannot offer positive profits, and so the price at date t must satisfy

$$p_t \geq \beta \left[(\beta^{-1} - 1) d + E(p_{t+1}) \right].$$

Appealing to the same transversality argument as before, it follows that the price p_t cannot exceed the right hand side of this inequality without growing faster than the discount rate indefinitely. Hence, we have

$$p_t = (1 - \beta) d + \beta [qd + (1 - q) p_{t+1}] \quad (2)$$

for $t \leq t^*$. This is a difference equation with terminal condition $p_{t^*} = D$.

When $q = 1$, the solution is $p_t = d$ because migration will stop after one period, before the mass of high types exceeds the housing stock. When $q = 0$, the price at each date t is the present discounted value of earning rents $(1 - \beta)d$ until date t^* and generating housing services of $(1 - \beta)D$ from t^* on. House prices rise over time in this case, but only because of discounting. As a result, house price growth, p_{t+1}/p_t , is at most $1/\beta$, the risk-free rate. Intuitively, if house prices grew faster than this, agents could buy houses, rent them out, and earn more than the risk-free rate with certainty. Finally, for $0 < q < 1$, house prices during the migration wave rise with t towards D but collapse to d if the migration wave stops beforehand. In each of these cases, house prices are equal to the fundamental value of a house, just as when the population is fixed.

When $0 < q < 1$, the model allows for sustained house price growth that exceeds the risk-free rate $1/\beta$ as we see in the data. This requires both uncertainty and that high types have a sufficiently larger valuation of houses than low types. In particular, since the price will at most grow from d to D , price appreciation can only exceed $1/\beta$ if $D/d > 1/\beta$. The exact condition is as follows, and is proven in [Appendix B.1](#):

Proposition 1: For $q > 0$, if

$$\frac{D}{d} > 1 + \frac{1 - \beta}{\beta q} \quad (3)$$

then there exists a date $t \leq t^*$ such that if traders arrive through date t , then $p_t/p_{t-1} > 1/\beta$.

As $q \rightarrow 0$, it becomes impossible to satisfy condition (3). Only when $0 < q < 1$, so that it is uncertain whether the mass of high types will exceed the stock of housing, can house prices grow faster than the risk free rate. The price growth with each new arrival offsets the decline in price if new agents fail to arrive. However, even if realized house price growth

can exceed the risk-free rate, our next result shows that the *expected* rate of house price appreciation cannot exceed the risk-free rate $1/\beta$.

Proposition 2: For $t < t^*$, if traders arrive through date t , then $1 < E[p_{t+1}/p_t] < 1/\beta$.

Case, Shiller, and Thompson (2013) find that in cities with past high realized house price growth, survey respondents expect house price appreciation in the future to be far above the risk-free rate. The reason this cannot happen in our model is that we assume agents are risk-neutral, and so the expected return from buying a house cannot exceed the risk-free rate even if the realized return can. However, we could get higher expected house price growth if agents were risk-averse. Suppose we replaced the per period utility flow in (1) with $u(c_{it} + v_i h_{it})$, where $u(\cdot)$ is concave. In Appendix B.2, we confirm this will generate expected house price appreciation above $1/\beta$. Intuitively, risk-averse agents require compensation to hold a house when buying is risky. When the number of high types falls short of the number of houses, the marginal buyer is necessarily taking on risk. We prefer to work with risk-neutral preferences for analytical tractability.⁹

3.3. Incorporating Mortgage Lending

So far, we have assumed all agents have enough resources to buy a house. We now assume some agents are liquidity constrained and must borrow to buy their homes. They borrow from those with deep pockets, who may already own homes themselves. The latter would be willing to lend if the interest rate on loans was sufficiently attractive. We begin with a formulation in which agents are indifferent about how their mortgage payments are structured and then show how a small modification leads to a preference for mortgages in which agents repay their debt as quickly as their income allows. In the sections that follow, we discuss how this preference for fast repayment can relate to the use of backloaded mortgages.

To simplify, assume that there is no outstanding debt at date 0 and only agents who arrive from date 0 on need to borrow. For the cohort that arrives at date τ , let $\{\omega_{it}^\tau\}_{t=\tau}^\infty$

⁹By assuming agents are risk-neutral, we rule out the possibility of shocks to risk-aversion as a source of house price growth. But a shock to risk-aversion would imply either high realized price growth and low expected future price growth or low realized growth and high expected future price growth. By contrast, survey evidence suggests expected future price growth is higher in cities with high realized growth. This suggests price growth is driven by an increase in the amount of risk rather than a change in risk tolerance.

denote their income stream over time. That is, ω_{it}^τ denotes the income that agent i who arrived in the city at date τ earns at date $t \geq \tau$. For now, this income stream is certain. We assume that the present discounted value of income for each cohort is enough to pay for a house, but that agents do not earn enough upon arrival. Specifically,

$$\omega_{it}^\tau = 0 \text{ for } t = \tau; \quad (4)$$

$$\omega_{it}^\tau > (\beta^{-1} - 1) D \text{ for all } t > \tau. \quad (5)$$

Condition (4) implies an agent cannot offer any resources towards buying a house upon arrival. Condition (5) ensures her subsequent income can cover the required interest payment on a loan in the amount of the price of the house that charges the risk-free rate. It implies

$$\sum_{t=\tau+1}^{\infty} \beta^{t-\tau} \omega_{it}^\tau \geq D, \quad (6)$$

which means the present discounted value of an agent's income evaluated at the risk-free rate always exceeds the price of a house.

For now, we assume lenders have full recourse to seize a borrower's income. We will eventually relax this assumption and consider non-recourse mortgages, where lenders can only go after a house but not an agent's income. Full-recourse and condition (6) together imply mortgage lending is risk-free: A lender can always grab the borrower's income and ensure full repayment at the risk-free rate. When loans are risk-free, agents are indifferent about how mortgages payments are structured, since any principal that the borrower fails to pay down today can be saved at the risk-free rate and the interest income can be used to exactly cover the borrower's larger obligation. The riskless case is a natural benchmark because house price dynamics are identical to the case where all home buyers have deep pockets. This is because agents are indifferent between buying a house outright or borrowing to pay for it. There is no additional cost to borrowing to buy a home, so demand for housing will be the same as if agents were not liquidity constrained.

To break the indeterminacy in mortgage choice, loans must be risky for lenders. We therefore introduce a small probability ε per period that a borrower loses her ability to earn

income, earning 0 instead of ω_{it} from then on. In this event, the borrower will be unable to repay her remaining debt. She could sell the house, but the price may fall short of her obligation. We assume that when the borrower cannot pay back her loan, the lender recovers only a fraction $\theta < 1$ of the sale price. Thus, lenders can incur losses. These losses will be greater if migration stops and house prices fall between when the borrower purchased her house and when she lost her ability to earn. To minimize these agency costs, it is optimal for lenders and borrowers to structure mortgages to ensure the fastest possible repayment, which is achieved by devoting all available income to paying down the principal. This decreases the probability that the agent will be unable to repay their obligation by selling the house and, thus, reduces the agency costs of borrowing.¹⁰

The interest rate on the optimal mortgage exceeds the risk-free rate, given there are expected losses from default. Since the interest rate exceeds the risk-free rate, low types will strictly prefer renting to buying. If ε is small enough, high types would still want to buy a house immediately upon arrival, given the utility they get from ownership. We can formalize this by taking the limit as $\varepsilon \rightarrow 0$. In this case, the equilibrium path for house prices converges to the equilibrium price path when there is no risk of default. By taking the limit rather than assuming $\varepsilon = 0$, we select a particular equilibrium in the economy without income risk in which only high types buy houses and use a particular type of mortgage, even though they are indifferent among mortgages when there is no income risk.

The optimal contract features a repayment plan in which households spend all of their income each period. While this is far-fetched, we could assume households face exogenous necessary expenditures as in [Piskorski and Tchistyi \(2011\)](#) and [Mayer, Piskorski, and Tchistyi \(2013\)](#) and reinterpret ω_{it} as discretionary income. That is, agents choose the mortgages that use up all of their discretionary income, even as they continue to consume while paying off their loans. There is some evidence that borrowers do prefer to repay their mortgages quickly. For example, [Dhillon, Shilling, and Sirmans \(1990\)](#) show that mortgages have shorter terms in regions where incomes are high relative to house prices or high in absolute terms.

¹⁰[Piskorski and Tchistyi \(2011\)](#) study optimal contracts in a setting with several common features to ours, and also argue that maximally fast repayment will be optimal while house prices grow. [Hart and Moore \(1994\)](#) also describe a model in which borrowers repay as fast as possible, not because that minimizes transaction costs but because a large outstanding obligation would give the borrower bargaining power over the lender and allow them to reduce their obligation.

The fact that backloaded mortgages were rare in the U.S. except in cities with fast house price growth is also consistent with a desire for faster repayment. Thus, while obviously a simplification, our theory of mortgage choice that implies the fastest repayment possible seems like a reasonable starting point.

3.4. Summary

To recap, our framework features two key elements: persistent uncertainty about long-term housing demand, which allows for the possibility of sustained house price growth in excess of the risk-free rate, and a preference to repay mortgages as fast as possible. In what follows, we use this framework to explore the implications of different, but not mutually exclusive, explanations for the popularity of backloading in cities with high price growth.

4. Income growth with liquidity constraints

The first explanation concerns income growth. In our model, agents want to pay down their mortgages as quickly as possible. Hence, agents whose incomes are set to grow, meaning ω_{it} rises with t , would seek mortgages with rising payments. They prefer these to equally affordable long-maturity mortgages where both initial and subsequent payments are low, because they want their payments to rise as fast as their income allows.¹¹

By this logic, IOs should be more popular in cities where incomes are set to grow more. If cities with high house price growth also experienced higher income growth, this could explain why IOs were concentrated in cities with fast house price growth. Although we model income as exogenous, it is not hard to see why cities with house price growth might also feature rising incomes. Consider a city that experiences stochastic productivity growth. In particular, suppose city-level productivity grows at a constant rate, but that this growth might permanently stop each period with constant probability, just as we assumed about migration. If labor markets in the city are competitive, wages would grow with productivity. Higher wages would attract increasingly more migration, including by some who value home

¹¹Cocco (2013) argues that households with rising incomes may also buy larger homes and would be unable to afford the initial payments if they had to also pay for principal. Our framework abstracts from this channel since we assume all houses are identical.

ownership. This would lead to the kind of house price dynamics we derived above.¹²

We now examine whether IOs were indeed more common in cities where incomes were set to grow faster and whether this can help explain the concentration of IOs in cities with high price growth. Our approach follows Cocco (2013) who uses individual-level data from the UK to see whether income growth is related to a preference for IOs. He proposes two tests. First, he looks at whether households who took out IOs had faster income growth after buying their house than those who took out traditional mortgages. If those households correctly expected faster income growth, we should observe their incomes grew faster on average. Second, he uses information on borrowers from the time of purchase, such as their age and occupation, to forecast their income, and looks at whether households with predictably higher income were more likely to use IOs.

We do not have individual-level data on income. Furthermore, our focus is on patterns across cities rather than households. Therefore, we look at whether IOs were more common in cities with higher realized income growth as well as in cities with an industry mix in 2005, when IO usage was at or near its peak, that predicts higher income growth. For realized income growth, we use the average annual per capita income growth between 2003 and the year in which house prices peaked. To calculate expected income growth, we regressed average annual per capita income growth for the 2001-2005 period on 2001 employment shares and used the coefficients from this regression and employment shares in 2005 to predict income growth for each city over the 2005-2009 period.¹³

The first two columns of Table 4 show how the maximum share of IOs in each city is related to these variables. In line with the model, cities with higher actual income growth and higher expected income growth are associated with a significantly larger IO share. This is consistent with what Cocco (2013) finds using individual-level data on UK borrowers between 2000 and 2008.¹⁴ The last column of Table 4 indicates whether or not the popularity of IOs

¹²Since wage growth is stochastic in this setup, borrowers might have to refinance their mortgages if wage and house price growth stopped earlier than expected. Below we report that borrowers with IOs were less likely to refinance when house prices fell than traditional mortgage borrowers.

¹³See Appendix A for the list of industries included in the regression. The adjusted R^2 of the regression is .77 but it is not a good predictor of income growth over the 2005-2009 period ex-post due to the Great Recession.

¹⁴Cocco (2013) finds expected income growth does not help to explain IO use in the UK in 1991-2000 when IOs were less regulated and more prevalent. By contrast, we find a role for expected income growth in

Table 4: The role of income growth

Independent Variable	Dependent variable		
	IO (1)	IO (2)	Price (3)
IO			0.42*** (0.04)
Expected income growth	1.38*** (0.29)		0.21 (0.11)
Realized income growth		3.81** (1.22)	1.12** (0.42)
Controls	No	No	Yes
Adjusted R^2	0.17	0.08	0.77
Observations	240	240	240

Note: OLS regressions of Maximum 4 quarter price appreciation or maximum IO share on the indicated variables, weighted by number of mortgages. See the text for a description of the variables included in the regressions. Robust standard errors are in parenthesis. The superscripts ***, **, and * denote statistical significance at the .1, 1 and 5 percent levels respectively.

in cities with high realized or expected income growth can explain why IO usage is such a good indicator of house price appreciation. We regress our measure of house price growth on the maximum share of IOs but now include our measures of realized and expected income growth as explanatory variables. Including these variables does nothing to moderate the extent to which a high IO share in a city predicts a faster rate of house price appreciation. Indeed, realized income growth is already one of the explanatory variables in our baseline regression in Table 2. Even though realized and predicted income growth help explain the affinity for IOs in some cities, they cannot explain why IOs were so popular in cities with rapid house price growth.

5. Demographics and heterogeneity in buyer characteristics

The next explanation we consider for why IOs were concentrated in cities with rapid house price growth concerns demographics. Recall that earlier we observed that if households face necessary expenditures, they would choose mortgages that exhaust their disposable income

the US at a time when IOs were prevalent and regulation was relatively lax.

rather than actual income. Suppose households in two cities had the same income growth, but households in one city were younger and had larger necessary expenditures due to young children. Then we would expect to see more backloaded mortgages in the city with younger households. The logic is the same as in the previous section on income growth.

[Chiang and Sa-Aadu \(2014\)](#) argue that higher mobility might also give rise to a preference for backloaded mortgages. Their argument relies on agents being risk-averse, and so does not emerge in our benchmark setup. Still, we can use our framework to provide a sense of their argument. Consider two agents who both value home ownership, but one intends to live in the city forever while the other knows they will have to leave after one period. Both value owning their house while living in the city, and so both may opt to buy housing. The agent that intends to remain in the city will not be concerned about the possibility that house prices will collapse, since she will not sell her house. By contrast, the agent who has to move will be affected by house prices. The more the borrower repays after one period, the larger her equity stake in the house and, thus, the more exposed she is to house price risk. Under some conditions, the mover will prefer to minimize her exposure to this risk and not repay any principal.

These considerations suggest that IOs should be more popular in cities where households are younger and more mobile. Moreover, if cities with younger and more mobile populations are associated with faster house price appreciation, this logic could explain why IOs were concentrated in cities with rising house prices. To explore this possibility, we compiled data on the median age for each city from the 2000 Census and on each city’s average gross migration rate between 2000 and 2005. The latter is defined each year as half the sum of a city’s in-migration and out-migration over the year divided by its beginning of year population. The first two columns of [Table 5](#) show how the maximum share of IOs in each city is related to these measures. Cities whose residents are younger are more likely to use IOs, although the coefficient is not statistically significant. IOs were also more common in cities with higher turnover rates, a pattern that is statistically significant at the 5% level.

Of course, there can be a host of other demographic differences across cities that will be related to mortgage choice, e.g., patience and risk aversion. While it is impossible to control for all of these factors, to the extent that populations are more homogeneous within states

Table 5: The role of heterogenous buyer characteristics

Independent Variable	Dependent variable			
	IO (1)	IO (2)	IO (3)	Price (4)
IO				0.26*** (0.05)
Median age	-0.01 (0.01)		-0.00 (0.00)	0.00 (0.00)
Gross migration		2.97* (1.24)	-0.54 (0.44)	0.84** (0.30)
Controls	No	No	No	Yes
State fixed effects	No	No	Yes	Yes
Adjusted R^2	0.00	0.06	0.84	0.94
Observations	240	240	240	240

Note: OLS regressions of Maximum 4 quarter price appreciation or maximum IO share on the indicated variables, weighted by number of mortgages. See the text for a description of the variables included in the regressions. Robust standard errors are in parenthesis. The superscripts ***, **, and * denote statistical significance at the .1, 1 and 5 percent levels respectively.

than across states, we can try to control for these differences using state fixed effects. Of course, this controls for differences across states beyond just demographics. We include state fixed effects in column (3) of Table 5. The adjusted R^2 rises to 84% in this case, suggesting differences in IO usage are largely between rather than within states. Adding state fixed effects eliminates a role for gross mobility: For cities within the same state, the coefficient on gross migration turns negative and statistically insignificant. This suggests gross migration is correlated with some other factor associated with IO usage that varies across states.

In the last column of Table 5, we examine whether the popularity of IOs in cities with low median age, high gross migration, or in particular states explains why IO usage is such a good indicator of house price appreciation. Controlling for these variables, particularly state fixed effects, does reduce the coefficient on the share of IOs relative to the baseline regression in Table 2. However, the coefficient remains highly statistically significant. When we restrict attention to variation among cities within the same state, a high IO share remains a strong indicator of rapid price appreciation, even after we control for that city's median age and gross migration rate. Neither age, mobility, nor variables that vary across states explain why

IOs were so popular in cities with rapid house price growth.

6. Affordability

The explanations we have considered so far focus on features that make IOs appealing to certain borrowers but are not directly related to house prices. While these explanations can account for why IOs were more popular in some cities than others, they cannot explain why IOs were more popular in cities with rapid house price growth. We now turn to an explanation that relates directly to house prices, namely that borrowers used IOs for affordability reasons as housing became more expensive.

We can use our model to illustrate this argument. Suppose income is constant across all cohorts and over time, i.e., $\omega_{it}^\tau = \omega$ for all i , τ and $t > \tau$. Since we assume agents have no resources when they arrive, they must borrow the full value of the house upon their arrival, p_τ . The fastest repayment path would oblige borrowers to pay ω until they pay off their loan. That is, with constant incomes, mortgages will feature fixed payments for a set maturity. To determine this maturity, note that as $\varepsilon \rightarrow 0$, the interest rate tends to $1/\beta$. Using the familiar formula for the payment on a fixed-payment mortgage of loan size p_τ , maturity T , and gross interest rate $1/\beta$, the maturity T consistent with a payment of ω must solve

$$\frac{(\beta^{-1} - 1)}{1 - \beta^T} p_\tau = \omega.$$

If p_τ rises relative to ω , borrowers would be forced to take out longer maturity loans, given it takes more time for the same fixed payment to pay off a larger loan at the same interest rate. This logic implies borrowers should extend the maturity of their loans rather than shift towards backloaded mortgages. Indeed, Table 3 shows that mortgages with maturities of over 30 years were more common in cities with rapid house price growth. However, there may be a limit on how much lenders are willing to extend the maturity on their loans. Although IO mortgages offer only a temporary reprieve from affordability concerns, this relief can be extended through refinancing. In this way, households could approximate a long maturity mortgage by repeatedly refinancing a backloaded mortgage. In some markets, therefore, IOs may have been the best available contract that constrained borrowers had access to.

To the extent that affordability generates a preference for IOs, we should observe that IOs were more popular in cities where house prices were high relative to income. This is not the same as our finding that IOs were common in cities with rapid house price growth. Although rapid house price growth will be associated with higher prices, initial house prices in these cities may have been low. Furthermore, incomes could have grown alongside house prices. Cities with rapid house price growth thus need not be those where housing was least affordable. Indeed, our findings below suggest they were not.

Table 6: The role of affordability

Independent Variable	Dependent variable	
	IO (1)	Price (2)
IO		0.40*** (0.10)
Peak house price to income ratio	0.06*** (0.00)	0.00 (0.01)
Controls	No	Yes
Adjusted R^2	0.79	0.77
Observations	240	240

Note: OLS regressions of Maximum 4 quarter price appreciation or maximum IO share on the indicated variables, weighted by number of mortgages. See the text for a description of the variables included in the regressions. Robust standard errors are in parenthesis. The superscripts ***, **, and * denote statistical significance at the .1, 1 and 5 percent levels respectively.

To explore the role of affordability, we compiled Census Bureau data on median house prices in 2000 by city. We then used our house price index to arrive at a level of house prices for each city and year in our sample. We divided this price by the corresponding per capita nominal income, and took the maximum value of this ratio between 2003 and 2008 to arrive at a peak ratio of price to income for each city. The first column in Table 6 shows that the maximum share of IOs in each city is highly related to this affordability measure. This one variable alone accounts for almost 80% of the cross-city variation in IO use. There is a clear preference for IOs in cities where median house prices were high relative to average income per capita.¹⁵ At the same time, the second column in Table 6 shows that adding this

¹⁵Bäckman and Lutz (2017) also argue that affordability plays an essential role in explaining the popularity of IOs in Denmark, although their analysis does not use regional variation as we do.

affordability measure to the benchmark regression has little impact on the extent to which the IO share predicts the rate of house price growth. Accounting directly for affordability cannot explain the concentration of IOs in cities with rapid house price growth.

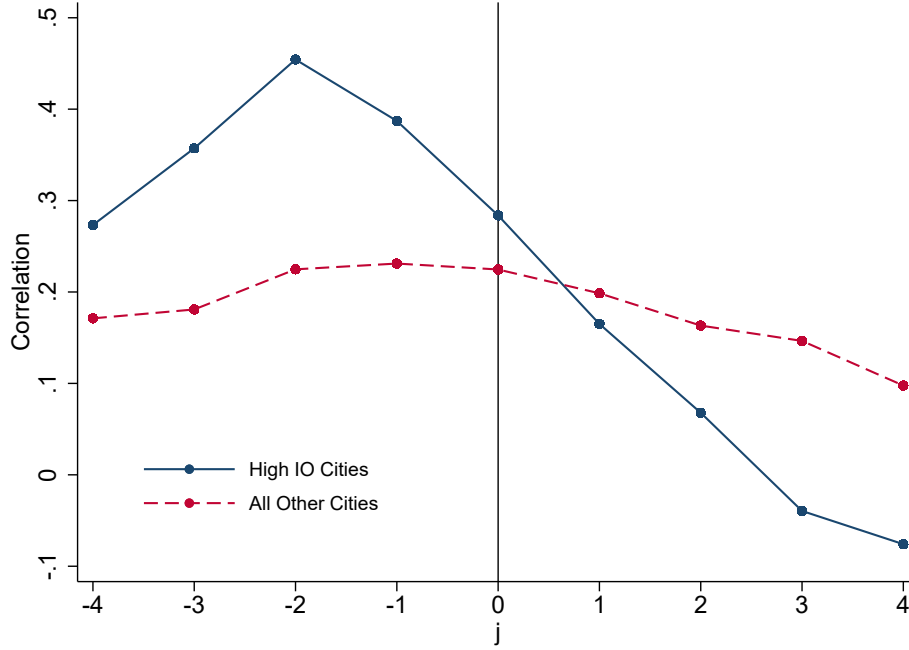
Our model suggests another way to explore affordability. Since households in our model want to pay down their debt as quickly as possible, they should be reluctant to use backloaded mortgages until prices rise. That is, house price growth should lead the use of IOs. We now investigate this prediction. Since we do not require the same set of city-level covariates to do so, we expand the sample to all 376 cities for which we have both house price and mortgage data. In addition, we use data for 2000q1 through 2006q4 to focus on the period of rising house prices.

Figure 3 shows the correlation between the change in log IO shares in quarter $t + j$ with the change in log real house prices at quarter t . For the 35 cities with the highest peak IO shares, each of which was at least 33%, the growth in IOs clearly leads the growth in house prices. In the remaining cities, the growth in house prices is positively correlated with both past and future growth in the IO share, although the peak correlation is still between the change in IOs and subsequent change in prices.

Table 7 reports Granger causality regressions of log house price growth, Δhp , on log IO share growth, Δio . The first column reports the results for all 376 cities. Here, we find that house price growth Granger causes growth in IOs. The effect is statistically significant but small. The second column reports results for the 35 cities with the highest peak IO shares. For these cities we cannot reject the hypothesis of no Granger causality, and the point estimate is negative. Once again, although we find evidence consistent with the affordability hypothesis in the broad cross section, cities with the highest IO share, and that also exhibit among the fastest house price growth, do not conform with the affordability hypothesis. In those cities, the use of IOs did not occur following house price appreciation, and if anything seems to pre-date house price growth, as indeed we saw for Phoenix in Figure 1.¹⁶

¹⁶Dokko et al. (2015) also compare the timing of house price growth and mortgage choice. They look for break-points in house price growth to identify the start of the boom in house prices for each city, and find that different types of alternative mortgage products rose after this date. However, for IOs their data shows an increase that predates the boom, in line with what we find.

Figure 3: Growth of IO share leads house price growth



Note: Figure displays cross correlations of change in log IO share at quarter $t + j$ with change in log real house price at quarter t . High IO cities are those cities with a maximum share of IOs in excess of $1/3$.

Table 7: House prices do not predict IOs in high IO cities

	All Cities (1)	High IO Cities (2)
Sum of Δio coefficients	0.58*** (0.03)	0.61*** (0.06)
Sum of Δhp coefficients	0.09* (0.04)	-0.11 (0.10)
F-statistic for exclusion of Δhp coefficients (p -value)	3.43 (0.02)	1.83 (0.14)
Adjusted R^2	0.40	0.46
Lags	3	3
Number of cities	376	35
Number of quarters	24	24

Note: Panel regressions of log changes in IO share (Δio) on its own lags and lags of log changes in house prices (Δhp). The number of lags is the lowest value such that we could not reject the hypothesis of no-autocorrelation in the residuals up to that value using the [Arellano and Bond \(1991\)](#) test. Standard errors are robust to correlation in the residuals across cities. The superscripts ***, **, and * denote statistical significance at the .1, 1 and 5 percent levels respectively.

7. Expected house price appreciation

In the previous section, we explored the possibility that past house price growth led households to use IOs for reasons of affordability. Survey evidence indicates that respondents in cities with past house price growth also expected high future house price growth. These expectations of future growth might explain the popularity of IOs independently of past realized growth. Now, we consider this possibility.

The argument for why expected future house price growth might encourage IOs is laid out in [LaCour-Little and Yang \(2010\)](#) and [Brueckner et al. \(2016\)](#). These papers assume borrowers want to postpone repaying their debt, in contrast to our setup. We can capture this scenario in our framework as well by assuming that some high types are impatient, i.e., their discount rate is below β . These impatient agents will want to delay their repayment and enjoy earlier consumption. Lenders will charge them higher interest rates to cover the risk that the borrower might lose her earning ability before repaying her obligation, which will limit the extent to which these impatient agents will be able to backload. The two papers argue that, all else being equal, higher expected house price growth should mitigate default concerns and make backloading more affordable.

A challenge for this logic is that when prices are endogenous, something in the environment must change for expected house price growth to increase. In our model, rapid house price growth is associated with greater risk: Realized house price growth can be high only when there is also a risk that house prices can fall. While it is true that a rise in house prices will mitigate losses from potential default, a fall in prices will exacerbate them. The possibility of house price growth in the good state of the world may lead lenders to charge less in interest for backloaded mortgages, but lenders have to benefit sufficiently when house prices rise to cover their expected losses if house prices fall. Therefore, the relationship between expected house price growth and the affordability of backloaded mortgages is ambiguous.

In principle, lenders can charge an interest rate on backloaded loans that is both high enough to compensate for taking on the risk of a fall in house prices and lower than what they would charge if house prices were constant. However, this creates a situation in which borrowers have an incentive to refinance their loan if house prices rise. Indeed, our model

suggests agents should be able to do this. House prices rise only if migration continues, and each arrival lowers the odds that house prices will fall. Since this makes lending less risky, new lenders would be willing to refinance existing loans at a lower rate. Thus, lenders would be unwilling to make backloaded loans in the first place. As [Gorton \(2008\)](#) and [Mayer et al. \(2013\)](#) discuss, these incentives can be overcome by stipulating a prepayment penalty on borrowers that will either prevent them from refinancing or provide lenders with fee income if borrowers do refinance. In practice, interest rates on backloaded mortgages were not much higher than on non-backloaded mortgages. Hence, lenders would have needed to profit from prepayment fees. [Gorton \(2008\)](#) argues that this was precisely the business model lenders were using.

Before we examine whether this story can explain the use of IOs in cities with rapid house price growth, we first confirm that backloaded mortgages were indeed used in this way. If lenders coupled backloaded mortgages with prepayment penalties to collect fees when house prices appreciate, we should observe that such mortgages were more likely to refinance than other types of mortgages, even though borrowers would have incurred a penalty for doing so. Our Black Knight dataset does not allow us to test this prediction since it only indicates whether a loan was paid off early and not the manner of the payoff. To distinguish between sales and refinancing, we merged these data with recorder of deeds data on individual properties from DataQuick.

As we saw in [Table 1](#), relatively few IOs featured prepayment penalties, although they were prevalent among Option-ARMs. This pattern is consistent with the above story, since if impatient households want to backload, they will prefer an Option-ARM that can be even more backloaded than an IO. Therefore, we consider both types of mortgage. In particular, we compare the propensity to refinance of borrowers with these mortgages with those who used non-backloaded ARMs. As their name suggests, Option-ARMs involve adjustable rates, and almost all of the IOs in our sample did too. This makes non-backloaded ARMs a natural comparison group. The incentives to refinance fixed-rate mortgages are different and so these mortgages are not directly comparable.

We estimate the propensity of borrowers with first-lien IO, Option-ARM and all other ARM mortgages originated for purchase in 2005 and 2006 to refinance by the end of 2010. In

estimating the propensity to refinance, we follow [Elul, Souleles, Chomsisengphet, Glennon, and Hunt \(2010\)](#) in using a linear probability model with a 6th order polynomial in the number of months since origination as a substitute for a proportional hazard model. In each case, the dependent variable is a dummy equal to 1 if a mortgage refinances in that quarter and 0 otherwise. A mortgage remains in our sample until it is either repaid or the borrower defaults. We use a large number of mortgage characteristics as controls, as well as city-quarter fixed effects that allow for cyclical patterns and time-invariant characteristics to differ across cities. The mortgage characteristics we use as controls are described in [Appendix A.1](#). Given these controls, in any given quarter we are comparing mortgages with similar characteristics that originated in the same city at different dates and thus face different house price appreciation, after controlling for the typical tendency to refinance as a function of time since origination. Our focus is the impact of the cumulative price change since origination and its interaction with mortgage type. We define $\Delta^+ \text{House Price} \equiv \max(\Delta \text{House Price}, 0)$ as the change in house prices if they increase relative to the origination date and $\Delta^- \text{House Price} \equiv -\min(\Delta \text{House Price}, 0)$ as the change in house prices if they decrease relative to the origination date. The interaction between price changes and mortgage type tells us whether a particular type of mortgage was more or less likely to refinance when house prices appreciated or depreciated.

Columns (1) and (4) in [Table 8](#) show that all of the borrowers in our sample were more likely to refinance when house prices rose, since the coefficients on $\Delta^+ \text{House Price}$ are positive. They were also less likely to refinance when house prices fell, given the coefficients on $\Delta^- \text{House Price}$ are positive. Furthermore, the coefficients on the interaction terms suggests that refinancing was more responsive to house prices among borrowers with IOs, and even more responsive among borrowers with Option-ARMs. However, the greater price sensitivity of refinancing among borrowers with Option-ARMs appears to be related to the fact that these mortgages disproportionately imposed prepayment penalties (PPP). When we compare IOs and Option-ARMs that either both stipulate prepayment penalties, in columns (2) and (5), or both omit these penalties, in columns (3) and (6), the two mortgages look similar. Refinancing is most responsive to house prices among borrowers with backloaded mortgages with prepayment penalties and is least responsive among borrowers with backloaded mort-

Table 8: Propensity of backloaded mortgages to refinance

Independent Variable	Mortgage Type					
	IO			Option-ARM		
	All (1)	PPP (2)	No PPP (3)	All (4)	PPP (5)	No PPP (6)
Type	-0.003*** (0.000)	-0.017*** (0.001)	-0.001 (0.000)	-0.003*** (0.001)	-0.007*** (0.001)	0.004*** (0.001)
Δ^+ House Price	0.065*** (0.003)	0.044*** (0.004)	0.069*** (0.003)	0.029*** (0.004)	0.023*** (0.004)	0.043*** (0.004)
Δ^- House Price	-0.032*** (0.005)	-0.029*** (0.006)	-0.027*** (0.005)	-0.010 (0.006)	-0.006 (0.006)	-0.019** (0.006)
Type $\times \Delta^+$ House Price	0.020*** (0.003)	0.180*** (0.005)	-0.015*** (0.003)	0.072*** (0.003)	0.119*** (0.004)	-0.014** (0.005)
Type $\times \Delta^-$ House Price	-0.007* (0.003)	0.013** (0.004)	-0.012*** (0.003)	-0.016*** (0.003)	-0.013*** (0.004)	-0.019*** (0.004)
Adjusted R^2	0.02	0.02	0.01	0.02	0.02	0.01
Observations	1,321,531	722,083	1,175,742	1,025,361	863,907	737,748
Mortgages	102,642	59,633	89,238	84,201	70,557	59,873

Note: Linear probability models of the propensity of holders of first lien mortgages originated for purchase in 2005 and 2006 to subsequently refinance by quarter before the end of 2010. The OLS regressions include controls for mortgage characteristics (see Appendix A.1), a 6th order polynomial in months since origination and city-quarter dummies. ' Δ^+ House Price' denotes the maximum of zero and the cumulative price change since origination. ' Δ^- House Price' denotes the absolute value of the minimum of zero and the cumulative price change since origination. 'Type' is a dummy indicating whether the mortgage is of the type indicated in the column header, where 'PPP' or 'no PPP' indicates whether or not the mortgage has a pre-payment penalty. In addition to IOs (Option-ARMs) the regressions include all ARM originations excluding Option-ARMs (IOs). Estimates are based on a random 15% sample of our merged Black-Knight/DataQuick dataset. The superscripts ***, **, and * denote statistical significance at the .1, .1 and 5 percent levels respectively.

gages without prepayment penalties. Thus, refinancing behavior is consistent with the notion that backloaded mortgages were structured in a way that allowed backloading in exchange for rewarding lenders with fee income when house prices grew.¹⁷

Table 9: The role of pre-payment penalties and option-ARMs

Independent Variable	Dependent variable		
	IO (1)	IO (2)	Price (3)
IO			0.45*** (0.07)
PPP	1.22*** (0.17)		-0.01 (0.15)
Option-ARM		1.75*** (0.16)	-0.00 (0.24)
Controls	No	No	Yes
Adjusted R^2	0.47	0.70	0.77
Observations	240	240	240

Note: OLS regressions of Maximum 4 quarter price appreciation or maximum IO share on the indicated variables, weighted by number of mortgages. ‘PPP’ and ‘Option ARM’ denote maximum shares of mortgages with these attributes. See the text for a description of the variables included in the regressions. Robust standard errors are in parenthesis. The superscripts ***, **, and * denote statistical significance at the .1, 1 and 5 percent levels respectively.

We now examine whether this mechanism can explain the concentration of IOs in cities with rapid house price growth. Although IOs did not disproportionately feature prepayment penalties, it could be that IOs with prepayment penalties were precisely those that prevailed in cities with rapid house price growth. If this were true, controlling for the share of mortgages with prepayment penalties or for other indicators of the presence of impatient borrowers, such as the share of Option-ARMs, would reduce the predictive content of IOs for house price growth. Columns (1) and (2) of Table 9 show that the peak IO share in each city is in fact strongly related to the share of mortgages with prepayment penalties and the share of mortgages that are Option-ARMs. However, the last column of Table 9 shows that adding these variables to the baseline regression has virtually no impact on how the IO share

¹⁷Note that not all borrowers who faced a prepayment penalty would have incurred these penalties when they refinanced. In practice, prepayment penalties were typically in place for only a fixed period, and some of those who refinanced waited until after the penalty expired to refinance.

predicts house price growth. While we find evidence consistent with expected price growth facilitating backloading, it does not appear to be the reason IOs were so popular in cities with rapid house price appreciation.

8. Speculative home buyers

A recurring theme of our analysis so far is that each of the proposed explanations for the popularity of IOs can account for some of the variation in IO use across cities but not why IOs were particularly common in cities with rapid house price growth. We now confirm that this remains true when we consider these explanations jointly.

The first two columns of Table 10 report coefficients from regressions of the peak IO share in each city on all of the covariates we have considered so far, both with and without state fixed effects. Even without state fixed effects, the adjusted R^2 is 84%. Adding state fixed effects increases the adjusted R^2 to 94%. The variables associated with the explanations we have considered so far can thus explain nearly all of the variation in IOs across cities. But the last two columns of Table 10 show that when we include both the predicted IO share from these regressions and the residual IO share, both are significant in explaining maximum 4-quarter house price growth. The variation in IOs that cannot be accounted for by these factors remains strongly and significantly predictive of rapid house price growth.¹⁸ Something else must explain why IOs were so popular in these cities.

We now offer a potential explanation for the residual popularity of IOs. The explanations for the popularity of IOs we have considered so far involve people who value housing only for the services it provides. In terms of our model, only high types buy houses; low types are indifferent about home ownership and are put off by the transaction costs associated with borrowing. However, low types might buy houses if we modified our model to allow for non-recourse mortgages, i.e., loans in which the lender cannot seize the borrower's income in case of default. In practice, several US states restricted mortgages to be non-recourse, and even in states that allowed recourse it was not always exercised.

The reason non-recourse mortgages induce low types to buy housing is that they make

¹⁸We also added state fixed effects to the last two columns in Table 10. The coefficients on residual IO share remain highly significant.

Table 10: Comparing Predicted and Residual IO Share

Independent Variable	Dependent variable			
	IO (1)	IO (2)	Price (3)	Price (4)
Predicted IO share			0.46*** (0.04)	0.47*** (0.04)
Residual IO share			0.39** (0.12)	0.29** (0.09)
Expected income growth	0.49* (0.22)	0.08 (0.11)		
Realized income growth	0.12 (0.60)	0.87* (0.39)		
Median age	-0.00 (0.00)	-0.00 (0.00)		
Gross migration	0.43 (0.44)	-0.73* (0.37)		
Peak house price to income ratio	0.04*** (0.01)	0.04*** (0.00)		
PPP	-0.01 (0.18)	-0.08 (0.15)		
Option ARM	0.46 (0.26)	0.44** (0.16)		
Controls	No	No	Yes	Yes
State fixed effects	No	Yes	No	No
Adjusted R^2	0.84	0.94	0.77	0.77
Observations	240	240	240	240

Note: OLS regressions of Maximum 4 quarter price appreciation or maximum IO share on the indicated variables, weighted by number of mortgages. ‘Predicted IO share’ and ‘Residual IO share’ in columns (3) and (4) correspond to the fitted values and residuals from the IO regressions in columns (1) and (2), respectively. See the text for a description of the variables included in the regressions. Robust standard errors are in parenthesis. The superscripts ***, **, and * denote statistical significance at the .1, 1 and 5 percent levels respectively.

strategic default profitable. If lenders have recourse, assumption (6) implies default is pointless for an agent with income, since they will be forced to pay out of their income anyway. But if lenders have no recourse, low types can buy housing and gamble at their lender’s expense: They can buy a house in the hope that more migrants come and prices rise, but

then default and walk away if migrants fail to arrive.¹⁹

We defer the formal analysis of non-recourse mortgages to Appendix B.3. Here, we just sketch the equilibrium that emerges. During the migration wave, both high and low types buy houses. High types buy because they value home ownership. Low types buy because they want to speculate. As in Allen and Gale (2000), demand by speculators gives rise to a *bubble* in housing, by which we mean that house prices exceed the fundamental value of a house, which in Section 3.1 we defined as the expected present value of the housing services derived from the last house built. Intuitively, low types value houses not because of the services they yield or rents they can charge, but because of the profits they can earn if migrants come. This means they value houses only for their upside potential, and would buy a house even if its price exceeds its fundamental value. The option value of default drives a wedge between price and fundamental value. Although lenders want to avoid lending to low types, if the two types have the same income and buy the same housing, they will not be able to tell them apart. If lenders want to lend to high types, they must also lend to low types. Thus, absent recourse, during the migration wave we should see an increased share in home buying by short-term buyers who buy only with the intent to sell to others. This is consistent with evidence in DeFusco, Nathanson, and Zwick (2018) and Mian and Sufi (2018) that much of the increase in sales volume in housing markets with large house price increases during the housing boom was due to “flippers” or buyers who sold their property within two years of their initial purchase.

Appendix B.3 also shows that lenders offer two types of contracts during the migration wave. The contract that low types take is designed to encourage them to sell the asset early. The intuition for this, as observed in Barlevy (2014), is that since houses are overvalued, lenders and borrowers would be jointly better off selling the house rather than holding on to it. One way to accomplish this is to encourage the borrower to repay his loan quickly, e.g., via a balloon payment. Since the balloon constrains the borrower more than a traditional mortgage, it must offer other features to draw speculators. Speculators can be compensated by offering them low initial payments. Low initial payments effectively act as a bribe to induce

¹⁹High types may also default if house prices fall and buy a house at a lower price. In practice default restricts future access to credit, at least for some time, and they may not be able to buy another house once they default. We assume high types never default.

them to sell quickly. In practice, IOs may have provided enough incentive for borrowers to sell the house before their payments reset even without an explicit balloon payment. Balloon mortgages are rare in our data, and may have been discouraged by anti-predatory lending laws in some states.²⁰ Since high types still prefer to repay their debt as fast as possible, lenders will also offer mortgages that appeal to these types. In equilibrium, low types are indifferent between the two mortgages and would use the faster repayment mortgage if that were the only one offered. Since lenders cannot avoid low types and prefer that they use IOs, they will offer both types of mortgages and not just those with fast repayment.

If this mechanism is at work in our data and can help explain why IOs were concentrated in cities with rapid house price growth, then we should observe IOs and high price growth be more pronounced in non-recourse areas. Our framework suggests another test. Lenders offer IOs to encourage speculators to sell houses faster than they would with traditional mortgages. We cannot observe how borrowers who use IOs would have behaved if they took out traditional mortgages. However, in the model those who choose traditional mortgages are not speculators, and so they should be even less likely to sell. Thus, we should see that borrowers with IOs are more likely to sell their homes than borrowers with traditional mortgages when house prices rise. By the same logic, when house prices fall, we should see that borrowers with IOs are more likely to default than borrowers with traditional mortgages. We now investigate these implications of speculation in our model.

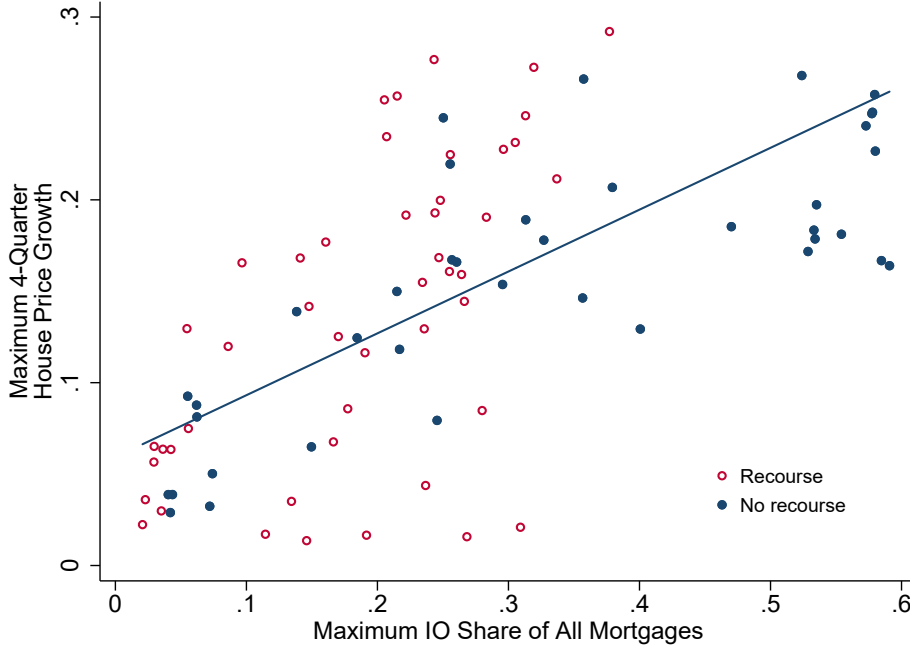
Figure 4 reproduces the scatter plot of maximum IO share and maximum 4-quarter price appreciation for cities with inelastic housing supply from Figure 2, but now distinguishes between cities in states with recourse mortgages (open circles) and those with non-recourse (solid circles), using the classification in Ghent and Kudlyak (2011).²¹ As is clear from the figure, the cities with the highest IO shares are those in states without recourse. More generally, among cities with a sufficiently high rate of house price appreciation, the maximum IO share is considerably higher in non-recourse states than in recourse states. This is consistent

²⁰Ideally, lenders would like to pay speculators not to buy a house at all rather than lend to them and then encourage them to sell. However, offering to pay people not to borrow may attract many more agents into the market. We assume this is the case, so that in equilibrium both types borrow and buy homes.

²¹As Ghent and Kudlyak (2011) point out, California requires that the original loan against a property be non-recourse, but does not require a refinanced mortgage to be non-recourse. Since we focus on for-purchase mortgages, we follow them and classify the California loans in our sample as non-recourse.

with the view that non-recourse encourages the use of IOs.

Figure 4: Impact of recourse in cities with in-elastic housing supply



Next, we consider our model’s predictions for the propensity of borrowers with IO mortgages to sell and default. To do so, we exploit the same individual mortgage data, sample period, and regression framework we used to examine refinancing behavior in Table 8. Since our prediction concerns the behavior of borrowers with IOs compared with borrowers with traditional mortgages, we use all non-backloaded mortgages as our comparison group. Table 11 shows our results. We find that the propensity of a borrower to sell his house in response to a price increase is twice as large for borrowers with IOs than for borrowers with traditional mortgages. Likewise, the propensity of a borrower to default in response to a price fall is twice as large for borrowers with IOs.

Our findings for default rates are consistent with results in [LaCour-Little and Yang \(2010\)](#), [Brueckner et al. \(2016\)](#), and [Amromin et al. \(2018\)](#). However, none of these papers consider differences in the propensity of IOs to sell in response to a house price increase. Interestingly, [Cocco \(2013\)](#) finds that households who took out IOs in the UK were less likely to move than other type of borrowers, even between 1991 and 2000 when IOs were relatively unregulated. By contrast, in the US these borrowers seem less attached to their homes, at

least when house prices rise.²²

Table 11: Propensity of IOs to Sell or Default

Independent Variable	Dependent Variable	
	Sale	Default
IO	0.000* (0.000)	0.005*** (0.000)
Δ^+ House Price	0.018*** (0.001)	-0.013*** (0.001)
Δ^- House Price	-0.007*** (0.001)	0.068*** (0.002)
$\text{IO} \times \Delta^+$ House Price	0.019*** (0.001)	-0.012*** (0.002)
$\text{IO} \times \Delta^-$ House Price	-0.002 (0.001)	0.072*** (0.001)
Adjusted R^2	0.01	0.03
Observations	3,888,597	3,888,597
Mortgages	262,718	262,718

Note: Linear probability models of propensity of holders of first lien mortgages originated for purchase in 2005 and 2006 to subsequently sell or default before the end of 2010. Other than the type of transaction being considered the regressions are formulated as in Table 8. See that table for definitions of the regressors. The regressions include all mortgages except for option-ARMs. Estimates are based on a random 15% sample of our merged Black-Knight/DataQuick dataset. The superscripts ***, **, and * denote statistical significance at the .1, 1 and 5 percent levels respectively.

The evidence we have presented is therefore consistent with the possibility that it is the use of IOs by speculators that accounts for their residual popularity in cities with rapid house price growth. While it is not surprising that borrowers in non-recourse states would be willing to take out such loans in order to gamble on house prices, the question is why lenders would be willing to extend such loans given the risk. Our model suggests lenders might have been willing to go along because they wanted to encourage borrowers to sell more quickly. Is there any support for this view? Although lenders may not have realized that house prices were set to fall broadly and significantly, recall that IOs were largely confined

²²For robustness, we considered restricting our comparison group to only non-backloaded ARMs. Borrowers with IOs remain more likely to default in response to a fall in house prices. However the propensity to sell in response to a house price increase is sensitive to including hybrid ARMs known as 2/28s and 3/27s in which the interest rate is fixed for 2 or 3 years before the first reset. These mortgages should have appealed to borrowers who expected to move within 2 to 3 years and who would have otherwise taken out fixed rate loans. When we excluded these hybrid loans, IOs were more likely to sell in response to a rise in house prices.

to certain geographic areas. And in those areas, there was certainly concern about the possibility of a bubble. For example, Fed Chairman Alan Greenspan testified on June 9, 2005, that “although a ‘bubble’ in home prices for the nation as a whole does not appear likely, there do appear to be, at a minimum, signs of froth in some local markets where home prices seem to have risen to unsustainable levels.”²³ Mian and Sufi (2018) provide evidence that survey respondents in cities where house prices surged were more likely to report that buying a house at that time was not a good idea, either because house prices were too high or because they expected house prices to fall. In addition, even before the crisis, IOs attracted attention as a vehicle for speculators. For example, Williams (2006) reports that some of the borrowers attracted to alternative mortgage products included those who bought homes for investment purposes. There are other signs that lenders in hot markets were wary. For example, recall that in Table 3 we found that cities where house prices surged had less rather than more leverage. Ono, Uchida, Udell, and Uesugi (2013) similarly find that when land prices surged in Japan, down payment requirements for business loans increased. It seems reasonable that lenders would have taken other precautions, including encouraging faster resale, in these markets.

Finally, Minsky (1982) also observed that speculative booms seem to be associated with loans in which borrowers need only pay the interest on what they borrow. His interpretation of this pattern is quite different from ours. Rather than using these loans to encourage speculators to sell, he argued lenders get swept up in the euphoria surrounding speculative manias and speculate themselves. Our dataset does not allow us to divine the motivations of lenders. But according to both views, these contracts are a sign of speculation. And some of the policy implications we discuss in the conclusion would be the same under either view.

9. Conclusion

In this paper, we argue that one of the distinguishing features of U.S. cities where house prices surged during the 2000s was their use of interest-only mortgages. When we sort through the various explanations that have been advanced for why these mortgages might have been

²³Speech available online at <http://www.federalreserve.gov/boarddocs/testimony/2005/200506092/default.htm>.

popular, we find they can explain a large fraction of the variation in IOs across cities but not the entirety of their popularity in cities with rapid house price growth. We then argue theoretically that if lenders have limited recourse, IOs may arise because of speculation. In line with this explanation, we find that cities with similar house price growth featured more IOs in non-recourse states, and that borrowers who used IOs behaved in ways that are consistent with speculation. This suggests that the popularity of IOs in cities with rapid house price growth may be indicative of speculative demand for housing in those cities.

We conclude with some policy implications of our findings. The first is that policymakers who are worried about speculative bubbles when asset prices rise should look not only at whether the growth in asset prices is accompanied by greater credit, as is often emphasized, but also at the *type* of credit used to finance asset purchases. However, our results do not mean that evidence of a rising share of IOs should always be viewed as alarming, nor do they mean that policymakers looking at mortgage choice should only focus on IOs. Our analysis suggests the popularity of IOs can be explained by a variety of factors that have nothing to do with speculation. As such, a policymaker confronted with a rise in IOs should look further to determine whether their use can be explained by any of these other factors. For example, a policymaker should look at whether IOs are increasing in areas without recourse, whether their rise begins before or after house prices rise, and whether their use increases in areas with high house prices relative to income or areas with growing industries. This should help to determine whether the increase in IOs reflects speculation or more benign forces. We also want to stress that in our model, when speculation occurs, lenders offer mortgages that reward speculators for effectively committing themselves to selling the assets they buy faster than they would otherwise. IO contracts are one way of achieving this, but there are others. One example is mortgages with balloon payments that offer lower interest rates. Any feature that creates an incentive for borrowers to sell their asset earlier rather than later could, in principle, achieve the same outcome.

A second implication of our analysis is that banning IOs may not preclude speculation. In our model, for example, it would not curb speculation. Uncertain migration leads to risky house price growth that encourages agents to speculate and to use IOs. It is not the introduction of IOs that induces agents to speculate. Rather, lenders want to limit

their risk exposure and prefer mortgages that create incentives for borrowers to sell early. However, even if lenders offer IOs because they get swept up in a speculative fervor, as [Minsky \(1982\)](#) argues, eliminating these loans would not prevent or forestall the underlying euphoria. Instead, our results suggest that allowing for full recourse loans may be more effective in curbing speculation, since among the cities with high price appreciation, it was in states without recourse where IO use, and presumably speculation, was greatest. This argument is also consistent with findings by [Bäckman and Lutz \(2017\)](#) that in Denmark, where loans are subject to recourse, IOs were highly popular yet do not appear to have been used for speculation, and default rates remained low even when house prices fell. Of course, determining whether allowing for recourse is desirable requires a more general theory than the one we have developed here, one that can speak to both the costs and benefits of limiting recourse.

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A. Data

This appendix provides a detailed description of our data construction.

A.1. Mortgage Data

Our mortgage data is primarily drawn from Black Knight Financial Services Services (BK) mortgage performance data, formerly known as McDash. We describe this data below, as well as other mortgage datasets we either merged with or used to supplement the BK data.

A.1.1. Black Knight Financial Services Mortgage Data (McDash)

The BK data is reported at a monthly frequency, based on data provided by various mortgage servicers on the loans they service. From these monthly reports we construct a single “static” file that includes a single record on each loan ever observed based on information on the loan at origination as well as over the life of the loan. We use this information to calculate the mortgage shares as well as identify the types of the loans included in the linear probability regressions.

An issue with BK is that different servicers begin to report data to BK at different dates. When a servicer joins, they typically only report on their outstanding loans. Mortgages that originated before the servicer began reporting to BK are therefore disclosed if they survive into the reporting period. This leads to survivorship bias in the data. Some have argued for only using data from 2005 on, once a significant number of servicers already began to report their data. For our purposes, this would throw out the most relevant period in which IOs and prices were rising. An alternative approach argues for only including mortgages that are reported in BK shortly after their origination date, and throwing out any mortgage the servicer reports but which we know was originated some time ago. This would preserve mortgages issued before 2005 by servicers who had already contracted with BK. This approach is used, for example, by [Foote, Gerardi, Goette, and Willen \(2010\)](#). The problem with this approach is that it may lead to biases due to heterogeneity across servicers. As mentioned by [Williams \(2006\)](#) (p11), IOs were highly concentrated, with a small number of lenders accounting for the bulk of such mortgages. If such servicers happened to report late to BK, as indeed appears to be the case, restricting attention to mortgages that are reported soon after origination would make it seem as if IOs surged later than they actually did. For this reason, we chose to include all mortgages in BK, regardless of whether they were originated before the servicer began to report to BK.

To get a sense of the extent of survivorship bias in the data we use, we compared mortgage counts in BK to those reported under the Home Mortgage Disclosure Act (HMDA). The latter dataset is reported to regulators in real time and should be free of any survivorship bias. Up until early 2003, the ratio of the number of mortgages we observe in BK to the number of mortgages reported in HMDA exhibits a rising trend, suggesting data in the early years of our sample undercounts mortgages. But we see no clear trends from 2003 on; the share of all for-purchase mortgages in BK to all mortgages in HMDA in 2003q1 (62%) is no

different from 2010q4 (61%). This is consistent with the fact that interest rates bottomed out in 2003, so refinancing should be a lesser issue for mortgages originating after this date.

We also looked for evidence of survivorship bias in IOs. In particular, we looked at the number of IOs in the LoanPerformance (LP) database that we discuss below, which provides data on all mortgages securitized in private-label mortgages pools of nonprime mortgages. Again, this data should not be subject to survivorship bias. When we compare the ratio of the number of IO mortgages in LP to the number of IO mortgages in the BK data that are identified as privately securitized, we find no trend between from 2003q1 on, with the ratio fairly stable around 60%. This suggests survivorship bias is not an important problem from 2003 on. Moreover, since backloaded mortgages are more likely to pay early, to the extent there is survivorship bias, it should cause our series on the use of such mortgage to lag true usage earlier in our sample. As such, it should make the use of IOs appear to lag house price growth, biasing against our findings.

Using the BK data, we identify first-lien (LIEN_TYPE), for-purchase (PURPOSE_TYPE_LP) mortgages originating in each CBSA and each quarter (ORIG_DT) and classify them using criteria we describe below. Mortgages in the data are reported by zip code, which we then aggregate to the CBSA level. For zip codes that do not fall entirely within a single CBSA we assigned all mortgages for that zip code to the CBSA with the largest share of houses for that zip code.

It is possible to double count mortgages if a mortgage was transferred between servicers in BK, i.e. if one servicer sold the mortgage to another. To avoid this, we matched all loans in our data on zip code, origination amount, appraisal amount, interest type, subprime status, level of documentation, the identity of the private mortgage insurance provider if relevant, payment frequency, indexed interest rate, balloon payment indicator, term, indicators for VA or FHA loans, margin rate, and an indicator of whether the loan was for purchase or refinance, treating missing and unknown values as wildcards. Loans that matched on all these criteria were treated as duplicates, and we kept only one record in such cases.

To identify IO mortgages, we use the IO flag (IO_FLG) reported by BK, which in turn is based on payment frequency type (PMT_FREQ_TYPE). We do not include any VA and FHA residential loans in our count of IOs. Since BK only started classifying loans as IO in 2005, for mortgages that originated and terminated before 2005, we looked at whether the initial scheduled payment in the first month (MTH_PI_PAY_AMT) was equal to the interest rate on the mortgage that month (CUR_INT_RATE) times the initial amount of the loan (ORIG_AMT). Using mortgages that survive past 2005 revealed that in a small but non-negligible number of IOs, the scheduled payment was not equal to but exactly twice the monthly interest rate times the initial loan amount, perhaps because of a quirk in the reporting convention of some servicers. Experimenting with the post-2005 data led us to classify as IOs those mortgages where the ratio of the scheduled payment to the interest rate times original loan amount was in either $[0.985, 1.0006]$ or $[1.97, 2.0012]$. This approach correctly identified 98.5% of IOs while falsely identifying about 1.5% of non-IOs as IO in the post-2005 period.

Subprime mortgages in BK are mortgages whose mortgage type (MORT_TYPE) is coded as Grade 'B' or 'C', following [Foote et al. \(2010\)](#). For robustness, we experimented with two other measures of the share of subprime mortgages using other datasets. One is the ratio of the number of mortgages in subprime mortgage pools for each CBSA and quarter reported

by LoanPerformance (see description below) to the number of mortgages in each CBSA and quarter. The other is the share of mortgages in HMDA in each CBSA and quarter that were originated by lenders identified in HMDA as subprime lenders.

Other mortgage classifications are constructed as follows. Long-term mortgages are mortgages with an amortization term (TERM_NMON) strictly greater than 360 months. Option-ARM mortgages are mortgages with code OPTIONARM_FLG set to ‘Yes’. Fixed rate and ARM mortgages are identified with code PROD_TYPE set to ‘10’ and ‘20’ respectively. All mortgages that have a known type (PROD_TYPE not ‘Unknown’ or missing) but are not classified above as IO, Option-ARM, Fixed or ARM are classified as ‘Other’.

To assign whether a mortgage is privately securitized we make use of the fact that while it takes some time for mortgages to be either privately securitized or purchased by government sponsored enterprises (GSEs), the turnover rate for these mortgages once they end up securitized is quite low. For mortgages in which the INVESTOR_TYPE field is available 12 months after origination, we assign the investor type to the value of INVESTOR_TYPE for this month. However, investor type may be unavailable 12 months after origination: the mortgage may be terminated before 12 months, the mortgage may have lasted longer than 12 months but the servicer did not report the loan to BK until at least 12 months after the loan originated, or because the data may be missing. For mortgages where investor type is not available 12 months after origination, we proceed as follows. If the loan was first reported to BK at least 7 months or more after origination, we use the first investor type reported. This would give us the investor type at least 6 months after origination, which tends to be highly persistent over the life of the mortgages in our sample. If the loan was first reported to BK within 6 months of origination, we use the last investor type reported if the loan terminated before 12 months. Otherwise, we treat investor type as missing. Privately securitized mortgages have an investor type which corresponds to a privately securitized mortgage pool. GSE mortgages are mortgages whose investor type is GNMA, FNMA, or FHLMC. Portfolio mortgages are those with a portfolio investor type.

Mortgages are classified as having a pre-payment penalty if the PP_PEN_FLG is set to ‘Yes’. In cases where this variable is ‘Unknown’ or missing we exclude the loan from the sample in our regressions that distinguish between loans with and without pre-payment penalties.

Hybrid ARMs (2/28, 3/27) are determined using the FIRST_RATE_NMON variable which states the number of months the initial interest rate is fixed. We exclude these ARMs by excluding mortgages with FIRST_RATE_NMON greater than or equal to 24 and less than or equal to 36 months.

We also identify mortgages for properties that are reported by the borrower as purchased for investment rather than with the intent of the owner to occupy the property. Such mortgages are identified with an occupancy status (OCCUPANCY_TYPE) given as “Non-owner/Investment.”

To be included in the counts in Table 1 a loan must be known to be sub-prime, privately securitized, have a pre-payment penalty and be taken out by an owner that does not intend to occupy the property.

For the share variables, we computed the maximum share of each mortgage type among all first-lien for-purchase mortgages in each CBSA between 2003q1 and 2008q4 that have known attributes.

All of these maximum shares are computed at the CBSA level, and used in our cross-sectional analysis where the primary unit is a CBSA. When we look at the propensity of different mortgages to default or terminate due to either a sale or a refinance, we instead analyze data at the level of individual mortgages. Here, we use the set of controls suggested by [Elul et al. \(2010\)](#) to analyze the propensity for default. These variables include the first observed interest rate (CUR_INT_RATE from the loan’s first appearance in the dynamic data), FICO score (FICO_ORIG) and its square, the log of the original loan amount (ORIG_AMT), two indicators of private mortgage insurance, one by loan type (LOAN_TYPE) and the other as reported by the mortgage insurance company (PMI_CODE_TYPE), privately securitized flag as defined above, GSE investor type as defined above, FHA loan type flag (LOAN_TYPE), condo property type flag (PROP_TYPE), a flag for low/no documentation (DOCUMENT_TYPE), flags for 15-year and 40-year mortgages (identified from the variable TERM_NMON), and the loan to value ratio (LTV_RATIO).

A.1.2. Recorder of Deeds data (DataQuick)

The BK mortgage data described above does not include information on the nature of property transactions. As a result, we cannot distinguish between a mortgage that paid early because the property was sold and one where the mortgage paid early because the loan was refinanced. To distinguish between the two, we matched the mortgage data from BK with data from the DataQuick (DQ) dataset on recorder of deeds, which was subsequently purchased by and renamed as CoreLogic. The DQ dataset contains information on transactions by property. To the extent we can match this to the BK dataset, we can determine how the mortgage paid off early.²⁴

To match records between BK and DQ, we initially matched records using static data available from the time that the mortgage is originated. Broadly, we matched records with the same zip code and closing date in which the price of the house (house value) and the amount of the loan (origination amount) were the same in the two databases. We also required the mortgage be identified as for-purchase in both datasets. We could also identify from the DQ data whether a mortgage has a fixed or adjustable rate schedule. However, there was some evidence that this variable was not always recorded correctly in DQ, and so we also matched mortgages that matched along other characteristics regardless of whether they were classified as fixed or adjustable in DQ.

We considered several different criteria for matching. If at least one of these criteria were satisfied we considered the mortgage matched. While BK records a single origination date for each mortgage, DQ lists two dates for each mortgage, the filing date when in the mortgage was filed with the recorder of deeds and the transfer date in which ownership was transferred. From our match, it appears that the filing date typically occurs on or before the origination date, while the transfer date typically occurs on or after the origination date. Our strictest criterion matched records in BK and DQ from the same zip code with identical house values and origination amounts and where the origination date exactly matches either the filing date or transfer date. Another criterion we used required that either the filing date fell between 21 days before to 7 days after the origination date or the transfer date fell

²⁴A complete documentation of our matching algorithm is available upon request.

either between 5 days before the origination date to 21 days after the origination date or else between 30 and 37 days after the origination date. Since some servicers in BK reported the closing date for a mortgage as the 1st of the month in which the mortgage originated regardless of the true origination date, we considered mortgages where the house value and origination amount matched exactly, and either the filing date or transfer date occurred in the same month as in DQ, but the mortgage was listed as originating on the 1st of the month in BK. For the same date criteria, we also considered mortgages where the origination amount matched exactly, where the house value in BK and DQ were within \$1000 of one another, or where the origination amount matched exactly while the house value in DQ was listed as \$0, or where the house value in both datasets matched exactly but the origination amount was equal to \$0 in DQ. We found that variation in origination amount tended to produce many false matches, i.e. this variable was recorded with more care than house value. Across all criteria and cities, we were able to match about 40% of the mortgages in BK to DQ rising to about 50% of the mortgages from 2009.

Once loans from the two datasets have been matched on these static criteria, we took all the mortgages that we matched and were identified in BK that were paid in full and which included a paid-in-full date in BK. For these mortgages, we looked at whether there was either a sale or refinance on the same property in DQ anywhere from 30 days before to 30 days after the paid-in-full date. To avoid spurious matches in which the transaction in DQ that occurred within 30 days of the paid-in-full date in BK did not represent a sale or refinance of the original mortgage we matched between BK and DQ, we required that either the name on the original mortgage transaction was the same as the one when the mortgage terminated, or else that there was a chain of transactions in which the name on the original mortgage transferred ownership with no money changing hands to another entity, who transferred ownership with no money changing hands to some other entity, and so on, until the name associated with the final transaction. Among mortgages in which another transaction was recorded in DQ within 30 days of the paid-in-full date in BK, we could connect the name on the original mortgage to the final transaction, and identify the later transaction as either a sale or refinance, in 95% of the cases.

Our sample for the linear probability regressions included all BQ mortgages that were of a given type and for which we had a full set of controls that never pay in full or default plus all mortgages that meet this criteria but do pay in full and we are able to match with DQ and determine whether the property was sold or the mortgage was refinanced.

A.1.3. Other Mortgage Data

We also used data from the LoanPerformance (LP) data to supplement the BK data. The LP data reports mortgages in private-label mortgages pools of nonprime mortgages, meaning Alt-A and subprime mortgages. We used this data in two ways. First, we used it together with HMDA data to obtain an alternative estimate of the share of mortgages in each CBSA and each quarter that were subprime. Second, in contrast to the BK data, the LP data matches all liens against a property and reports the combined loan-to-value (CLTV) ratio for each property, including second liens. This allowed us to compute the fraction of first-lien for-purchase mortgages in LP in which the cumulative LTV of all loans at origination exceeded 80%.

We used HMDA data to construct another measure of the share of subprime mortgages in a city. In particular we used the share of loans issued by known subprime lenders as classified by HMDA.

A.2. House Price Data

Our primary measure of house price appreciation is the Federal Housing Finance Agency (FHFA) house price index, computed at the level of Core-based Statistical Areas (CBSAs) as defined in 2009 by the Office of Management and Budget. CBSAs with populations greater than 2.5 million are divided into Metropolitan Divisions.²⁵ For these CBSAs, FHFA reports data for each Division rather than the CBSA as a whole. We follow this convention throughout, using Metropolitan Divisions in lieu of the CBSA where applicable.

For robustness, we also constructed CBSA-level price indices based on the CoreLogic House Price Index and the Zillow Home Value Index. CoreLogic reports prices at the same CBSA level as FHFA. Zillow was available to us at the CBSA level as well, but for fewer cities.

For each price series, we construct our price variables as follows. We first convert each house price series into a real series by dividing through by the Consumer Price Index for urban consumers as reported by the Bureau of Labor Statistics.

For each CBSA, we identify the quarter within the period 2003q1-2008q4 in which the real price peaks in each respective CBSA. If we denote the price in a given city at date t by p_t , then the quarter in which price peaks is just

$$t^* = \arg \max_t \{p_t\}_{t=2003q1}^{2008q4}$$

Our summary measure of real house price appreciation in each city is the highest 4-quarter growth in real house prices between $t = 2003q1$ and t^* , i.e.

$$\text{Max4QGrowth} = \max \{\ln(p_t/p_{t-4})\}_{t=2003q1}^{t^*}$$

A.3. Other Data

We compiled additional cross-sectional data on CBSAs on non-mortgage data from various sources. Where necessary, we used translation tables from MABLE/Geocorr2K, the Geographic Correspondence Engine based on the 2000 Census from the Missouri Census Data Center, to convert data to the CBSA level. For each variable and except where noted below, we calculated both the average level and the average change between 2003q1 and the quarter in which real houses peak in that CBSA (or 2003 and the year in which the peak occurs for annual variables).

Population for each CBSA comes from the Census Bureau's Current Population Reports, P-60, at an annual frequency. All of our averages use log average annual population. We

²⁵The CBSAs that are divided into Metropolitan Divisions are: Boston-Cambridge-Quincy, MA-NH; Chicago-Naperville-Joliet, IL-IN-WI; Dallas-Fort Worth- Arlington, TX; Detroit-Warren-Livonia, MI; Los Angeles-Long Beach-Santa Ana, CA; Miami-Fort Lauderdale-Miami Beach, FL; New York-Northern New Jersey-Long Island, NY-NJ-PA; Philadelphia-Camden-Wilmington, PA-NJ-DE-MD; San Francisco-Oakland-Fremont, CA; Seattle-Tacoma-Bellevue, WA; and Washington-Arlington-Alexandria, DC-VA-MD-WV.

work with log population in 1000s.

Real per capita personal income for each CBSA comes from the Bureau of Economic Analysis at an annual frequency. We work with log real per capita personal income in 1000s of 2005 dollars.

Unemployment rates for each CBSA come from the Bureau of Labor Statistics (BLS), and are available at a monthly frequency. We aggregate up to a quarterly frequency by averaging the months in each quarter and then compute quarterly averages. We work with unemployment rates in percentage points. Property tax rates for each CBSA are constructed from data in the American Community Survey (ACS) from the US Census Bureau, using an extract request from IPUMS USA (available at <http://usa.ipums.org>). In particular, we took data on annual property taxes paid (PROPTX99) and house value (VALUEH). Since PROPTX99 is a categorical variable, we set the tax amount to the midpoint of each respective range. Thus, a tax in the range of \$7,001-\$8,000 is coded as \$7,500. Anything above \$10,000 is coded as \$10,000. For each household, we estimate the tax rate as the ratio of taxes paid divided by the value of the house. We then compute the median tax rate across all households in the survey in each CBSA in each year. Focusing on the median mitigates the top-coding in taxes paid. Since the ACS has its own definition of metro areas, we need to use the IPUMS metro area-to-MSA/PMSA translation table and then use a MSA/PMSA-to-CBSA table from GEOCORR2K. We also weight households by household weight (HHWT). The number of cities for which the property tax variable is available is substantially lower in 2003 compared to other survey years. For this reason we use tax rates in percentage points in 2000 for the level and changes between tax rates in percentage points between 2000 and the year of the peak real house price.

Industry employment shares for the years 1995 and 2000 use county-level employment counts from the Bureau of Economic Analysis, available an annual frequency. The county-level data are aggregated into CBSAs using Office of Management and Budget’s 2009 definitions, then we calculate each industry’s share of total nonfarm employment. The industries include NAICS two digit codes 11, 21, 22, 23, 31-33, 42, 44-45, 48-49, 51, 52, 53, 54, 55, 56, 61, 62, 71, 72, 81, 92.

The gross migration data is from [Davis, Fisher, and Veracierto \(2015\)](#) who construct city-level in- and out-migration rates based on the IRS county-to-county migration matrices.

The maximum price-to-income ratio variable was calculated as follows. First we obtain the median level of house prices in each US county in 2000 from the Census Bureau. These medians are calculated by the Census Bureau using the micro data from the 2000 Decennial Census of Housing.²⁶ The median house price for a city is identified as the housing-unit-share-weighted sum of median prices in the counties comprising a city where the housing units are based on the same underlying 2000 Decennial Census of Housing and are calculated by the Census Bureau. We identify median house prices for each year after 2000 by applying the growth of the FHFA price index for that city to the 2000 median price over the relevant period. The price-to-income ratio in each year is obtained by dividing the nominal price by nominal per capita personal income for the city described above. The maximum price-to-income ratio is the maximum value of this last variable over the 2003-2008 period.

The median age variable is population-weighted average of median ages in each county

²⁶These house prices are self reported and correspond to single family homes only.

comprising a city. The median ages and population by county are obtained from the Census Bureau and are based on the 2000 Decennial Census.

B. Theory

B.1. Proofs of Propositions

Proof of Proposition 1: Rearranging (2) implies

$$\frac{p_{t+1}}{p_t} = \frac{1}{\beta(1-q)} \left(1 - \frac{d}{p_t}\right) + \frac{d}{p_t}$$

This expression will exceed $1/\beta$ if

$$\frac{1}{\beta(1-q)} \left(1 - \frac{d}{p_t}\right) + \frac{d}{p_t} > \frac{1}{\beta}$$

or, upon rearranging,

$$\frac{d}{p_t} < \frac{q}{1 - \beta(1-q)} \quad (7)$$

The highest price we can observe before t^* occurs at date $t^* - 1$, when from (2) we know that

$$p_{t^*-1} = (1 - \beta)d + \beta qd + \beta(1 - q)D$$

Substituting this for p_t implies

$$\frac{d}{(1 - \beta(1 - q))d + \beta(1 - q)D} < \frac{q}{1 - \beta(1 - q)}$$

which can be rearranged to yield

$$\frac{1 - \beta(1 - q)}{\beta q} < \frac{D}{d}$$

Hence, if $\frac{D}{d} > \frac{1 - \beta(1 - q)}{\beta q}$, the growth rate p_{t^*}/p_{t^*-1} will exceed $1/\beta$.

Proof of Proposition 2: Recall that if cohorts arrive through date t , then

$$p_t = (1 - \beta)d + \beta E_t[p_{t+1}]$$

Rearranging, we get

$$\begin{aligned} E_t \left[\frac{p_{t+1}}{p_t} \right] &= \frac{1}{\beta} - \frac{1 - \beta}{\beta} \frac{d}{p_t} \\ &= \frac{1}{\beta} \left(1 - \frac{d}{p_t}\right) + \frac{d}{p_t} \end{aligned}$$

Since $d < p_t < D$, then as long as $t < t^*$, we have

$$\frac{d}{p_t} < 1$$

and so

$$1 < E \left[\frac{p_{t+1}}{p_t} \right] < \frac{1}{\beta}$$

as claimed.

B.2. Risk Averse Borrowers

This section considers the case where home buyers are risk averse. In particular, we replace the utility in (1) for cohort τ with

$$\sum_{t=\tau+1}^{\infty} \beta^t u(c_{it} + v_i h_{it}) \quad (8)$$

where $u''(\cdot) \leq 0$. The utility function in (8) assumes consumption and housing services are perfect substitutes. It also assumes individuals from cohort τ only care about consumption from date $\tau + 1$. This assumption substantially simplifies the analysis but is not essential.

For tractability, we further assume individuals earn a constant income stream that begins to accrue one period after they arrive. That is, $\omega_{i\tau}^\tau = 0$ and $\omega_{it}^\tau = \omega$ for $t = \tau + 1, \tau + 2, \dots$. We continue to maintain condition (6) by requiring

$$\frac{\beta}{1 - \beta} \omega > D$$

This ensures homeowners could repay a loan of D at an interest rate of $1/\beta$.

In addition, we assume a large group of risk-neutral lenders with ample wealth who discount at rate β . This ensures the gross equilibrium risk-free rate will equal $1/\beta$.

Finally, we assume $t^* = 2$, meaning uncertainty is resolved at date 2. This implies

$$p_t = \begin{cases} d & \text{for all } t \geq 2 \quad \text{w/prob } q \\ D & \text{for all } t \geq 2 \quad \text{w/prob } 1 - q \end{cases}$$

Hence, we only need to solve for house prices at date 1.

To determine the equilibrium price at date 1, we work backwards from date 2, when all uncertainty is resolved. If $p_2 = d$, low types will be indifferent about owning a house, since they value a house at d , while high types will strictly prefer to own a house, since they value a house at D . If instead $p_2 = D$, low types will prefer to sell a house rather than own it, while high types will be indifferent about owning a house. Hence, we can assume without loss of generality that a high type will own a house from date 2 on, i.e. he will either keep a house he bought earlier or buy a house if he hasn't yet, and that a low type will not own a house from date 2 on, i.e. he will either sell a house he bought earlier or not buy a house if he hasn't yet.

For a low type who arrives at date 1, if he does not buy a house at date 1, then since he will not buy a house at date 2 he will consume his permanent income from date 2 on, i.e. $c_{it} = \omega$ for $t \geq 2$. The expected utility as of date 1 from this strategy is

$$\frac{\beta}{1-\beta} u(\omega) \quad (9)$$

Alternatively, a low type can buy a house at date 1. Since low types are indifferent between occupying a house or renting it out, we can proceed as if a house purchase is purely an investment. That is, the low type will be able to rent out his house for $(\beta^{-1} - 1)d$ at date 2, then sell the house at price p_2 , against which he will owe p_1/β from borrowing to buy the house at date 1. Hence his wealth W_2 at date 2 is given by

$$W_2 = \begin{cases} \frac{\omega}{1-\beta} + (\beta^{-1} - 1)d + d - \frac{p_1}{\beta} & \text{with probability } q \\ \frac{\omega}{1-\beta} + (\beta^{-1} - 1)d + D - \frac{p_1}{\beta} & \text{with probability } 1 - q \end{cases}$$

Since $u(\cdot)$ is concave, a low type agent will choose a constant consumption c_{it} from date $t = 2$ on. This means $c_{it} = (1 - \beta)W_2$, or

$$c_{it} = \begin{cases} \omega + (\beta^{-1} - 1)(d - p_1) & \text{with probability } q \\ \omega + (\beta^{-1} - 1)(d - p_1) + (1 - \beta)(D - d) & \text{with probability } 1 - q \end{cases}$$

The expected utility for the low type is then

$$\frac{\beta}{1-\beta} \left[(1 - q) u(\omega + (\beta^{-1} - 1)(d - p_1) + (1 - \beta)(D - d)) + qu(\omega + (\beta^{-1} - 1)(d - p_1)) \right]$$

Hence, a low type will buy a house at date 1 iff

$$(1 - q)u\left(\omega + \frac{1 - \beta}{\beta}(d - p_1) + (1 - \beta)(D - d)\right) + qu\left(\omega + \frac{1 - \beta}{\beta}(d - p_1)\right) \geq u(\omega) \quad (10)$$

Next, we consider high type agents. Suppose a high type buys a house at date 1. Since he will keep the house at date 2, purchasing the house immediately involves no uncertainty. At date 2 he will have $\omega/(1 - \beta) - p_1/\beta$ in non-housing wealth, D in terms of housing wealth, and $(\beta^{-1} - 1)D$ worth of housing services they can consume. With concave utility, the optimal plan would be to set the sum of his consumption and the consumption equivalent value of housing services each period to a fraction $1 - \beta$ of these resources, i.e.

$$c_{it} + (\beta^{-1} - 1)Dh_{it} = (1 - \beta) + \frac{D - p_1}{\beta} + D$$

for all $t \geq 2$. This will yield an expected utility of

$$\frac{\beta}{1-\beta} u\left(\omega + (\beta^{-1} - 1)(D - p_1)\right)$$

Alternatively, a high type could wait to buy a house at date 2. In this case, his non-housing wealth at date 2 will equal $\omega / (1 - \beta) - p_2$ and his housing wealth will equal D . From date 3 on he will be able to consume housing services. Again, the optimal plan would be to set the sum of his consumption and the consumption equivalent value of housing services each period to a fraction $1 - \beta$ of his wealth, i.e.

$$c_{it} + (\beta^{-1} - 1)Dh_{it} = (1 - \beta) \left(\frac{\omega}{1 - \beta} + D - p_2 \right)$$

Since housing services only become available at date 3, the agent will enjoy more consumption at date 2 and then reduce his consumption intake but increase his intake of housing services from date 3. Since p_2 is equal to d with probability q and D with probability $1 - q$, the expected utility as of date 1 from waiting to buy a house at date 2 is given by

$$\frac{\beta}{1 - \beta} \left[\begin{array}{l} (1 - q) u(\omega) \\ + qu(\omega + (1 - \beta)(D - d)) \end{array} \right]$$

Hence, a high type will buy a house at date 1 iff

$$u \left(\omega + \frac{1 - \beta}{\beta} (D - p_1) \right) \geq (1 - q) u(\omega) + qu(\omega + (1 - \beta)(D - d)) \quad (11)$$

We now show that if low types are willing to buy a house, high types will as well. A low type will buy iff (10) holds. Since $u(\cdot)$ is concave, the utility of the expectation of the arguments on the RHS exceeds the expression on the RHS. Since $u(\cdot)$ is increasing, this inequality implies the expectation of the arguments on the RHS exceeds ω , i.e.

$$\omega + (\beta^{-1} - 1)(d - p_1) + (1 - \beta)(1 - q)(D - d) \geq \omega$$

We can rearrange this condition to get

$$p_1 \leq (1 - \beta)d + \beta(qd + (1 - q)D)$$

That is, low types will only buy the house at date 1 if the price at date 1 is less than what they expect to earn from buying the house, renting it out in period 2 and then selling it. Since $D > d$, it follows that

$$p_1 < (1 - \beta)D + \beta(qd + (1 - q)D)$$

With a little algebra, we can rearrange this inequality to obtain

$$(1 - \beta)q(D - d) > (\beta^{-1} - 1)(D - p_1)$$

Appealing to the fact that $u(\cdot)$ is concave, this implies condition (11). The latter condition ensures high types will want to buy housing at date 1. It follows that in equilibrium, high types will strictly prefer to buy houses. Since they buy houses from low types, low types must in equilibrium be indifferent between buying housing at date 1. This means that in

equilibrium, condition (10) must hold with equality, i.e.

$$(1 - q)u\left(\omega + \frac{1 - \beta}{\beta}(d - p_1) + (1 - \beta)(D - d)\right) + qu\left(\omega + \frac{1 - \beta}{\beta}(d - p_1)\right) = u(\omega) \quad (12)$$

This equation determines p_1 . From this equation, it follows that we can drive p_1 arbitrarily close to d by making $u(\cdot)$ sufficiently concave. To see this, define $x = \omega + (\beta^{-1} - 1)(d - p_1)$. Then we can rewrite (12) as

$$(1 - q)u(x + (1 - \beta)(D - d)) + qu(x) = u\left(x + \frac{1 - \beta}{\beta}(p_1 - d)\right)$$

As we make $u(\cdot)$ more concave, the only way for this equality to hold is if $x + (\beta^{-1} - 1)(p_1 - d)$ tends to x , or, alternatively, if p_1 tends to d . The expected house price growth, $E_1[p_2/p_1]$ will then tend to $q + (1 - q)D/d$. If D/d is sufficiently large, specifically if it exceeds $(1/\beta - q)/(1 - q)$, the expected growth rate $E_1[p_2/p_1]$ will exceed $1/\beta$.

B.3. Non-Recourse Lending

This section considers the case of non-recourse mortgages, i.e. where lenders can only go after the house a borrower purchased but not his income.

In what follows, we return to the case where agents are risk-neutral. We assume all houses at date $t = 0$ are owned outright by agents, meaning they have no outstanding debt obligations. New cohorts start arriving at date 1, but have no resources upon arrival to pay for a house. To avoid analyzing the timing of purchases, we assume individuals must buy a house when they arrive or give up on the option to buy a house. We further assume borrowers cannot refinance their loans.

We impose several other assumptions to facilitate the analysis. First, we assume each cohort has a strictly positive fraction of low types, i.e. $\phi > 0$. But we want this fraction to be small, i.e. $\phi \approx 0$, so lenders can expect to recover most of their loans even if low types borrow and then default, and the interest rate on loans will be close to the risk-free rate.

Second, we assume that the size of each arriving cohort, n , is small. To motivate this assumption, note that there are two relevant threshold dates in our economy. The first is t^* , the smallest integer that exceeds $\phi_0/[(1 - \phi)n]$. At date t^* , high types will buy out the entire stock of housing. The second threshold, which we denote t^{**} , is the smallest integer that exceeds ϕ_0/n . At date t^{**} , the original non-high types who own houses at date 0 would get rid of their housing if they sold one unit to each agent who arrived between date 1 and t^{**} . Since $\phi_0/n < \phi_0/[(1 - \phi)n]$, it follows that $t^{**} \leq t^*$. We want this inequality to be strict, meaning the original owners can sell their housing *before* high types occupy all available houses. For any value of ϕ , we can always set n to be sufficiently small that this condition will be satisfied. Formally, our analysis involves letting both ϕ and n tend to zero, but with n tending to 0 quickly enough to ensure $t^{**} < t^*$.

Finally, we assume all agents earn a constant income ω for the first t^* periods of their life, starting with the first period after they arrive. We further assume that ω is small enough that agents will have a debt obligation that exceeds d for the first t^* periods of their loan. If this is true for the first cohort of home buyers who buy at date 1, it will necessarily be

true for subsequent cohorts who will face even higher house prices. We do need to make sure that the income agents earn after t^* is high enough to ensure they can afford to buy a house when they borrow at the risk-free rate. For simplicity, we set the probability an agent becomes disabled ε to zero to rule out income risk. The only default risk then is due to low types who may walk away if house prices fall. Given this risk, lenders will not lend to an agent to buy more than one house, since an agent only derives high utility from one house and will default on any other house if house prices fell.

As a preview of our results, an equilibrium will have the following structure. During the migration wave, all members of each cohort will buy a house. High types buy because they derive a large service flow from housing and intend to live in their house indefinitely. Low types buy because they want to speculate, i.e. to sell the house at a higher price if more high types arrive later and default otherwise. The absence of recourse makes such speculation profitable. New agents buy houses from those who own houses that have the lowest reservation price, which will be those with the lowest debt obligation against the house. Thus, until date t^{**} , agents will buy houses from those who already own these houses at date 0. From date t^{**} on, new buyers will buy houses from low types with the longest tenure as homeowners, i.e. from low types who were the first to arrive among current low type homeowners. Once we establish this is the equilibrium, we discuss the types of mortgages that will be used.

We first argue that high types will buy houses. Let p_t denote the price of houses if new cohorts arrive through date t . Appealing to the transversality condition as before, we know the price of housing cannot exceed D . Now, suppose $p_t = D$ for some $t < t^*$. Then agents who don't value houses at D would all want to sell at this date: Waiting will not yield a higher price but there is a risk the price will fall to d if the migration wave stops. But this cannot be an equilibrium, since there would not be enough agents to buy all of the housing that low types want to sell. Hence, $p_t < D$ for all $t < t^*$. For small ϕ , the interest rate that ensures lenders earn zero profits will be close to the risk free rate. High types would then be strictly better off buying when they arrive than not buying at all. At date t^* , house prices must equal D if migration continued. Any remaining non-high type owners would prefer to sell at this date, and so the only equilibrium is one where high types buy these houses. Without any remaining uncertainty, high types are indifferent about borrowing at the risk-free rate to buy housing at this price.

Next, we argue that low types will also buy houses. Before date t^{**} , there must be some original owners of houses who hold on to their houses given each agent can buy at most one house. But we now argue that there must also be original owners who are willing to sell. The only other agents who might sell are low types who previously bought the house. But we assumed their income ω was low enough that their debt obligation exceeds d for the first t^{**} periods of their loan. If they sell at date t , they will earn $p_t - L_t$, where L_t denotes their debt obligation at date t and, which by assumption, exceeds d . If they wait to sell next period, they will earn $\beta((\beta^{-1} - 1)d + E_t[p_{t+1}])$, and if charged the risk free rate they will owe L_t/β . Thus, without default, they would be indifferent between selling today and waiting. But if they default when prices fall, they will benefit because the house they sell is worth less than their debt obligation, so they get an additional benefit from waiting and partly default on their obligation. Since this option to default is not available to original owners who have no debt against the house, original owners will be more willing to sell. By

the same logic, those who have a larger debt obligation will prefer to wait to sell even when agents with a smaller debt obligation are indifferent.

The above discussion implies that for $t < t^{**}$, original owners will both hold and sell houses, meaning they must be indifferent between the two. This means

$$\beta \left((\beta^{-1} - 1) d + E_t [p_{t+1}] \right) = p_t$$

If migration continues into date $t + 1$, the price of housing p_{t+1} will exceed $E_t [p_{t+1}]$, and low types could earn a return above $1/\beta$ by buying a house at price p_t , then renting it out and selling it at date $t + 1$. Since agents can always default and continue consuming their income, low types will want to buy houses as long as ϕ is small and they are charged an interest rate close to $1/\beta$.

From date t^{**} on, house prices will be determined by the indifference of a marginal owner who has some debt obligation against the house. This marginal owner will suffer less if migration stops next period than an agent with no outstanding debt, so house prices don't grow as much as they do in the first t^{**} periods. But it will still be the case that the price must rise if migration continues and falls to d if migration stops.

Next, we argue that the price of housing p_t exceeds the value of housing services from the last unit of housing. Denote this value by f_t . We can characterize f_t recursively as follows. Before date t^* , the value of the last house is that it can be used to provide housing services to a low type. Thus, it generates a flow value of $(\beta^{-1} - 1) d$. If migration continues through date t^* , the house can be used to provide housing services to a high type. If migration stops before t^* , the house can only ever be used to provide housing services to a low type. Hence, f_t is given by

$$f_t = \beta \left((\beta^{-1} - 1) d + \beta (q d + (1 - q) f_{t+1}) \right)$$

Note the similarity with (2), which characterizes prices in the economy with recourse. We now argue that without recourse, the price p_t will exceed f_t . It cannot fall below this level, or else the lenders who finance new home buyers would simply buy a house themselves. Suppose, then, that $p_t = f_t$. We focus on $t = t^{**}$. At this date, those who buy houses will buy them from a low type agent who arrived earlier and still has a debt obligation that exceeds d . But $p_t = f_t$, such an agent would prefer not to sell. Selling today yields a gain of

$$p_t - L_t = f_t - L_t$$

while waiting one period yields a gain of

$$\beta (1 - q) \left((\beta^{-1} - 1) d + p_{t+1} - \beta^{-1} L_t \right) + \beta q \cdot 0$$

Since $L_t > d$, the latter expression is strictly higher than

$$\beta (1 - q) \left(q (d - \beta^{-1} L_t) + (\beta^{-1} - 1) d + p_{t+1} - \beta^{-1} L_t \right)$$

and since $p_t \geq f_t$ for all t , this last expression is bounded below by

$$f_t - L_t$$

Hence, we cannot have an equilibrium in which $p_t = f_t$ at date t^{**} , since if we did then no agents would be willing to sell houses at date t^{**} . But if $p_t > f_t$ at date t^{**} , it must also be higher before date t^{**} from the fact that agents with no debt obligation must be indifferent between selling and waiting at these dates.

Finally, we turn to the type of mortgages that would trade during the migration wave. Suppose only one type of mortgage were offered. Then this mortgage would stipulate the fastest possible repayment. For if the only mortgage offered did not stipulate the fastest possible repayment, a lender could offer a contract with faster repayment and a slightly lower interest rate. High types would prefer this mortgage since a lower interest rate and faster payments means they have to pay less in total. But as long as the interest rate was only a little lower, low types would still prefer the original mortgage since slower repayment increases the option value to default. This way, a lender would only attract high types but earn slightly lower profits on each, meaning it can increase its total profits. The original contract with less than the fastest repayment could thus not have been an equilibrium.

Next, suppose the only contract offered in equilibrium was the fastest repayment mortgage. Some of these mortgages will not be repaid by date t^{**} , and so some agents who borrowed to buy a house after date 1 must wait until date t^* to sell. A lender could then do better by offering two contracts instead of one: the one with the fastest repayment, and another that forces the borrower to sell the asset by date t^{**} . Recall that at this date, any agents who have no debt obligation would have sold off their asset. In particular, there exist agents with a positive debt obligation who are indifferent about selling a house. That means that agents without a debt obligation would strictly prefer to sell, since they don't receive the benefit from the option to default. If we consider a lender and low type borrower together, their total value for the asset is the same as an agent who has no debt obligation against the asset. Thus, we can make the two of them jointly better off than under the original contract. This requires a contract that induces the borrower to sell the asset at date t^{**} . To make sure the borrower is willing to take this contract, the borrower's utility must be weakly higher than the contract with the fastest repayment path. But since both agents are collectively better off, it will be possible to do this and leave the lender better off. Hence, a single contract cannot be an equilibrium. The equilibrium must feature separation.

As discussed in [Barlevy \(2014\)](#), the equilibrium is a Spence-Miyazaki-Wilson separating equilibrium in which high types cross-subsidize low types. Lenders will offer high types contracts that require the fastest possible repayment, since these are least desirable to low types, and will offer low types contracts that encourage early repayment in exchange for some reward to the borrower for accepting a contract with more constraints. The interest rate on the contracts offered high types will offset the losses expected from lending to low types. Intuitively, since the asset is a bubble, selling it is better than holding it indefinitely. By the same logic, it is also better selling the asset than holding it for too long.

There are various ways to induce the borrower to sell the house they buy more quickly in exchange for some reward. One example is a mortgage with a balloon payment that is paired with a low interest rate. Another is an IO with low initial payments that becomes unaffordable. Thus, our framework does not imply speculation must result specifically in an IO mortgage rather than a balloon mortgage. However, if we considered an environment in which the only mortgages lenders could offer were those that pay as fast as possible and IOs, then in equilibrium both would be used. By contrast, if lenders had full recourse, the same

framework would imply lenders would only offer mortgages with fast repayment even if they could offer IOs. In that sense, non-recourse encourages the use of IOs when house prices are uncertain.

Once we restrict lenders to IOs and fast repayment mortgages, we can further argue that the interest rates on these two types of mortgages must be such that low types are exactly indifferent between the two types of contracts. If that weren't the case, then a lender could offer only the mortgage with fast repayment and attract only high types, earning a profit. But this contradicts the fact that we know both contracts are offered in equilibrium. Hence, low types are indifferent. In addition, lenders must believe that low types will continue to borrow from them if lenders only offered the contract with the fastest possible repayment to sustain this equilibrium. An equilibrium is thus both separating and involves particular beliefs on the part of lenders.

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