Selection, Leverage, and Default in the Mortgage Market*

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Abstract

Borrowers with large mortgages relative to their home values are more likely to default. This paper asks whether this correlation is due to moral hazard—the high balances and payments associated with large mortgages causing borrowers to default—or adverse selection—ex-ante risky borrowers choosing larger loans. To separate these information asymmetries, we exploit a natural experiment resulting from (i) the unique contract structure of Adjustable Rate Mortgages and (ii) the unexpected divergence, during the 2008 crisis, of two financial indices used to determine interest rate adjustments for these loans. We find that moral hazard is responsible for 60-70 percent of the baseline correlation between leverage and default, but adverse selection explains the remaining 30-40 percent. We construct and calibrate a simple model of mortgage choice and default with asymmetric information to highlight the policy tradeoff informed by these estimates. We show that optimal regulation of mortgage leverage must weigh losses from defaults against under-provision of credit due to adverse selection.

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I Introduction

In the years since the financial crisis, leverage—particularly mortgage leverage—has come sharply into relief as a critical element of financial stability.[1] As the crisis made clear, highly leveraged homeowners pose the largest risk of default when real estate prices fall. This observation is at the heart of recent macroprudential policies targeting household borrowing.

In this paper, we empirically separate two potential explanations for the correlation between leverage and default with the goal of informing and assessing macroprudential policy. The first explanation, sometimes called moral hazard, is a causal effect.[2] All else equal, higher leverage may directly lead borrowers to default. This may be because the borrower is more likely to owe more than the home is worth or because they are unable or unwilling to meet the larger monthly payments necessary to repay the loan. The alternative is adverse selection: ex-ante riskier borrowers simply prefer higher leverage mortgages. Despite a substantial theoretical literature examining these classical information asymmetries in credit markets, distinguishing adverse selection from the causal effect remains a fundamental challenge for empirical work.

Yet separating the two is crucial for understanding how leverage is determined in equilibrium[3] and, consequently, for designing mortgage policy. As we show, a policymaker that attributes the correlation solely to a causal effect will (i) *overestimate* the reduction in defaults generated by regulations on leverage and (ii) *underestimate* a significant source of welfare losses, as adverse selection entails safe borrowers taking inefficiently small loans to differentiate themselves from riskier types.

Our research design isolates these different explanations by exploiting a natural experiment generated by the unique contract structures of Adjustable Rate Mortgages (ARMs). These mortgages typically have interest rate adjustments tied to either LIBOR or Treasury rates. Though the choice of financial index was not salient prior to the financial crisis, the unanticipated divergence of these two indices during the 2008 crisis caused similar borrowers to unexpectedly face substantially different interest rates. We focus specifically on two types of products: Option ARMs and 5/1 ARMs, whose particular contract details enable us to disentangle adverse selection from the causal effects of borrowers balances and monthly payments.

Because Option ARMs feature fixed monthly payments in the early years, unexpected changes in interest rates for these loans create variation in the ex-post *balances* borrowers owe. Our analysis instruments for borrower loan balance using an interaction of financial index and origination

[1] See, e.g. Geanakoplos and Pedersen (2012), Mian and Sufi (2015), and Korinek and Simsek (2016).

[2] This terminology in credit markets is used, for example, by Adams, Einav and Levin (2009).

[3] Do lenders require down payments to ensure that borrowers repay ex-post (moral hazard) or to solve an ex-ante screening problem by sorting borrowers with different unobserved risk types (adverse selection)? Berger, Frame and Ioannidou (2011) provide recent empirical evidence on this question in credit markets.

month. This approach allows us to (i) identify adverse selection by comparing borrowers with different endogenous leverage choices ex-ante, but identical realized balances (and payments) ex-post, and (ii) identify the causal effect of loan balances by comparing borrowers with identical initial leverage choices and different realized balances. We estimate that moral hazard is responsible for 60-70 percent of the baseline correlation between leverage and default, while adverse selection is responsible for the remaining 30-40 percent. The moral hazard effect is directly policy relevant, quantifying how effective ex-post regulations that reduce balances are in preventing defaults.[4] Our estimates imply, for example, that a 10-point reduction in a borrower's LTV 24 months after origination would reduce the average probability of default by over 4 percentage points.

Our analysis on 5/1 ARMs uses the same underlying variation in interest rates. However, the interest rate shock for these borrowers instead directly impacts monthly payments after loan reset. With this product, our natural experiment allows us to (iii) identify the causal effect of loan payments by comparing borrowers with identical initial leverage choices but different immediate payments and, subsequently, to (iv) test whether borrowers differentially select initial leverage based on their sensitivity to payments. We estimate that an additional $100 in monthly payments, sustained over a year, leads to a 2.3 percentage point increase in default rates. While this result is consistent with a broader literature examining the role of ARM reset shocks, we also find evidence of selection on borrower's sensitivity to these payment shocks: borrowers who are prone to defaulting in response to higher monthly payments tend to choose higher leverage mortgages.

Our final step is to quantify the equilibrium implications of ex-ante regulation in the presence of moral hazard and adverse selection by simulating a simple structural model that is calibrated to our estimates. While it is clear that restrictions on mortgage contracts may have profoundly different impacts on equilibrium with and without adverse selection, there is no standard framework to evaluate such regulations. Even the appropriate characterization of equilibrium in competitive contexts with adverse selection is controversial, and equilibria may fail to exist under conventional definitions.[5] To ensure the existence of equilibrium, we use the robust equilibrium concept recently proposed by Azevedo and Gottlieb (2017). We consider, as an example, the impact of a reduced LTV cap—a widely used policy tool intended to reduce mortgage defaults.

We find that this policy is indeed effective in limiting defaults, but the effect is smaller than a naive regulator—one who attributes the full correlation between leverage and default to a causal effect—would expect. Furthermore, for such a regulator, the presence of adverse selection generates significant unexpected welfare losses due to knock-on effects. The leverage cap lowers defaults at the expense of borrower welfare and pushes borrowers above the cap to mechanically take smaller loans.

[4] e.g. the Home Affordable Refinance Program Principal Reduction Alternative (HAMP PRA).
[5] e.g. Rothschild-Stiglitz.

Though these effects are unsurprising; the key insight is that selection magnifies the welfare consequences of leverage caps by restricting the contract space borrowers can use to signal their type. As a result, the regulation propagates through the whole distribution: those below the cap also choose to take smaller loans in order to maintain a separation from riskier types, and interest rates adjust upwards across the entire LTV distribution. Appropriately accounting for adverse selection, we estimate that default externalities on the order of $313,000 per default are necessary to make a reduction in the LTV cap from 100 to 90 welfare neutral. A naive regulator would underestimate this by 40 percent.

This paper's foremost contribution is to the growing empirical literature on asymmetric information in credit markets.[6] Complementing Karlan and Zinman (2009), a number of influential papers attempt to distinguish between adverse selection and moral hazard by exploiting ex-ante variation—experimental, regulatory, or institutional—in the set or shape of contracts offered. These include Ausubel (1999) and Agarwal, Chomsisengphet and Liu (2010) on the US credit card market; Adams, Einav and Levin (2009) and Einav, Jenkins and Levin (2012, 2013) on subprime auto loans; Hertzberg, Liberman and Paravisini (2018) on online consumer credit; and Dobbie and Skiba (2013) on payday lending. However, separately identifying moral hazard effects in these contexts requires an assumption about why the relevant variation in ex-ante contracts does not also generate selection of borrowers on unobservables.

We contribute to this broader literature by isolating ex-post variation in the loan balance that is *unknown* to borrowers when selecting contracts. In contrast to Karlan and Zinman (2009), whose setting closely resembles the canonical Stiglitz and Weiss (1981) framework, we explicitly study the richer contract space of collateralized lending—which also characterizes the majority of consumer lending. A large theoretical literature (e.g. Bester, 1985) shows that the use of collateral in credit contracts has significant implications for both welfare and the expression of adverse selection in equilibrium. By screening borrowers using contracts that differ along two dimensions—interest rates and leverage—lenders can avoid the credit rationing that characterizes unsecured lending. Further, we propose and simulate a framework to evaluate policy in the presence of these asymmetries.

We also add to the papers above by studying the largest and arguably most important consumer debt market in the United States.[7] Though this literature is in broad agreement regarding the importance of borrower leverage as a driver of defaults and broader macroeconomic factors (Mian and Sufi, 2018); there remains considerable debate regarding the specific market frictions driving this relation-

[6]This paper is also heavily indebted to broader empirical work on asymmetric information in insurance and other markets. Particularly Chiappori and Salanié (2000), Cardon and Hendel (2001), Finkelstein and Poterba (2004), Finkelstein, McGarry et al. (2006), Finkelstein and Poterba (2014), Hendren (2013), as well as recent work examining the welfare implications of information asymmetries such as Einav, Finkelstein and Cullen (2010), Einav et al. (2013), and Einav, Finkelstein and Schrimpf (2010).

[7]Mortgage balances represented 68 percent of consumer debt in the first quarter of 2016. See the Federal Reserve Bank of New York's May 2016 Quarterly Report on Household Debt and Credit.

ship. A small handful of empirical papers explicitly consider information asymmetries in mortgage markets, including Edelberg (2004), who uses structural assumptions to test for adverse selection and moral hazard in a broad class of consumer debts, and Ambrose, Conklin and Yoshida (2015) and Jiang, Nelson and Vytlacil (2014), who consider selection into and within low documentation mortgages.[8] Despite the significance of the mortgage market, the well-documented importance of screening in mortgage lending (e.g. Keys et al., 2010), and the quantity of theoretical work on information asymmetries (e.g. Brueckner, 2000; Dunn and Spatt, 1988; Stanton and Wallace, 1998; Harrison, Noordewier and Yavas, 2004; Chari and Jagannathan, 1989); attempts to cleanly separate adverse selection and moral hazard in this market are relatively rare.

The estimated moral hazard effect directly contributes to the literature on the causes of mortgage default, in which the role of home equity is a major concern. Vandell (1995) provides an overview of early research on borrower's exercise of the default option. More recent work, including Bajari, Chu and Park (2008), Foote, Gerardi and Willen (2008), Elul et al. (2010), Bhutta, Shan and Dokko (2010), and Gerardi et al. (2015), has stressed the joint importance of triggers such as liquidity and job loss alongside home equity in mortgage default. However, the majority of this literature identifies the impact of home equity on default using variation that results from changes in local home prices. A key exception is Ganong and Noel (2017), which uses experimental evidence from the HAMP program based on a sample of loan modification applicants. In contrast to that paper, which focused on deeply underwater borrowers, we find strong evidence of moral hazard along both dimensions of loan payments as well as balances causally driving default decisions. Relative to that literature overall, we provide a new source of borrower-level variation in home equity that avoids the potential for measurement error and other endogeneity concerns inherent to the use of home price variation. Additionally, we show that while borrower exposure to income shocks may be exogenous; borrowers may be selected on the dimension of sensitivity to these liquidity pressures.

The identification strategy complements a series of papers investigating the impacts of interest rate resets on delinquency and other outcomes for borrowers with Adjustable Rate Mortgages. This includes Fuster and Willen (2017), Tracy and Wright (2012), Di Maggio et al. (2017), and Gupta (2017), who also utilizes the distinction between different indices. Because those papers examine more traditional Adjustable Rate Mortgages, none are able to identify the impacts of loan liability on default, focusing instead on the liquidity impacts of monthly payment shocks that typically accompany rate resets. Our primary innovation comes in developing a research design that cleanly translates interest rate resets into variation in borrower's balances.

Finally, the simulation analysis adds to a large literature analying the effects of macroprudential

[8] There is also related work in the home equity lending market, in particular Agarwal et al. (2011), who explore dynamic relationships, and Agarwal, Chomsisengphet and Liu (2016), who follow the strategy of Adams, Einav and Levin (2009).

policy. As suggested by Cerutti, Claessens and Laeven (2017), macro-prudential caps (along the dimensions of Loan-to-Value or Debt-to-Income) are in place in over 41 countries as of 2014. A growing literature explores the ways in which this prudential regulation impacts credit markets, and evaluates their effectiveness. These include: Greenwald (2018), Gete and Reher (2016), DeFusco, Johnson and Mondragon (2017), and Behn, Haselmann and Vig (2017). Other papers examine the ultimate determinants of borrower leverage choice, such as Bailey et al. (2017). Our paper differs from this literature by exploring the role of adverse selection as well as moral hazard, and expanding the scope of analysis beyond a tight bandwidth around the local cap. Our analysis suggests that, in the presence of competitive pricing and selection, macroprudential caps may have unintended consequences by affecting equilibrium loan sizes and relativeborrowers' prices even for borrowers far from the binding cap.

The paper is structured as follows: Section II lays out key definitions and presents a model of information asymmetries in the mortgage market. Section III provides background information on ARMs and the data used in the paper. Sections IV and V present the empirical strategy and results, respectively. Section VI shows the results of simulations, and Section VII concludes. In the Appendix, Section B describes the contracts offered to borrowers and provides initial tests for information asymmetries, and Section C contains additional robustness tests.

II Definitions and a Model of Information Asymmetries

In this section, we define adverse selection and moral hazard as they pertain to the relationship between mortgage borrowers and lenders. We then discuss why we might expect information asymmetries to exist in mortgage markets, highlighting a particular sort of borrower-level heterogeneity—individual differences in willingness to default—that provides a source of adverse selection. We develop a simple model of mortgage choice and default incorporating this heterogeneity following Brueckner (2000) and show that it gives rise to a Spence-Mirrlees single crossing condition. Finally, we briefly outline the equilibrium implications of such a model, focusing on the potential for underprovision of credit due to adverse selection.

II.1 Definitions of Adverse Selection and Moral Hazard

The definitions of adverse selection and moral hazard that we specify follow largely from those used in Adams, Einav and Levin (2009):

(I) *Adverse Selection:* The mortgage market exhibits adverse selection if unobservably risky borrowers—those who are more likely to default with contract terms held equal—select higher leverage contracts.

(II) *Moral Hazard:* The mortgage market exhibits moral hazard if there is a causal relationship between the borrower's loan liability and default. That is, all else equal, a larger loan increases the probability of default. We consider two distinct mechanisms generating this effect:

(i) *Causal Effect of Loan Balance:* There is a causal effect of the loan burden on default if, all else equal—including any immediate payment obligations—a larger loan balance increases the probability of default.

(ii) *Causal Effect of Loan Payment:* There is a causal effect of loan payments on default if, all else equal—including the net loan balance—a larger required payment today increases the probability of default.

Defining adverse selection in this way is fairly standard and adheres closely to the discussion in Chiappori and Salanié (2013) on insurance markets. Adverse selection exists if there is an exogenous correlation between a borrower's demand for leverage and the unobservable credit risk he poses to the lender. While there are a number of possible underlying models that could generate such a relationship, the equilibrium implications of the correlation are largely independent of the source, so we do not specify a mechanism in the baseline definition.

Our definition of moral hazard is somewhat broader than usual. Typically, a credit market can be said to exhibit moral hazard if (i) the expected returns to the lender depend on some non-contractable action of the borrower and (ii) that action is itself influenced by the terms of the loan contract. If default is always considered a strategic choice, our definition aligns with this traditional notion. Default itself can be thought of as the non-contractable action taken by the borrower.[9] Note that strategic choices can, in principle, explain both mechanisms driving a moral hazard effect ((i) and (ii) above). Unsurprisingly, an increase in a borrowers balance may cause the liability to exceed the value of continuing to pay the mortgage. However, an increase in the immediate payment may also lead to a strategic choice if the borrower determines that the cost of carry exceeds the value of the mortgage.

Of course, default is not always an active choice. Borrowers may be insolvent or credit constrained to the extent that they are mechanically unable to make payments. Again, both (i) and (ii) above may, in principle, be explained by a mechanical effect. Clearly, an increased payment may force default for a borrower with limited access to cash, but an increase in the loan balance may also force the same cash-constrained borrower to default in certain circumstances. For instance, an increase in the loan

[9] Limited access to recourse for lenders provides an obvious explanation for the existence of moral hazard. The particular legal restrictions on contracts vary from state to state, with some explicitly prohibiting lenders from recovering any excess balance from the borrower beyond the home itself in the event of default. California, for example, has laws that explicitly prevent the lender from recovering any balance from the borrower beyond the home itself in the case of default for owner-occupied homes with 1-4 units. Alternatively, Illinois allows deficiency judgments that can only be relieved in bankruptcy. However, even in states with laws that are favorable to lenders, deficiency judgments are relatively rare in practice (Pence, 2006). As a result, lenders cannot effectively contract against borrowers defaulting when their mortgages are underwater.

balance may remove the borrowers ability to avoid default by refinancing the mortgage or selling the home. While much of our discussion highlights the strategic channel, the definitions we use do not exclude defaults due to a mechanical relationship. As in Adams, Einav and Levin (2009), whether the source is mechanical or strategic is not crucial for the policy implications we consider.

II.2 Sources of Information Asymmetries in Mortgage Markets

In this subsection, we suggest potential sources of adverse selection in the mortgage market. While the definition above is agnostic regarding mechanisms, understanding why selection might be present is helpful to frame further discussion.

What is the source of heterogeneity that generates adverse selection? As a baseline, consider a simple model of mortgage default—often referred to as the frictionless option model—in which borrowers strategically default immediately if the value of their home drops below the value of the mortgage. Unless borrowers and lenders have different beliefs about housing prices, this model leaves little room for private information. All borrowers default according to a uniform rule.

However, a large literature suggests that borrowers do not default according to a frictionless option model (see Vandell, 1995, for a review). There is significant heterogeneity in willingness to exercise the default option (Deng, Quigley and Van Order, 2000), and a growing consensus that negative equity is a necessary but not sufficient condition for default (Bhutta, Shan and Dokko, 2010; Elul et al., 2010). Borrowers typically do not default until they owe more on their mortgage than the home is worth, and sometimes significantly more. Note that there is no necessary need for a behavioral explanation for this phenomenon. There are real costs associated with default, including credit score reductions, moving costs, and social stigma.[10] These costs may differ in the population, and hence the equity thresholds at which borrowers default will vary in the population.

Heterogeneity in these thresholds provides a natural—albeit reduced form—source of adverse selection. Borrowers who know that they are unlikely to repay will be less sensitive to the size of the mortgage balance. One way to think about this framework is as a model of selection on (ex-post) moral hazard, as in Einav et al. (2013). Lenders cannot contract on the action of default, the willingness to take that action varies in the population, and borrowers are privately informed of their own willingness.

II.3 The Model

To capture the intuition described above, we propose a two-period model of borrower's leverage demand and default choice, following Brueckner (2000). Borrowers differ in a single dimension, which

[10] Even for a given cost of defaulting, borrowers may be heterogeneous in access to liquidity.

we refer to as the private default cost. This black box parameter represents all factors that influence the borrower's default decision at a given level of home equity. There are two primary takeaways from the model. First, the distribution of private default costs in the population determines the magnitude of the moral hazard effect, i.e., the increase in defaults generated by a given change in the loan balance. Second, a Spence-Mirrlees single crossing condition holds: borrowers with lower private default costs (i.e. risky borrowers) are relatively more willing to accept large balances.

In period 0, borrowers choose what portion of a risky housing purchase to finance. In period 1, the value of the home is realized, and borrowers choose whether to pay off their loan or to default. Mortgage contracts have two dimensions: the period 0 loan and the period 1 balance. We consider a non-recourse environment: in default, the borrower cedes the right to the home and is relieved of the loan balance.

Formally, let time be indexed by $t \in \{0, 1\}$ and borrowers be indexed by i. Borrowers must purchase a home with initial price H_0 and uncertain period 1 price H_1 distributed on support $[\underline{h}, \bar{h}]$ according to CDF $F(H_1)$. Lenders offer contracts of the form $\{L, B(L)\}$, where L is the value of the loan provided to the borrower in period 0, and $B(L)$ is the balance due on the loan in period 1.[11] In general $B(L)$ is increasing in L, that is, lenders demand higher balances for larger loans. A high leverage mortgage is one with a large L and correspondingly, a large $B(L)$.

Borrowers have per-period utility of consumption $u(\cdot)$, which is increasing and concave, receive income y_t in each period, which is not stochastic, and discount the future according to β. Each borrower i has privately known costs associated with defaulting, C_i, which captures the difference in dollar terms between defaulting and not defaulting.

Default Choice

In period 1, borrowers realize the value of their home and choose between repaying and defaulting. A borrower who repays retains the value of the home for net income $y_1 + H_1 - B$, while a borrower who defaults avoids paying the mortgage balance but incurs the default cost: $y_1 - C_i$. Borrowers choose to default when

$$H_1 - B < -C_i.$$

Borrowers with a low C_i are quicker to default, that is, for the same B they will default at higher home values.

This default rule demonstrates the importance of private default costs in determining the strength

[11] While other terms are often used to define mortgage contracts, these are usually equivalent to simple transformations of L and B in the two-period case. We could alternatively speak of the down payment $(H_0 - L)$, the interest rate $\left(\frac{B}{L} = 1 + r\right)$, and the original loan-to-value $\frac{L}{H_0}$.

of the moral hazard effect. For a given C_i, the expected fraction of borrowers defaulting at balance B is $F(B - C_i)$, and the marginal effect of an increase in B is $f(B - C_i)$. The calculation becomes even more complicated with heterogeneity in C_i, as one must integrate over the set of borrowers at a given B.

Contract Choice

In period 0, borrowers know C_i but face uncertainty about the period 1 home value. As a result, they choose $\{L, B\}$ to maximize

$$U(L, B; C_i) = u(y_0 - (H_0 - L)) + \beta \left[\int_{\underline{h}}^{B-C_i} u(y_1 - C_i) dF(H_1) + \int_{B-C_i}^{\bar{h}} u(y_1 + H_1 - B) dF(H_1) \right].$$

The term in brackets represents the expected period one utility, with the first term giving utility in the case of default and the second utility with repayment.

Note that the borrower's overall utility is increasing in the loan size L:

$$U_L(L, B; C_i) = u'(y_0 - H_0 + L) \geq 0.$$

Additionally, borrower utility is decreasing in the balance:

$$U_B(L, B; C_i) = -\beta \int_{B-C_i}^{\bar{h}} u'(y_1 + H_1 - B) dF(H_1) < 0.$$

This result is unsurprising. Holding the balance fixed, borrowers prefer larger loans, and holding the loan size fixed, borrowers prefer a smaller balance.

There are a variety of reasons why borrowers prefer to take out large loans. In the presence of credit constraints, L provides a method of smoothing consumption over time, so borrowers can consume period 1 income and the expected gains from the home in period 0. However, even if it is possible to borrow at the risk free rate, borrowers still value mortgage loans because they provide a form of insurance against low realizations of H_1.[12] An increased B effectively allows borrowers to give up consumption when H_1 is high in exchange for sure consumption (in the form of L) even when H_1 is low.[13]

At actuarily fair prices, borrowers prefer to take advantage of the insurance provided by a mortgage. In a totally frictionless context,[14] borrowers will choose an extreme form of full insurance when

[12] Assuming mortgage debt is non-recourse, but other debt cannot be forgiven.

[13] The mortgage literature refers to this as the put option contained in a mortgage: the borrower retains the right to sell the home to the bank in exchange for the balance on the mortgage.

[14] By totally frictionless, we mean a context with (i) borrowing and lending at the risk free rate, (ii) no default costs to the borrower, and (iii) lenders who can perfectly recover the home value after a default.

offered a fair price. In particular, they will take out as large a loan as possible and default on the loan in all states of the world. While this may seem surprising, it is a standard result: a risk averse agent will be willing to sell a risky asset for its expected value.

Yet borrowers with different values of C_i do not value this insurance equally. In fact, a Spence-Mirrlees single crossing condition holds:

$$\frac{\partial\left(\frac{U_B}{U_L}\right)}{\partial C_i} = \frac{-\beta u'(y_1 - C_i) f(B - C_i)}{u'(y_0 - H_0 + L)} < 0.$$

Because low C_i are more likely to default, all else equal, they are more likely to take advantage of the insurance provided by the mortgage. As a result, they are willing to accept smaller increases in the loan size L in exchange for the same increase in the balance B.

If borrowers with different levels of C_i, say $C_R < C_S$ (where R and S denote risky and safe borrowers), are offered the same menu of contracts, the single crossing condition constrains the set of contracts chosen. In particular, if these types buy contracts $\{L_R, B_R\}$ and $\{L_S, B_S\}$, respectively, it must be the case that $L_R \geq L_S$. Of course, for borrower C_S to be willing to accept a smaller loan, it must also be the case that $B_R \geq B_S$. Further, if C_R and C_S buy different contracts along one dimension, both inequalities must hold strictly.

II.4 Equilibrium Consequences of Single Crossing

In this subsection, we provide a brief graphical discussion of the consequences of single crossing on the equilibrium allocation of credit. The intuition is familiar from Rothschild and Stiglitz (1976) and numerous other works on screening. With two borrower types, single crossing makes pooled contracts unsustainable. Any contract that is sold to both risky and safe borrowers can be undercut by a contract that offers slightly less credit but only attracts safe borrowers. As a result, safe borrowers receive smaller loans in equilibrium (à la Rothschild-Stiglitz) than they would in a world of perfect information. This notion is analogous to the under-provision of insurance to safe types in insurance markets.

We first take a world with perfect competition amongst lenders and a regulatory limit of $L \leq H_0$ (i.e. an LTV cap of 100 percent). We consider borrowers who prefer loans at or above the LTV cap with fair prices.[15] Panels A and B of Figure I present the perfect information case. These figures show lenders zero profit curves (solid curves, labeled with $\pi = 0$) and borrowers' indifference curves (dashed lines, labeled with U) in the space of contracts (L, B).

[15]For large enough C_i or sufficient difference between y_0 and y_1 with borrowing constraints, borrowers may prefer smaller loans even at fair prices.

Borrowers prefer contracts to the southeast: larger loans with smaller balances. Lenders unambiguously prefer contracts to the west: smaller initial loans. However, the net effect of balance increases is ambiguous for lenders. Profits rise in the case of repayment, but the probability of repayment falls. With perfect information, borrowers choose initial loans right at the LTV cap. This holds whether there is a single borrower type, as shown in Panel A of Figure I, or multiple types, as in Panel B. With two borrowers (risky R and safe S), the riskier type must simply pay a higher balance for the same loan, as shown by $B_R > B_S$ in Panel B.

Panels C and D of Figure I zoom in on the boxed portion of the graph shown in Panel B and highlight the complications posed by the single crossing property if lenders cannot offer different contracts to different borrowers. The balance necessary to give lenders zero expected profits on a pooled contract lies above the balance paid by safe borrowers with perfect information. Because the indifference curves of the risky type are steeper than those of the safe borrower—risky types are willing to accept a larger increase in the balance for the same increase in the initial loan—there is a region of contracts that are preferred by the safe borrower to the pooled contract but also make non-negative profits for lenders. In Panel C, this region is shaded in gray. This generates an opportunity for cream skimming. Given any pooled contract, lenders may offer a contract with a slightly smaller initial loan that attracts only the low risk types.

Panel D shows the form of a Rothschild-Stiglitz equilibrium in this context, should it exist. Risky borrowers end up with the same loan they would get in a world with perfect information, while safe borrowers are forced to take a smaller loan to distinguish themselves from riskier types. The welfare loss from adverse selection comes from safe borrowers receiving these inefficiently small loans ($L_S < H_0$) relative to the perfect information outcome.

III Background and Data

In this section, we provide historical background on Adjustable Rate Mortgages (ARMs) generally and the Option Adjustable Rate Mortgage in particular. Our focus on the baseline ARM will be to isolate the role of payment shocks resulting from exogenous interest rate variation, as well as isolating selection on the dimension of liquidity sensitivity. We describe the nature of these interest rate shocks, which arise from differences in financial indices used to determine interest rates. On the Option ARM sample, we document a unique loan contract featuring fixed payments, for which these interest rate shocks instead accrue to loan balance. These loan features allow us to set aside the role of payment shocks, and analyze instead the role of mortgage balance variation on consumer default. Finally, we discuss the characteristics of borrowers that chose Option ARMs relative to the larger population of mortgage borrowers and describe the data sources used in the empirical analysis.

III.1 Background on ARMs

Though ARMs were commonplace prior to the Great Depression, U.S. regulation effectively limited residential mortgage products to long term fixed rate loans until the late 1970s. However, in 1978 the Federal Home Loan Bank Board began to allow federal savings and loan institutions to originate Adjustable Rate Mortgages (ARMs) in California, and by the end of 1981, restrictions on adjustable rate products had been significantly relaxed nationwide. Originations of ARMs grew rapidly, driven by high interest rates in that period, representing as much as 68 percent of all new mortgages for certain months in the 1980s (Peek, 1990).

The industry largely settled on what are called Hybrid ARMs. These mortgages feature fixed interest rates and payments for a set initial period, often 5 or 7 years. After the initial period, interest rates begin to adjust according to market conditions, usually changing annually or semiannually. Monthly payments are designed to be fully amortizing, that is, calculated to exactly pay off the loan over the full term at current interest rates. As a result, payments change to keep pace with interest rates and may unexpectedly increase if interest rates rise.

Payments on ARMs are determined by an annuity calculation taking into account scheduled amortization over the loan term (typically 30 years, but 15 years is common as well), as well as a composite (or market) interest rate to account for lender repayment. This composite rate is the sum of a fixed margin component (priced at loan origination), as well as a fluctuating index component tied to a market index. Variation in relative spreads on this market index result in within-month variation in interest rates and payments made by borrowers, which we exploit in our analysis.

To establish comparability of our analysis, we focus on 5/1 ARMs for which interest rates are fixed for five years after loan origination and reset at an annual frequency after loan origination. Additional caps and floors govern the speed of interest rate fluctuation. These are generally not fully binding in our sample period, but result in some attenuation of the passthrough impact of scheduled interest rate shocks on actual interest rates paid by borrowers. Over our sample period, this product was frequently offered to jumbo-prime borrowers whose loans were securitized in the private label securitization market. While the subprime and Alt-A components of this market have been extensively studied (see Ambrose, Conklin and Yoshida (2015) and Jiang, Nelson and Vytlacil (2014)), the jumbo-prime component of this market features private lenders, generally sophisticated borrowers, and large borrower leverage. Recent research (Adelino, Schoar and Severino (2016) and Foote, Loewenstein and Willen (2016)) has identified speculative activity among borrowers with greater incomes, credit scores, and loan balances as critical to the expansion of mortgage credit prior to the financial crisis. These institutional features make 5/1 ARMs an attractive environment to establish patterns of asymmetric information and leverage.

III.2 Background on the Option ARM

The Adjustable Rate Mortgage product protects lenders against interest rate risk, but exposes borrowers instead to the possibility of rapidly fluctuating interest rate variation. Lenders created the Option ARM product to help shelter borrowers with fluctuating incomes against this risk.[16] Banks wanted a product that incorporated floating interest rates while protecting borrowers from sharp payment increases and mortgage holders from the associated default risk. The Option ARM is characterized by a series of features that reflect this desire:

(I) *Fixed minimum payment schedule:* Borrowers are offered a relatively low initial payment, often based on the fully amortizing payment for an extremely low "teaser" interest rate. For the first 5 years, this payment adjusts upward once yearly by a fixed amount, usually 7.5 percent.[17] After 5 years, the minimum payment adjusts to the fully amortizing amount. This schedule may be interrupted if the loan balance rises above a fixed proportion of the original home value, often 110 or 125 percent.

(II) *Monthly interest rate changes:* While interest rates for most ARMs adjust annually or semi-annually, Option ARMs update much more frequently, usually monthly. As in typical ARMs, new interest rates are calculated as the sum of a fixed margin component and an index term to proxy for the cost of funds to the lender.

(III) *Negative amortization:* The minimum payment required in a given month will be often lower than the amount of accrued interest. In these circumstances, Option ARMs allow for negative amortization, that is, allow the excess interest accrual to be incorporated into the balance. As a result, the loan balance will typically grow in the early years of the mortgage.

(IV) *Proposed Payment Options:* The name, Option ARM, refers to a menu of payment options offered to borrowers on monthly statements. In addition to the minimum payment, statements offer the possibility of an interest only payment, covering the entirety of the interest accrual, along with amortizing payments calculated according to 15- and 30-year schedules. These possibilities are suggestions. Only the minimum payment is binding, and the borrower may in principle make any payment between the options or in excess of the 15-year amortizing payment (sometimes subject to certain caps). In practice most borrowers make the minimum payments every month.

[16] See Golden West's history of the Option ARM, available at http://www.goldenwestworld.com/wp-content/uploads/history-of-the-option-arm-and-structural-features-of-the-gw-option-arm3.pdf.

[17] In theory, 7.5 percent is a cap, and the minimum payment might adjust by less if a 7.5 percent increase were to exceed the fully amortizing payment. In practice, the cap is nearly always binding.

For the purposes of the identification strategy, (I) and (II) are key. Because payments are fixed for the first 5 years,[18] borrower's balances change as a function of realized interest rates. In the next subsection, we discuss these features in greater depth.

In the 1980s and 1990s, the Option ARM was primarily a niche product directed towards sophisticated borrowers. The flexibility of payments was intended to appeal to borrowers who expected their income to rise in the future or those with high income volatility. With the growth of a secondary market for non-traditional mortgages in the early 2000s, banks began to market Option ARMs as affordability products, allowing borrowers to purchase more expensive homes than they would be able to afford with a traditional mortgage. Borrowers might take out such loans with the intention of refinancing the mortgage or selling the home after several years, and thus never making payments much above the initial minimum. In the years leading up to the crisis, Option ARMs became a significant fraction of the market, representing approximately 9 percent of originations in 2006.[19]

As the crisis hit, borrowers with Option ARMs defaulted at high rates. In the sample studied here, 41 percent of borrowers were seriously delinquent (60 days past due) on their mortgages at some point within the first 5 years, and 33 percent wound up in foreclosure. The combination of high default rates and non-traditional features made Option ARMs a poster-child for excess in mortgage lending (see Amromin et al. (2011)). Their role in the crisis has been highlighted by various media sources and policymakers—Ben Bernanke noted that "the availability of these alternative mortgage products proved to be quite important and, as many have recognized, is likely a key explanation of the housing bubble." Despite these criticisms, recent research has argued that these loans approximate the optimal mortgage contract for reasons of protecting borrowers with stochastic income facing foreclosure costs (Piskorski and Tchistyi, 2010; Guren, Krishnamurthy and McQuade, 2018), or macroprudential policy (Campbell, Cocco and Clara, 2017).

III.3 Diverging Indices and Interest Rate Resets

Our identification strategy relies on interest rate divergences of financial indices used to determine interest rate adjustments. Interest rates for ARMs are typically tied to LIBOR or Treasury rates.[20]

Prior to the crisis, borrowers had little reason to prefer one index to another. Although there tended to be a spread between LIBOR and Treasury rates,[21] the two indices moved quite closely together, and any fixed difference could be accounted for in the margin. Furthermore, Bucks and Pence (2008)

[18]All analyses performed here consider outcomes within the first 5 years. Appendix Figure A.I presents a sample balance and payment trajectory for an Option ARM to highlight these product features from origination through that period.

[19]See the 2008 Mortgage Market Statistical Annual.

[20]Treasury rates are usually the 1-year Constant Maturity Treasury (CMT) or the 12-month Moving Treasury Average (MTA). Typically LIBOR refers to the 3-month LIBOR.

[21]For example, the spread between 1-year CMT and 1-year LIBOR was generally below 50 basis points.

suggest that borrowers tended to be relatively uninformed about their contract terms. When asked what index their loan depended on, only 25 percent of borrowers responded with even plausibly correct indices, while 30 percent of borrowers simply answered that they did not know.

If borrowers were unaware of the distinction between indices, why did some end up with a Treasury index and others with LIBOR? Much of the variation comes as a result of the lender. Appendix Table A.I shows the proportion of LIBOR-indexed loans for the top originators in the sample of Option ARMs. Most originators appear to specialize in either LIBOR or Treasury indices, and some offer only Treasury rates. A similar pattern can be seen among servicers, although slightly less pronounced. According to Gupta (2017), differences across lenders are often a function not of the borrowers they lend to, but rather their intentions on the secondary market.

The interest rate divergence between the two indices is illustrated in Panel A of Figure II, which shows the spread between the 1-year Constant Maturity Treasury (CMT) and 1-year LIBOR. While there were fluctuations in the years preceding the crisis, the difference was contained in a relatively narrow band. However, in mid-2007, Treasury rates began to fall and the spread increased, eventually peaking at over 3 percentage points in late 2008 following the Lehman Brothers bankruptcy filing and news of the AIG bailout. As a result, borrowers taking out similar loans prior to the crisis faced substantially different interest rates when their loans reset.

Panel B of Figure II displays this default consequences of interest shocks to 5/1 ARM borrowers in our sample. The black line shows the average difference in interest rates between resetting loans indexed to LIBOR versus Treasury for each month. Importantly, these interest rate divergences apply to resetting loans that month, and persist for the following year after reset. There is a noticeable spike in the in-sample difference in early 2009, corresponding to the late 2008 spike in Panel A. The red line in Panel B shows the in sample difference in default for resetting loans indexed to LIBOR versus Treasury. In sync with the spike in relative interest rates, there was a sharp spike in relative defaults in early 2009. In the month that LIBOR-indexed loans experienced the most severe difference in interest rates, they also exhibited the most severe difference in defaults. This figure demonstrates the basic idea behind the identification strategy. Borrowers face different interest rates depending on whether their loan is indexed to LIBOR or Treasury and as a result default at different rates.

For Option ARMs, required monthly payments are instead fixed for the initial period. As a result, changes in interest rates have no direct impact on monthly obligations. Because the mortgage must account for changes in the interest rate somehow, any additional interest accrual is incorporated directly into the balance. This means that for Option ARMs, the divergence between Treasury and LIBOR rates caused borrowers with otherwise identical loans to have sizable differences in loan balances ex-post. Appendix Figure A.II provides a stylized example of this pattern. Consider two identical $100,000 loans at origination, one of which faces a high realization of interest rates, while the other faces a low realization. Two years into the loan, the two borrowers will still have the same monthly payment, but the first borrower may owe thousands of dollars more than the second.

The impact of a LIBOR or Treasury index on the loan balance is not uniform across the sample period. Each origination month for each index generates a unique path of interest rates and a unique balance trajectory. Figure III demonstrates this difference-in-difference variation in borrower's balances. The plot shows the loan balance over time for four sample $100,000 loans: one LIBOR- and one Treasury-indexed loan originated in January 2005, and one of each originated in January 2007.[22] Each of the four shows a distinct balance trajectory.

III.4 Data

The data on ARMs and Option ARMs used in this paper are taken from a loan-level panel of privately securitized mortgages provided by Moody's Analytics (formerly provided by Blackbox Logic), representing over 90 percent of non-agency residential mortgage backed securities. These data provide detailed information about loans at origination, including borrower information, property characteristics, and contract terms. They also include dynamic information on monthly payments, loan balances, modifications, delinquency, and foreclosure. We focus on a sample of around 500,000 Option ARMs originated between 2004 and 2007, tied to either LIBOR or Treasury rates. To establish comparability with this sample, we also analyze a sample of around 450,000 5/1 ARMs originated in this period under the same criteria.

III.5 Summary Statistics: Balance Across Indices

Table I shows summary statistics for the primary sample studied here, divided between loans indexed to Treasury and those indexed to LIBOR. For Option ARMs highlighted in Panel A, note that Treasury is the dominant index, representing approximately 90 percent of loans. Despite this, the majority of variables are reasonably balanced across the two groups. Borrowers have fairly high FICO credit scores for both indices, with an average of 706 for Treasury loans and 714 for LIBOR loans. Furthermore, the majority of loans are low or no documentation—79 percent of Treasury loans and 77 percent for LIBOR. The original leverage choice, summarized by the origination loan-to-value ratio (LTV), is also quite similar across the two indices, at 76.6 for Treasury and 77 for LIBOR.[23] Nearly all loans are subject to some form of prepayment penalties, and the majority of both Treasury and LIBOR loans are

[22]These figures are based on simulated loans with a margin of 3.5 for both samples, based on the 3-month LIBOR and 12-month MTA respectively.

[23]We restrict the sample to loans with origination LTVs between 50 and 100.

for primary residences.[24] There is a difference in the average margin for each—3.21 for Treasury loans versus 2.85 for LIBOR—but this gap reflects the baseline spread between the indices themselves.

The four most common states for both indices are California, Florida, Arizona, and Nevada. While Treasury loans are slightly more concentrated in California, the overall geographic patterns are similar across states. Appendix Figure A.III shows the relatively uniform density: between 5 and 15 percent of loans are indexed to LIBOR in nearly all states. The largest difference between the two samples is in the timing of origination. LIBOR loans are significantly more concentrated in 2004, while Treasury loans are more heavily represented in 2005 and 2006. This pattern is also reflected in the slightly higher average balances for Treasury loans. Overall, the observable details in both groups are reasonably balanced.

Standard ARMs are highlighted in Panel B of table I. There are some greater discrepancies between Treasury and LIBOR-linked loans in this sample, such as along the dimensions of loan size (higher among Treasury loans), Low/No-doc (higher among Treasury loans), and prepayment penalties (higher among Treasury loans). To address identification concerns, our primary empirical approach will control for all of these loan dimensions, as well as an indicator for index value (Treasury or LIBOR) and loan origination month. The identifying variation comes from the relevant spread between Treasury and LIBOR-linked loans affected borrowers originated in some periods more than others.

III.6 In Comparison to the Broader Market

While the unique characteristics of the Option ARM may have attracted a certain sample of the population, the growth of the product was not the result of an inflow of observably low quality borrowers. Option ARM borrowers have relatively good credit scores. The average FICO score in the sample studied here is over 700, and a negligible number of borrowers have scores below 620.[25] In this observable dimension, borrowers with Option ARMs reflect the general pool of borrowers rather than some particularly subprime subset.[26]

The geographic patterns of Option ARM originations also reflect the broader mortgage market. As in the sample of Option ARMs, the top two states for mortgage lending are California and Florida, representing 24 percent and 9 percent of all originations, respectively. Arizona (3.5 percent) and Nevada (1.7 percent) are also prominent nationally. Furthermore, these states all experienced sig-

[24] The stated level of owner occupancy is likely an overstatement due to false reporting by unreported investors (Piskorski, Seru and Witkin, 2015).

[25] The average credit score in the US is below 690, while the average among conforming loans purchased by Freddie Mac is 723 (Frame, Lehnert and Prescott, 2008). 620 is a common threshold to identify subprime borrowers.

[26] Amromin et al. (2011) find that borrowers with complex mortgages tend to be sophisticated, with high incomes and credit scores relative to the subprime population.

nificant growth relative to the market as a whole in the years leading up to the crisis.[27]

The initial leverage choices of borrowers with Option ARMs are not out of line with the market as a whole. The average original LTV for Option ARMs, close to 77, is slightly larger than conforming loans purchased by Fannie Mae or Freddie Mac but below the average LTV for subprime adjustable rate mortgages.[28] The average initial loan size for Option ARMs is also larger than that of conforming loans,[29] although still below the conforming loan limit.

One peculiarity distinguishing Option ARMs from conforming loans is the rarity of income verification. Given low payments, protections against payment increases, and generally favorable expectations about housing prices, lenders were relatively unconcerned about borrower's ability to meet their monthly obligations. This was especially true given that most loans were made to borrowers with high credit scores.[30] This led to the prevalence of low or no documentation loans—nearly 80 percent in this sample. For these loans, borrowers provide little or no formal evidence of sufficient income to meet monthly payments, often simply stating income with no verification. In the market as a whole in 2007, low or no documentation loans represented only 9 percent of outstanding loans. However, nearly 80 percent of Alt-A securitizations in 2006 were low or no documentation, mirroring the pattern in this sample (Financial Crisis Inquiry Commission, 2011).

IV Empirical Strategy

IV.1 *Framework for Moral Hazard and Adverse Selection*

We begin with a discussion of the empirical separation of adverse selection and moral hazard in an OLS context. We supress, for the moment, a discussion of the role of monthly payments on default behavior.

More specifically, for borrower i in MSA j at loan age t, we consider models of the form:

$$D_{ijt+1} = \mathbb{1}\{\alpha E_{ijt} + \gamma L_i + x'_{ijt}\beta + \omega_{m_i} + \delta_{index_i} + \zeta_j + u_{ijt} > 0\}. \tag{1}$$

Here, D_{ijt+1} is a measure of default by time $t+1$. E_{ijt} is a measure of the borrower's negative equity, measured either as the current difference between a borrower's balance and the value of the

[27]All gained as a proportion of the market between 1996 and 2006: California by 25 percent, Florida by 60 percent, Arizona by 55 percent, and Nevada by 44 percent. All statistics presented here are available in the 2006 Mortgage Market Statistical Annual.

[28]The average original LTV for Fannie Mae and Freddie Mac in 2007 was 72 and 71, respectively, according to Frame, Lehnert and Prescott (2008). The average LTV for subprime adjustable rate mortgages was over 80 as early as 2004 (Chomsisengphet, Pennington-Cross et al., 2006).

[29]The average conforming loan size was $236,400 for purchases and $233,800 for refinances in 2006 (Avery, Brevoort and Canner, 2007).

[30]See `http://www.mortgagevox.com/meltdown/option-arms.html`.

home or as the current LTV. L_i is the borrower's initial leverage choice, measured as the original LTV. The vector x_{ijt} contains all time varying covariates relevant to the default decision as well as z_i, the set of all borrower characteristics and loan features known to the bank at the time of contracting. We include fixed effects for the origination month of the loan (ω_{m_i} or λ_{m_i}), the index choice (δ_{index_i} or μ_{index_i}), and the borrower's MSA (ζ_j or ϕ_j). Standard errors are clustered at the MSA level. Most specifications additionally allow for state specific time trends. We estimate the equation separately at different t, so do not include loan age effects. We interpret $\gamma > 0$ as evidence of adverse selection and $\alpha > 0$ as evidence of moral hazard.

The basic challenge in separately identifying α and γ—the effects of current equity and initial leverage on default—is the mechanical relationship between L_i and E_{ijt}. In the absence of other differences, borrowers with identical L_i will tend to have identical E_{ijt}. For borrowers consistently making minimum payments, there are only two factors that might cause those with identical L_i to have different E_{ijt}: differences in home prices or differences in interest rates that lead to different balances.

Unfortunately, shocks to home prices may, in general, be correlated with u_{ijt}. For example, a local labor market shock may influence both home prices and, separately, the borrower's probability of default. Additionally, because home prices can never be observed directly but rather must be inferred from the sale prices of surrounding homes, E_{ijt} is measured with error. Similarly, variation across time in interest rates is likely correlated with macro conditions, while cross-sectional variation potentially reflects borrower's endogenous contract choices. Isolating exogenous variation in E_{ijt} is non-trivial but necessary to accurately estimate α and γ.

In the next subsection, we illustrate the IV strategy that can address the challenges of consistently estimating α and γ. We also justify the use of this single equation model, showing that Equation 1 can be derived by collapsing a more comprehensive model that explicitly specifies the borrower's demand for leverage alongside the default choice. Doing so also clarifies the interpretation of α as the moral hazard effect and γ as the adverse selection effect. Finally, we propose a secondary strategy to jointly estimate leverage demand alongside the default choice. While more complex, this approach allows us to recover fundamental parameters more directly relevant for the simulation exercise performed in the last section.

IV.2 Identification

To address the biases in the estimation of moral hazard and adverse selection, we introduce an instrumental variable approach. In our analysis, E_{ijt} is instrumented by a function of the borrower's index choice and origination month:

$$E_{ijt} = f_t(m_i, index_i) + \lambda_{m_i} + \mu_{index_i} + z_i'\pi_t + \phi_j + e_{ijt}. \tag{2}$$

Continuing to supress the role of monthly payment shocks, this estimation will focus on the Option ARM sample for which these payments can be neglected. We focus on plausibly exogenous variation in E_{ijt} that comes from the interaction of the borrower's index and the origination month of the loan for this product. Each {Index Type, Origination Month} pair generates a unique trajectory of interest rates for a borrower. Utilizing this difference-in-difference variation allows us to control for any origination month-specific cohort effects or trends in the macro-economy, while also accounting for any fixed differences between borrowers with different indices.[31]

Equation 2 shows the basic framework for isolating this variation in E_{ijt}. The function $f_t(m_i, index_i)$ is effectively a set of instruments for E_{ijt}. These instruments capture changes in E_{ijt} that result from the interaction between the origination month m_i and the index, but are distinct from fixed month and index effects λ_{m_i} and μ_{index_i}.

Developing an instrument involves choosing a functional form for $f_t(m_i, index_i)$. In what follows, we focus primarily on a specification that exploits all possible variation in the interaction between the month of origin and the index, that is:

$$f_t(m_i, index_i) = \lambda_{m_i} \times \mu_{index_i}.$$

In words, we use a full set of fixed effects for every possible {Index Type, Origination Month} pair as instruments for the borrower's home equity. This specification has the advantage of limiting assumptions about functional forms and provides a large number of instruments.

However, because this large set of instruments does not provide an easily interpretable first stage and may suffer from problems associated with many weak instruments, we also consider a secondary option. The basic idea behind this exercise is to produce a strong predictor of a borrower's balance using only the origination month and index. To do so, we mechanically calculate the full balance trajectory for a sample loan for each index type and origination month. The sample loan sets all potentially endogenous terms, which vary for any given loan, to standard values.[32] As a result, the instrument captures the variation in the balance that is driven by the interest rate realizations while excluding any variation due to endogenous contract choices. We refer to the instrument developed using this calculation as the "simulated" instrument.

[31] The difference-in-difference framework allows us to control for fixed lender characteristics, even for originators or servicers who exclusively feature one of the two indices.

[32] A margin of 3.5, an initial loan size of $400,000, and a minimum payment based on a 1.75 percent teaser rate.

IV.3 Leverage Demand and Default Choices

In this section, we show that Equation 1 can be derived from a more explicit model of the borrower's leverage and default choices. We begin with the default rule suggested by the theoretical model in Section II. A borrower defaults if the value of the home (H) falls far enough below the balance (B) to justify incurring any default costs C_{ijt}. C_{ijt} is a reduced form parameter that captures any observable and unobservable factors that influence the borrower's decision to default at a given level of home equity. The default condition is then:

$$D_{ijt+1} = \mathbb{1}\{B_{ijt} - H_{ijt} > C_{ijt}\}.$$

A slight relabeling generates a condition that resembles Equation 1 above. First, let $E_{ijt} = B_{ijt} - H_{ijt}$, a measure of the borrower's negative equity. E_{ijt} is large when the borrower owes much more than the home is worth. Next, decompose C_{ijt} into its observable and unobservable components, where $-C_{it} = \sigma_{\varepsilon}(x'_{ijt}\beta + \omega_{m_i} + \zeta_j + \delta_{index_i} + \varepsilon_{ijt})$ and only $\varepsilon_{ijt} \sim N(0,1)$ is unobservable. Defining $\alpha = \frac{1}{\sigma_{\varepsilon}}$, we can write the default condition as:

$$D_{ijt+1} = \mathbb{1}\{\alpha E_{ijt} + x'_{ijt}\beta + \omega_{m_i} + \zeta_j + \delta_{index_i} + \varepsilon_{ijt} > 0\}. \tag{3}$$

While the borrower's contract choice is the result of a complex maximization problem, we abstract from this structure and specify a linear demand model for leverage. Letting L_i represent the original LTV chosen by borrower i:

$$L_i = z'_i\psi + \theta_{m_i} + \eta_{index_i} + v_i. \tag{4}$$

Within this framework, moral hazard and adverse selection have straightforward empirical predictions:

(I) *Moral Hazard:* $\alpha > 0$ provides evidence of a moral hazard effect, where α quantifies the impact of the borrower's equity on default.

(II) *Adverse Selection*: $\rho = Corr(v_i, \varepsilon_{ijt}) > 0$ provides evidence of adverse selection. Borrowers who choose higher than average L_{ij} based on unobservables (large v_i) are more likely to default holding home equity constant (large ε_{ijt}).

In the next subsection, we describe an approach to estimating Equations 3 and 4 jointly. However, to arrive at Equation 1, we collapse leverage demand and the default decision based on the correlation between v_i and ε_{ijt}. In particular, we write $\varepsilon_{ijt} = \gamma v_i + u_{ijt}$, where $\gamma > 0$ holds if the two are positively correlated, that is, if there is adverse selection.[33] Replacing v_i using Equation 4 gives $\varepsilon_{ijt} = \gamma(L_i - z_i'\psi - \theta_{m_i} - \eta_{index_i})$. Replacing ε_{ijt} in Equation 3, collapsing month and index fixed effects, and absorbing z_i into x_{ijt} gives Equation 1.

IV.4 Joint Model

Although the collapsed model in Equation 1 is more straightforward, there are also benefits to jointly estimating the leverage demand and default choice. Given the need to instrument for E_{ijt}, doing so actually involves estimating three equations:

$$\begin{aligned} D_{ijt+1} &= \mathbb{1}\{\alpha E_{ijt} + x_{ijt}'\beta + \omega_m + \zeta_j + \delta_{index} + \varepsilon_{ijt} > 0\} \\ L_i &= z_i'\gamma + \theta_m + \eta_{index} + v_i \\ E_{ijt} &= f(m_i, index_i) + \lambda_m + \mu_{index} + z_i'\pi_t + \phi_{jt} + e_{ijt}. \end{aligned}$$

We impose a parametric structure on the errors. In particular:

$$\begin{pmatrix} \varepsilon_{imt} \\ v_i \\ e_{it} \end{pmatrix} \sim N\left(\begin{matrix} 0 \\ 0 \\ 0 \end{matrix}, \begin{bmatrix} 1 & & \\ \rho_{\varepsilon v}\sigma_v & \sigma_v^2 & \\ \rho_{\varepsilon e}\sigma_e & \rho_{ve}\sigma_v\sigma_e & \sigma_e^2 \end{bmatrix} \right).$$

Again, we estimate cross-sectionally at different t and hence make no assumption about the evolution of errors over time. This specification allows a relatively straightforward estimation. We effectively employ a control function approach following Blundell and Powell (2004), incorporating an additional linear equation.

The benefit of this approach is that we are able to recover a few parameters that provide a basis for simulation in Section II. Perhaps most importantly, we directly recover $\rho_{\varepsilon v}$, the correlation between ε_{ijt} and v_i. This correlation determines the strength of the adverse selection effect. Furthermore, under the normality assumption, we are able to recover the underlying distribution of the default costs C_{ijt} for any individual i. Recalling that $-C_{ijt} = \sigma_\varepsilon(x_{ijt}'\beta + \omega_{m_i} + \zeta_j + \delta_{index_i} + \varepsilon_{ijt})$, we have:

$$C_{ijt}|x_{ijt}, \omega_{m_i}, \zeta_j, \delta_{index_i} \sim N\left(\frac{-(x_{ijt}'\beta + \omega_{m_i} + \zeta_j + \delta_{index_i})}{\alpha}, \frac{1}{\alpha}\right).$$

The distribution of C_{ijt} characterizes the moral hazard effect, while $\rho_{\varepsilon v}$ summarizes the degree to which borrower's knowledge of their place in this distribution impacts leverage demand.

[33] In the normal case, $\gamma = \rho\frac{\sigma_\varepsilon}{\sigma_v}$.

IV.5 Identification on the ARM Sample

The preceding sections focus on our identification on a sample of Option ARM loans, where the payment component of the loan can be ignored as required payments are minimal, progress according to a preset schedule, and does not vary across the identifying variation in index and origination month. In this section, we introduce the role of payment shocks and focus on our identification efforts on the 5/1 ARM sample, in which we focus on the identification of payment shocks and the measurement of selection along liquidity sensitivity:

$$D_{ijt+1} = \mathbb{1}\{\alpha E_{ijt} + \gamma L_i + x'_{ijt}\beta + \omega_{m_i} + \delta_{index_i} + \zeta_j + \eta r^o_{ijt} + \tau r^r_{ijt} + u_{ijt} > 0\}. \tag{5}$$

Where D_{ijt+1} remains the delinquency event for individual i originating his mortgage with loan age t, and additional covariates include r^r_{ijt} is the observed reset rate at the time of the first rate reset, and r^o_{ijt} is the interest rate at origination.[34]

As before, a difference-in-difference approach provides an instrument. However, in this case, the object of instrumentation is the interest rate upon reset:

$$r^r_{ijt} = f_t(m_i, index_i) + \lambda_{m_i} + \mu_{index_i} + z'_i\pi_t + \phi_j + e_{ijt}. \tag{6}$$

In measuring the reset interest rate, we consider both the composite rate—including both the index component as well as a margin term—as well as the actual monthly payment made by the borrower.

Our identifying assumption is $E[u_{ijt}|x_{ijt}] = 0$. Under this assumption, our test for the existence of payment shock effects comes down to the simple test of:

$$H_0 : \tau = 0$$

against:

$$H_1 : \tau > 0.$$

Moreover, finding that τ is different across different levels of origination leverage is evidence of ex-ante adverse selection affects along the dimension of sensitivity to liquiidty shocks.

[34] Note that for borrowers within a fixed loan duration, say 5/1, the origination month and 1st reset month are perfectly collinear, so there is no need to control for both.

V RESULTS

In this section, we describe the central empirical results of the paper. We begin by defining a few variables used in the analysis. We then document the correlation of leverage and mortgage default. Next, we describe first stage results: the instruments we use are correlated with borrower's balances and payments, are directly predictive of default in a reduced form, and do not predict borrower characteristics such as credit scores. We next turn to the results of the primary, single equation model of default. We find strong evidence of both moral hazard and adverse selection, which hold across numerous robustness checks. We begin our discussion on the Option ARM sample, where we can neglect the role of monthly payments, before focusing on a 5/1 ARM sample focusing on the role of payment shocks and selection on liquidity sensitivity. Finally, we discuss the estimation of the joint model of leverage demand and default choice, which provides parameters that directly inform the simulations presented in the next section.

V.1 Definitions of Key Variables

The empirical analysis revolves around three variables: default D_{ijt+1}, original leverage L_i, and current equity E_{ijt}. Here, we discuss the definitions of each as used below:

(I) **Default (D_{ijt+1}):** The standard definition for default used here is a borrower being 60 or more days past due on monthly payments. Typically, D_{ijt+1} measures the outcome of default between years t and $t+1$. However, when explicitly stated, D_{ijt+1} may also refer to default at any point between loan origination and $t+1$.

(II) **Original Leverage (L_i):** Original leverage is measured as original loan-to-value in percentage terms.

(III) **Current Equity (E_{ijt}):** we use two alternative measures of E_{ijt} throughout the analysis. The first is the borrower's *negative equity*. This is defined as the current balance on the loan less the value of the home. The second is the borrower's current *loan-to-value*, the ratio of the current balance to the current value of the home. Both of these measures grow as the borrower's balance increases and fall if the price of the home increases. As home values are generally only recorded when houses are sold, we follow the literature and impute the current home value based on local home price indices.[35]

Unfortunately, we do not observe E_{ijt} for borrowers who exit the sample prior to time t. This prevents us from using the full sample for specifications that incorporate current home equity.

[35] We use Zillow's zip code level home price index, available at http://www.zillow.com/research/data/.

However, given the contract terms for a mortgage—the margin, initial monthly payment, initial balance, and index—predicting the balance up to the first delinquency or partial prepayment is a straightforward mechanical calculation. Using just loan terms at origination and interest rates, we are able to predict the observed values of E_{ijt} with a high degree of accuracy ($R^2 > 0.95$). In regressions that incorporate the full sample, we use these imputed values of E_{ijt}, which are available for all borrowers, rather than the observed values.

V.2 *Correlation of Leverage and Default*

In this section, we motivate our subsequent analysis by illustrating the raw relationship between leverage and default. In Figure IV, we plot the relationship between original leverage and ex-post default both among the Option ARM (Panel A) and 5/1 ARM (Panel B) samples. The size of the dots illustrates the proportion of borrowers in each bin (tight bunching around round LTV amounts, particularly 80, is a noticible feature of our sample stemming from discontinuities in loan pricing). In both samples, we observe a monotonic relationship between original leverage decisions and ex-post default outcomes.

As our preceeding categorization has suggested, there are several possible explanations for this positive correlation:

(I) Adverse Selection, in this context, would suggest that borrowers who take on more leverage (put down lower down payments) are riskier in unobservable ways to the lender in their default threshhold should they be exposed to negative equity ex-post.

(II) Moral Hazard, in this context, suggests that borrowers with little equity are more likely to be exposed to negative equity in the future, or to situations in which higher monthly loan payments are binding and unaffordable to liquidity-constrained borrowers.

Alternatively, the raw relationship between leverage and default may simply reflect the role of other omitted variables (i.e., borrowers with low down payments may be more likely to live in regions that happened to experience large unemployment shocks ex-post).

The raw relationship between origination leverage and ex-post default persists in Figure V, which plots regression coefficients for bins of origination LTV against future default for a sample of 5/1 ARMs. Even when controlling for variables observable to the lender at the time of origination, we observe a monotonic relationship between levels of origination leverage and future default. To further separate the adverse selection and moral hazard components in a simple OLS context, we also add controls for ex-post current LTV. The fall in the magnitude of the coefficients on original leverage captures the moral hazard component—original leverage predicts default in part because it is associated with a higher likelihood of borrowers being in negative equity ex-post. A further set of controls also accounts for the monthly payment, to adjust for the fact that higher leverage also results in a greater financial burden of monthly payments.

We find that origination leverage predicts future defaults, even when controlling for an updated measure of leverage incorporating amortization and local house price shocks, as well as monthly payments. This residual component of the leverage-default relationship is consistent with the notion of adverse selection—that lenders use origination leverage to screen borrowers, and so those borrowers who take low down payments are more likely to be risky even controlling for observable characteristics, higher loan payments, and the likelihood of future negative equity. Though these regressions are consistent with a substantial role for both moral hazard and adverse selection in explaining the link between leverage and default; we next turn to a more fully identified model to isolate these components.

V.3 First Stage

Table II shows a first stage analysis of the pass-through of financial index shocks onto borrowers. Our primary instrument uses a difference-in-difference interaction of origination month and financial index on the interest rates faced by borrowers. Because this primary specification uses a large number of fixed effects, and hence does not provide an easy to interpret first stage, we use the simulated instrument described above—a single variable—to produce the coefficients in this table. We report F-statistics from both the simulated and fixed effect first stage approaches.

At 24 months, predictive power is strong, with F-statistics suggesting that the instruments are relevant in both the fixed effects and simulated instrument specifications (although the F-statistic drops below 10 when using fixed effects to predict negative equity).[36]

Panel B of this table illustrates a first stage specification for the 5/1 ARM sample. In these specifications, we regress the expected interest rate drawn from the relevant financial index (LIBOR or Treasury) against the composite interest rate faced by the borrower or actual monthly payment. In columns (1)-(4), we focus on the post-reset period in which these interest rate shocks are binding, though to address survival bias until that date we also generate simulated interest rates and payments in columns (5)-(8) using loan characteristics of all loans. The key message from Panel B is that changes in financial indices, unsurprisingly, impact the payments that borrowers make. The size of the pass-through is slightly less than 1 due to partially to the presence of caps and floors, which

[36]Because the current loan-to-value or negative equity at 24 months is only observed for loans that actually survive to those points, the first stage regressions in the first four columsn of Panel A are necessarily conducted on a selected sample. Columns (5)-(8) of panel A replaces the observed values of E_{ijt} with imputed values, which allows the use of the full sample. While the F-statistics only exceed 10 without covariates, both versions of the instrument are relevant (if weak) with the full sample.

attentuate to an extent large increases and decreases in the underlying financial indices.

Focusing next on the Option ARM sample, we conduct additional graphical analysis on the relevance of our instrument for E_{ijt} to address three points.

First, do borrowers actually have significantly higher E_{ijt} when the instrument suggests balances should be high? Confirming the regression analysis, Panel A of Figure VI shows that this is the case when examining different loan horizons. The plot presents the coefficient on the simulated instrument from the simplest possible specification for considering relevance: a regression of E_{ijt} on the instrument, controlling for origination month and index fixed effects. When the simulated instrument is high, borrower's E_{ijt} are high. This pattern holds across the first several years of the loan, although the size of the correlation declines over time.

Second, Panel B shows that borrowers also default more when the instrument is high. This is a reduced form and shows coefficients from an identical exercise to that in Panel A, replacing E_{ijt} with default D_{ijt}. Third, Panel C shows evidence of instrument exogeneity. Despite predicting borrower's balances and defaults, the instrument is not correlated with FICO credit scores, a key measure of borrower's creditworthiness.

V.4 Main Results: Single Equation Model

The primary specifications attempt to isolate adverse selection and moral hazard following Equation 1. In the main tables, we use linear probability models and a standard instrumental variables approach. In the Appendix, we show probit estimates, accounting for the endogeneity of E_{ijt} following Blundell and Powell (2004).

The main tables are structured to show three versions of each specification of interest: baseline, OLS, and IV. The first is a reference and shows the baseline relationship between original LTV and default, including relevant controls but excluding any measure of current equity. For OLS regressions, we add a measure of E_{ijt} to the baseline regression but do not account for endogeneity in E_{ijt}. Finally, in the IV regressions we explicitly instrument for E_{ijt} with the full set of $\lambda_m \times \mu_{index}$ fixed effects. The coefficient on E_{ijt} gives the moral hazard effect, while the coefficient on original LTV gives the adverse selection effects. Comparing the IV regressions to the baseline regressions gives a sense of the role of moral hazard in the overall correlation between leverage and default.

Table III presents the primary set of specifications for Option ARMs, showing a cross-section of borrowers 24 months after origination.[37] This table includes E_{ijt} defined as both current negative equity (Panel A) and current LTV (Panel B). In different specifications we include two levels of controls: a basic set with only origination month and index fixed effects, and a comprehensive set, including

[37]Other loan ages are shown in the Appendix.

MSA fixed effects, flexible controls for the original FICO credit score (dummies for each 20-point bin), state-level time trends, loan originator and servicer fixed effects, and controls for documentation, loan purpose, occupancy, property type, prepayment penalties, private mortgage insurance, second liens, and the original home value.

The left-hand side of Panel A shows that there is strong evidence of both adverse selection and moral hazard when defining E_{ijt} as current negative equity and including only basic controls. The estimated moral hazard effect in the IV specification suggests that a \$100,000 increase in negative equity increases the one year default probability by 4.5 percentage points (17 percent). The estimated adverse selection effect suggests that a 10-point increase in the borrower's original LTV is associated with a 3.3 percentage point (12.5 percent) increase in the one year default probability. The OLS results are quite similar, showing slightly larger moral hazard effects and a slightly larger role for adverse selection. Comparing the role of original LTV in the IV regression (0.331) to that in the baseline estimate (0.586) implies that adverse selection is responsible for more than half of the baseline correlation. However, it is crucial not to over-interpret the coefficient on original LTV with this limited set of controls. Without controlling for information available at loan origination, this result pools true selection on unobservables with lenders' steering of riskier borrowers towards smaller loans.

The right-hand side of Panel A includes the full set of controls and shows (i) a larger moral hazard effect and (ii) an adverse selection effect that is similar in levels but smaller as a fraction of the baseline estimate. The estimated moral hazard effect implies that a \$100,000 increase in negative equity increases the one year default probability by 8.9 percentage points (33.5 percent). The estimated adverse selection effect shows that, all else equal, borrowers who choose 10-point larger initial LTVs are 2.6 percentage points (10 percent) more likely to default between 24 and 36 months. However, including the full set of controls also leads to a significant increase in the baseline correlation between original LTV and default. As a result, adverse selection accounts for approximately 36 percent of the baseline correlation with appropriate controls. This leaves moral hazard responsible for the remaining 64 percent.

Panel B repeats the exercise from Panel A but defines E_{ijt} as current loan-to-value. With full controls, the effects are quite similar to those found in Panel A. Adverse selection is responsible for 32 percent of the baseline correlation between original LTV and default, while the remaining 68 percent is due to moral hazard. These estimates imply that borrowers that choose 10-point higher original LTVs are 2.3 percentage points more likely to default between 24 and 36 months, all else equal, while a 10-point increase in current LTV at 24 months increases the probability of default by just over 4 percentage points. Furthermore, specifications without controls highlight the potential complications of ignoring the information available to the bank. The OLS and IV show negative (although insignificant) coefficients on the original LTV when controlling for the current LTV.

V.5 Robustness for the Single Equation Model

Appendix C discusses a number of Appendix tables intended to serve as robustness checks to Table III and to provide alternative estimates of interest. Appendix Table A.II considers how the results in Table III change across three relevant subgroups. The basic results are as follows: we find stronger moral hazard effects in states with limited recourse vs. those with full recourse, stronger selection effects in no/low documentation loans versus full documentation loans, and minor differences in purchase vs. refinance mortgages.

To show that the effects we find are not specific to default at 24 months, Appendix Table A.III presents identical regressions to those in Table III, except with current E_{ijt} defined at 48 months and the dependent variable defined to be default between 48 and 60 months. The results are similar to those at 24 months, albeit somewhat muted.

To deal with the potential for differential survivial to 24 months, Appendix Table A.IV considers the impact of the original LTV and current E_{ijt} on cumulative default outcomes, that is, on default at any point up to 36 months. These estimates show strong evidence of both moral hazard and adverse selection. Details of the approach and estimation are outlined in Appendix C.

Appendix Tables A.V A.VI and A.VII explore further robustness. The results are robust to (i) alternative functional forms of E_{ijt}, (ii) probit and control function specifications, which are potentially more realistic than the linear probability model, (iii) the use of the simulated instrument rather than the full set of fixed effects, and (iv) alternative definitions of default, ranging from mild (30 days past due) to extreme (foreclosure).

V.6 Joint Model

The final step of our empirical analysis is to estimate a joint model of leverage demand alongside the default choice. Doing so allows us to recover parameters that more directly relate to the model developed in Section II and that can be used to inform the simulations developed in the next section. Because of the increased computational complexity of this estimation, we slightly reduce the richness of included controls, e.g. substituting MSA fixed effects with state fixed effects. We estimate the model separately at 24, 36, and 48 months, and again define E_{ijt} as both current LTV and home equity. These estimates are presented in Table V and qualitatively align with estimates from the single equation model.

The primary benefit is in providing estimates of three parameters: (i) $\rho_{\varepsilon}v$, the correlation between the errors in the leverage and default choices, where a positive value indicates adverse selection, (ii)

$\sigma_\varepsilon = \frac{1}{\alpha}$, the standard deviation of the default error in units of E_{ijt}, where a positive and significant value of α indicates moral hazard (corresponding to a finite positive value of σ_ε), and (iii) the mean of borrower's default costs, conditional on observables. This can also be interpreted as the default threshold, that is, the level of E_{ijt} above which the average borrower (with a given set of observables) defaults. While the estimates at 24 and 36 months show strong evidence of both adverse selection and moral hazard—a positive ρ and α—the estimates at 48 months are less precise.

The first and fourth columns display the estimated parameters at 24 months, with E_{ijt} defined in terms of negative equity and current LTV, respectively. The estimated threshold for default in the first column (at average values of observables) is just under \$100,000, meaning that a borrower will not default until the balance on their loan is \$100,000 above what the home is worth. The standard deviation of the default error in this specification is approximately \$190,000. Similarly, the fourth column suggests that the average borrower must owe 1.34 times what the home is worth before defaulting. The standard deviation of unobserved default costs in the population is just over 50 percent of what the home is worth: $\sigma_\varepsilon = 0.55$. Finally, the correlation between unobserved default costs and the unobserved portion of the original leverage (original LTV) choice—which measures adverse selection—is significant, and just under 0.07. We use these estimates to parameterize the model in the next section.

V.7 ARM Sample

Having established a decomposition of the relationship between leverage and default for the Option ARM sample, for which the payment component of debt could be ignored, we now turn to a deeper analysis of the role of payment shocks.

To do so, we focus on the 5/1 ARM sample. As discussed in the empirical specification section, the identification for this sample follows a similar approach deriving from the differential effect of financial index loan spreads on loans originated in different periods. However, while the impact of these interest rate shocks was felt primarily on the balance dimension; for 5/1 ARMs the impact is felt immediately as immediate increases in required monthly payments. Especially for borrowers who are credit constrained or in a position of negative equity, these higher monthly payments may drive default. In this section, we quantify this component and also establish initial selection along the dimension of liquidity sensitivity.

Table IV illustrates our main results for this sample. We observe that payment shocks have a strong impact on default. While this is not surprising in the context of prior work using interest rate shock variation among ARMs, we additionally document that there appears to be selection along this dimension. This can be seen in Panels B and C, in which the magnitude of the effect of interest rate shocks on borrower default is higher among borrowers with greater origination leverage. This effect demonstrates that a component of the selection dimension can be attributed to the fact that borrowers with higher initial leverage are more likely to respond to future income shocks due to default.

VI Simulations and Welfare Analysis

In this section, we highlight why an appropriate estimation of moral hazard and adverse selection has implications for public policy. We begin by considering an LTV cap, intended to capture an element of macroprudential regulation around leverage comparable to those implemented and considered by many countries. These policies are commonly motivated by moral hazard concerns—limiting consumer leverage limits the scope for ex-post strategic default. In our analysis, we do in fact quantify the value of these policies in lowering default rates, and identify precisely the appropriate default externalities that policymakers need to envision in order to jusfify these policies. The key innovation in our analysis, however, is the introduction of adverse selection. We argue that ignoring the role of adverse selection leads policymakers to (i) *overestimate* the reduction in defaults generated by a reduction in the LTV cap and (ii) *underestimate* the welfare loss generated by borrowers taking smaller mortgages. We consider a slightly expanded version of the model suggested in Section II and use the equilibrium concept proposed by Azevedo and Gottlieb (2017) to address the challenges of evaluating counterfactual policies in competitive markets with adverse selection.

VI.1 The Impact of Home Equity and Ex-Post Balance Writedowns

The estimated moral hazard effect has direct policy relevance. It captures the causal effect of a change in home equity on the probability of default, which is necessary to predict the effectiveness of ex-post principal writedowns in preventing mortgage defaults. The estimates in Table III suggest that, for the sample studied here, a 10 percentage point reduction in all borrowers' LTV at 24 months would have reduced defaults within a year by just over 15 percent. Relative to the literature, these estimates are on the large side, but not outside of normal bounds. For example, Bajari, Chu and Park (2008) find that a 25-point increase in the current LTV is necessary to generate a 15 percent increase in the default probability. Alternatively, Elul et al. (2010), find that borrowers with increasing CLTV from between 100 and 110 to between 110 and 120 raises the quarterly default hazard by about 30 percent of the mean.

After the crisis, policies of this form were enacted, for example the Home Affordable Mortgage Refinance Program Principal Reduction Alternative (HAMP PRA). Scharlemann and Shore (2016) use a kink in the schedule for HAMP PRA to analyze the effectiveness of the regulation. They estimate that principal writedowns— balance reductions of 28 percent on average—reduced the quarterly delinquency hazard by 18 percent (from 3.8 percent per quarter to 3.1 percent). However, their study examines only those who participated in the program (and hence were already delinquent), while my estimates consider the full population of active borrowers.

VI.2 A Model to Evaluate Ex-Ante Regulations

Understanding the effects of ex-ante regulations on welfare requires the specification of a model of borrower and lender behavior, and an equilibrium concept. We begin with the model, which is a minor expansion of the one presented in Section II.

VI.2.B Consumer Preferences

Given a contract $\{L_k, B(L_k)\}$, we characterize the observed portion of a borrower's ex-ante utility exactly as in Section II:

$$U_i(L_k) = u(y_0 - (H_0 - L_k)) + \beta\Big[\underbrace{\int_{\underline{h}}^{B(L_k)-C_i} u(y_1 - C_i)dF(H_1)}_{\text{Default}} + \underbrace{\int_{B(L_k)-C_i}^{\bar{h}} u(y_1 + H_1 - B(L_k))dF(H_1)}_{\text{Repayment}}\Big].$$

As in the theoretical model, the only source of heterogeneity in U_i is C_i, the borrower's private costs of default. However, in practice, borrowers choose mortgages on the basis of a number of factors beyond just their default costs. Recall that the estimated correlation between the leverage choice and a borrower's private default costs was only 0.07. In a richly specified model, initial mortgage choice might also be a function of heterogeneity in borrower's income, preferences (e.g. risk aversion or intertemporal elasticity of substitution), or period 0 knowledge of future C_i.

We abstract from these details and consider a simplified model in which borrowers' utility for a contract with a particular leverage choice is characterized by an observed portion, as defined above, and an independent, idiosyncratic error ϵ_{iL}:

$$V_i(L_k) = U_i(L_k) + \epsilon_{iL}.$$

This error captures, in a reduced form way, all factors that influence borrowers with the same C_i to choose different contracts. When the variance of ϵ_{iL} is high, there is a weak relationship between C_i and the chosen L. When the variance is low, the correlation increases.

It is convenient to specify ϵ_{iL} to be type 1 extreme value, in which case a borrower's choice probability for a given L can be written as:

$$P_{ik} = \frac{e^{\gamma U_i(L_k)}}{\sum_{k'} e^{\gamma U_i(L_{k'})}},$$

where γ is a viscosity parameter determined by the variance of ϵ_{iL}. Of course, this specification imposes a standard independence of irrelevant alternatives (IIA) assumption, which may not hold in a more sophisticated model of heterogeneity across borrowers.

VI.2.B Lender Profits

With these choice probabilities in hand, computing lender profits is straightforward. We assume lenders are able to recover a fraction $\delta \leq 1$ of what the home is worth in the case of default. The expected profits of a lender selling contract $\{L_k, B(L_k)\}$ to borrower i with private default cost C_i are:

$$\pi(L_k, B(L_k); C_i) = -L_k + \frac{1}{1+r_f}\Bigg[\underbrace{\int_{\underline{h}}^{B(L_k)-C_i} \delta H_1 dF(H_1)}_{\text{Default}} + \underbrace{\int_{B(L_k)-C_i}^{\overline{h}} B(L_k) dF(H_1)}_{\text{Repayment}}\Bigg].$$

The expected profits of a lender are the profits for each individual i, multiplied by the probability that i chooses contract k, integrated over the distribution of C_i (specified here as $G(C)$):

$$\Pi_k = \int P_{ik}\pi(L_k, B(L_k); C_i) dG(C).$$

VI.2.B Equilibrium Concept

There is no clear consensus on the appropriate definition of equilibrium in competitive markets with adverse selection (Chiappori and Salanié, 2013). Furthermore, because equilibria often fail to exist under standard concepts, e.g. Rothschild-Stiglitz, evaluating the counterfactual implications of policy can be difficult. However, a recent development by Azevedo and Gottlieb (2017) characterizes an equilibrium concept that is both robust—an equilibrium always exists—and straightforward to implement in a variety of applications. Equilibria of this form satisfy three requirements: (i) consumers optimize over the available set of contracts, (ii) lenders make zero profits on each contract, and (iii) there is free entry, in the sense that the equilibrium is robust to small perturbations, as defined formally in Azevedo and Gottlieb (2017).

For the purposes of simulation, utilizing this equilibrium concept is straightforward. We calculate equilibrium in what Azevedo and Gottlieb (2017) call a perturbation. We propose a fixed set of contracts (in the example presented, every integer LTV between 50 and 100). We then consider a mass of uniformly distributed behavioral borrowers equal to 1 percent of the population, who always choose a given contract. Behavioral borrowers pay back the loan in all states of the world and, as a result are costless to the lender. We use a fixed point algorithm to determine equilibrium. In each iteration, consumers choose optimally taking prices as given, and interest rates are adjusted up or down for profitable or unprofitable contracts. Convergence is achieved when profits across all contracts fall below a predefined threshold. The existence of behavioral borrowers is crucial for convergence to intuitive equilibria. Because behavioral borrowers are costless, the interest rate on any contract that is only purchased by these types is reduced until either (i) a risky borrower is indifferent between the contract and his current choice or (ii) the interest rate reaches the risk free rate. This rules out equilibria with contracts that have arbitrarily high prices and only make zero profits because they are not chosen.

VI.2.B Calibration

We calibrate three features of the simulation to the estimates from Table V. We define the mean and variance of the private costs of default based on those estimated in Column 4 of V. Furthermore, we choose γ, or equivalently the variance of ϵ_{iL}, so that the correlation between borrowers' choice of L and C_i in Regime I below matches the estimated $\rho_{\varepsilon v}$ in Column 4. All other parameters are set based on the data when possible and explicitly described in the bottom panel of Table VI. For the purposes of the simulation, I assume that borrowers have exponential utility, with CARA coefficient a.

VI.3 Welfare Implications of an LTV Cap

We consider the implications of a decreased LTV cap, that is, a limit on the initial loan provided by lenders. This can be thought of as roughly the mirror image of a standard policy in insurance markets: a mandated minimum level of coverage. We evaluate three policy regimes:

(I) **LTV Cap of 100**: In the first regime, lenders do not observe C_i, and equilibrium is as discussed above, with all loans making zero profits. The set of potential contracts contains all original LTVs between 50 and 100.

(II) **LTV Cap of 90 (No Supply Response)**: The second regime presents a naive view of the impact of an LTV cap of 90, ignoring the impacts of adverse selection. This regime evaluates the choices made by borrowers if an LTV cap of 90 were implemented but lenders did not otherwise adjust their contracts. As a result, lenders may make positive or negative profits under this regime.

(III) **LTV Cap of 90 (With Supply Response)**: The final regime considers the equilibrium allocation of credit when lenders are able to endogenously adjust contracts in response to a change in the LTV cap.

VI.3.C A Naive Evaluation of an LTV Cap: No Supply Response

We first consider a comparison of Regimes I and II, which can be thought of as the anticipated response to an LTV cap for a naive policymaker. For these purposes, we consider a naive regulator to be one who understands borrower preferences and can anticipate the contracts borrowers will choose from any given set, but who disregards adverse selection. Such a policymaker believes that the proportion of defaults for a given contract does not depend on the population purchasing that contract, and hence that there will be no supply response to a change in the LTV cap. The intuition behind this comparison is demonstrated by the dark and light gray bars in Figure VII. This figure shows results with an exaggerated degree of adverse selection, to better present the patterns across the three regimes, while Table VI presents numbers based on simulations calibrated to the empirical results.

The black bars illustrate the allocation of original LTV under Regime I and exhibit a basic pattern of adverse selection. While borrowers would prefer initial loans with LTVs of 100 in a world with perfect information, the clustering of the riskiest borrowers raises the interest rate of a 100 LTV loan significantly. As a result, safe borrowers take smaller loans to distinguish themselves from risky types and avoid paying inflated interest rates.

Under the naive view, the only borrowers impacted by the regulation are those initially choosing LTVs above 90. The borrowers who choose contracts with original LTVs below 90 in Regime I will continue to do so, while the majority of those choosing original LTVs above 90 will bunch close to the LTV cap, creating the large mass of borrowers captured by the gray bars in Figure VII.[38] Furthermore, the naive view will expect a significant reduction in defaults generated by the regulation. Because it assumes no heterogeneity across borrowers in default propensities, it also expects that those that choose an LTV of 90 under Regime II will default at the same rate as borrowers choosing an LTV of 90 under Regime I.

Columns 1 and 2 of Table VI compare Regimes I and II. There is indeed a reduction in loan size, from $270,055 to $246,265, and a corresponding reduction in average interest rates from 8.6 to 7.5 percent. This corresponds to a welfare loss of just over $8,000. Under the naive view, the expected number of defaults is significantly larger than the true reduction, even without a supply response. The naive view suggests that an LTV cap of 90 would cut the proportion of defaults by 35 percent, from 0.12 to 0.078. Appropriately accounting for the risk of the borrowers initially allocated above 90 reveals the true reduction to be just 24 percent.

[38]Because borrowers have a random component ϵ_{iL} of their preference for contracts, and because of the IIA assumption, borrowers who initially chose LTVs above 90 will not strictly choose contracts at 90. Rather, they will distribute their choices across remaining loans such that the relative choice probabilities are the same before and after the regulation.

VI.3.C Allowing a Supply Response

In addition to overstating the reduction in defaults generated by the regulation, the naive view understates the reduction in mortgage size generated by knock-on effects of the regulation. Reducing the LTV cap does indeed force some risky borrowers to decrease their LTV to 90. However, as a result, the interest rates on 90 LTV loans must also rise. Correspondingly, some borrowers who previously chose LTVs of 90 will choose slightly smaller loans, thereby leading lenders to increase interest rates on those smaller loans, causing further knock-on effects. In the presence of adverse selection, leverage can be seen as a sorting device. Eliminating high LTV loans does not eliminate the incentive of borrowers to distinguish themselves, but instead forces them to do so over a smaller range of loans.

The leftward shift of the white bars in Figure VII relative to the light gray bars demonstrates the additional reduction in mortgage size due to knock-on effects. In the calibrated simulations of Regime III, shown in the third column of Table VI, the knock-on effects cause an additional reduction in loan size of more than $250 on average. Furthermore, because lenders in Regime III appropriately account for the reallocation of risky borrowers, the interest rates of all contracts rise from 7.5 percent on average to 7.9 percent. As a result, the average borrower has a final balance that is nearly $600 larger under Regime III than Regime II. The reduction in loan size and increased borrower balance combine to generate a welfare loss that is $617 larger per borrower in Regime III as compared to Regime II.

Optimal regulation involves balancing reductions in defaults with the welfare loss that results from borrowers taking smaller loans. In the simulations provided here, a naive regulator overstates the number of defaults by 11 percent and underestimates the welfare loss due to reductions in loan size by 7.5 percent. The naive estimates suggest that for this regulation to be welfare neutral, default externalities on the order of $194,000 per default are necessary. When accounting for adverse selection, much larger default externalities are necessary to justify the regulation, on the order of $313,000 per default.

VII CONCLUSION

In this paper, we empirically separate moral hazard from adverse selection in the mortgage market. We begin by developing a theoretical framework to highlight the sources of information asymmetries. In the model, moral hazard exists as the result of limited recourse: lenders cannot contract against borrowers choosing to default when it is in their ex-post interest to do so. Adverse selection, on the other hand, results from borrower heterogeneity in willingness to default. Borrowers differ in access to liquidity, value of future credit access, attachment to the home, and many other factors that influence the default choice. If borrowers know about this heterogeneity when choosing mortgage contracts, riskier borrowers will tend to prefer larger loans.

The primary empirical contribution lies in separating adverse selection from moral hazard. We do so by exploiting a natural experiment resulting from two features of Option ARMs: fixed payments and variable interest rates. Because monthly payments do not change, the balances borrowers owe are a direct function of market interest rates. This creates a distinction between borrower's initial leverage choices and the balances they owe ex-post. To isolate plausibly exogenous variation in balances, we focus on difference-in-difference variation in interest rates that comes as the result of the financial index used to determine rate adjustments. Because of the unexpected divergence between LIBOR and Treasury rates during the crisis, borrowers experienced substantially different balances as a function of the loan's index and origination month.

This variation in borrower's balances allows us to construct a series of instruments to identify the causal effect of home equity on default—the moral hazard effect—and subsequently to back out the role of adverse selection. We find significant evidence of both information asymmetries. Moral hazard is responsible for 60-70 percent of the baseline correlation between leverage and default, while adverse selection is responsible for the remaining 30-40 percent. The estimated moral hazard effect at 24 months suggests that a policy that reduced all borrower's loan-to-values at 24 months would have reduced defaults by over 8 percent.

We separately identify the role of moral hazard and adverse selection on monthly payments by focusing on an ARM sample. As in prior research, we find a strong role for shocks to monthly payments in driving default behavior. However, we also find evidence for selection on liquidity sensitivity: borrowers with higher down payments default more frequently in response to the same shock to monthly payment.

We then translate what these estimates of moral hazard and adverse selection imply for macroprudential policy. As in standard insurance models, adverse selection imposes an externality on low risk borrowers, who must take smaller loans than they would in a world with perfect information in order to distinguish themselves from riskier types. The final contribution of this paper is to construct and simulate a model of competitive equilibrium to consider the consequences of this externality for policy. Because even defining competitive equilibrium is a notorious challenge in the presence of adverse selection, we use the robust equilibrium concept recently developed by Azevedo and Gottlieb (2017).

We evaluate the impact of a reduction in an LTV cap, a common policy aimed at reducing defaults by limiting borrower's initial leverage. We find that a naive policymaker who does not account for adverse selection will significantly *overestimate* the number of defaults prevented by a reduced LTV cap and significantly *underestimate* the welfare losses generated by borrower's taking smaller loans.

The effects of the cap propagate through the distribution. Risky borrowers are forced to take smaller loans, but safer borrowers choose to do so as well in order to differentiate themselves. Relative prices adjust for all borrowers, even those far from the binding leverage cap. We estimate that externalities on the order of $313,000 per default are necessary to make a reduction in the LTV cap from 100 to 90 welfare neutral.

This paper separates adverse selection from moral hazard in a particular segment of the mortgage market and examines a single policy. However, the relative role of these information asymmetries is relevant to some of the most important policy questions for the market as a whole. There is significant debate over a number of core mortgage regulations in the US, including the mortgage interest tax deduction and the role of the GSEs. Some argue that the potential magnitude of positive externalities from homeownership is insufficient to justify the current level of intervention in the mortgage market. The existence of adverse selection provides an additional rationale for intervention. Even in the absence of positive homeownership externalities, policies that encourage borrowers to take on larger loans may be welfare enhancing in the presence of adverse selection.

Along these lines, understanding the importance of information asymmetries may help to explain when and why some segments of the mortgage market break down. For some observable portions of the population, mortgage credit is effectively unavailable. If this is due to moral hazard, there is little room for welfare improving intervention. Defaults may simply be so high in those populations that no interest rate is profitable for borrowers, even in the absence of adverse selection. However, if these markets are unravelling due to adverse selection, there may indeed be place for regulation. While this paper provides only a first step, fully understanding the relative roles of adverse selection and moral hazard is key to determining the effectiveness of a broad class of mortgage policies.

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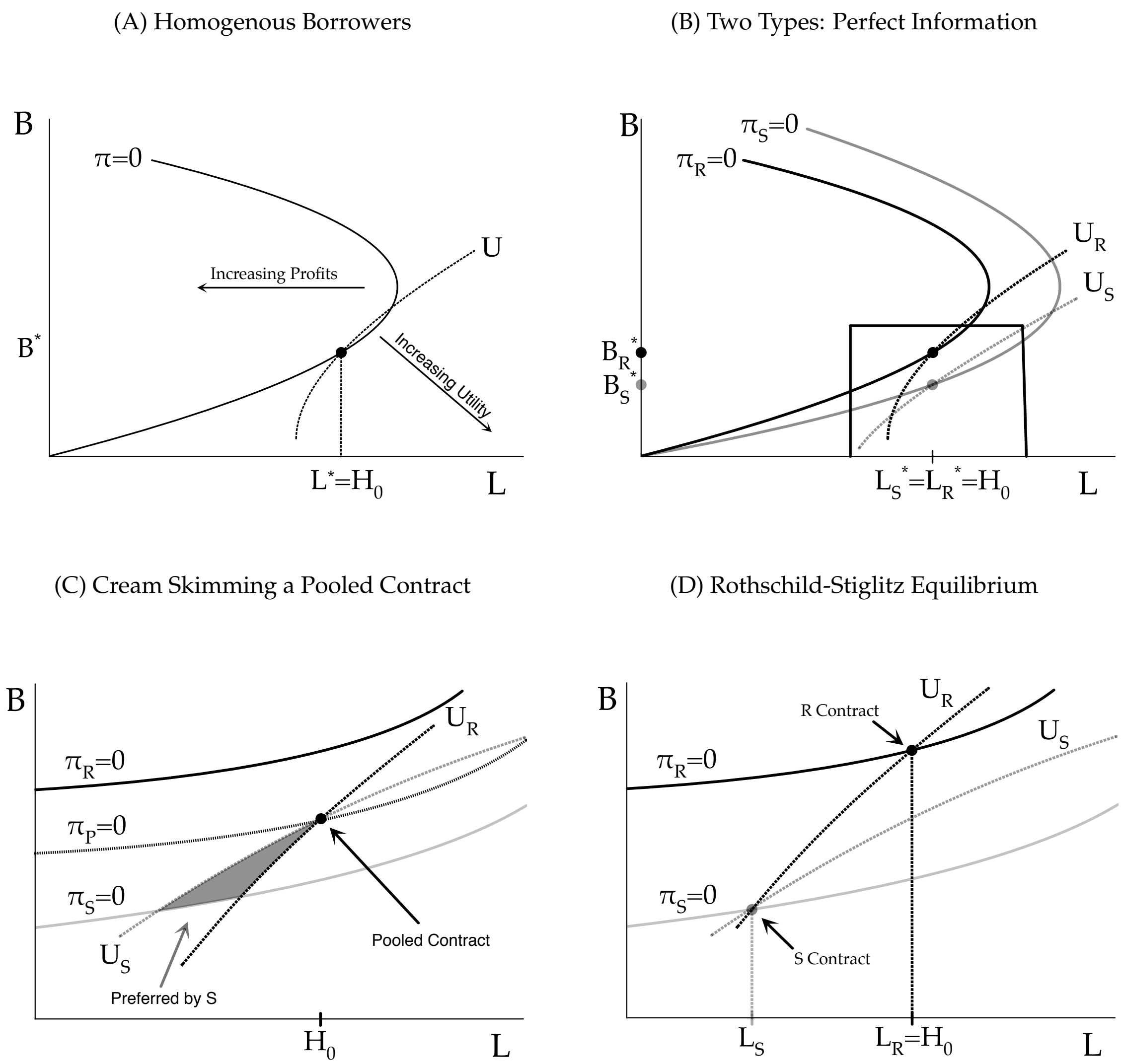
FIGURES

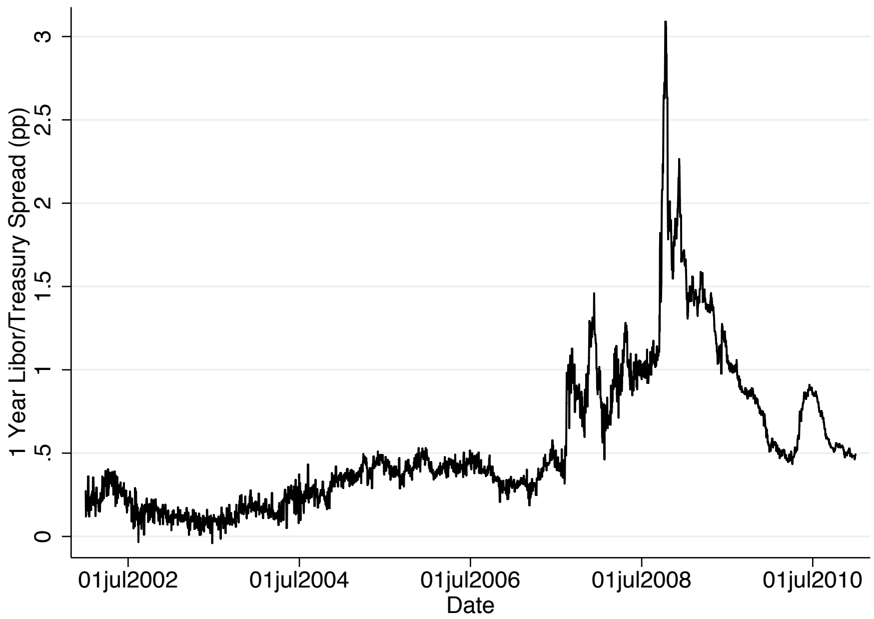
FIGURE I
THEORY: EQUILIBRIUM CONTRACTS WITH AN LTV CAP OF 100



Each graph shows the contract space for stylized two period mortgage loans. Balance is shown on the y-axis, the initial loan is shown on the x-axis. Borrowers' indifference curves are marked with U, and lenders' zero profit lines are marked with Π. Borrower utility increases with contracts offered to the southeast, lender profits increase with contracts offered to the west. Panel A displays the equilibrium contract with a single borrower type and an LTV cap of H_0. Panel B shows the equilibrium contract with a risky (R) and safe (S) borrower, and perfect information. Both borrowers receive loans of H_0, but the riskier type pays a higher interest rate. Panel C zooms in on the boxed area of Panel B, and shows the difficulty of sustaining a pooled contract with single crossing when lenders cannot observe risk types. The shaded region shows profitable contracts preferred by the borrower to the pooled contract. Panel D shows the form of a Rothschild-Stiglitz equilibrium, should it exist. The safe borrower takes a smaller loan, $L_S < L_R$, than they would with perfect information.

FIGURE II

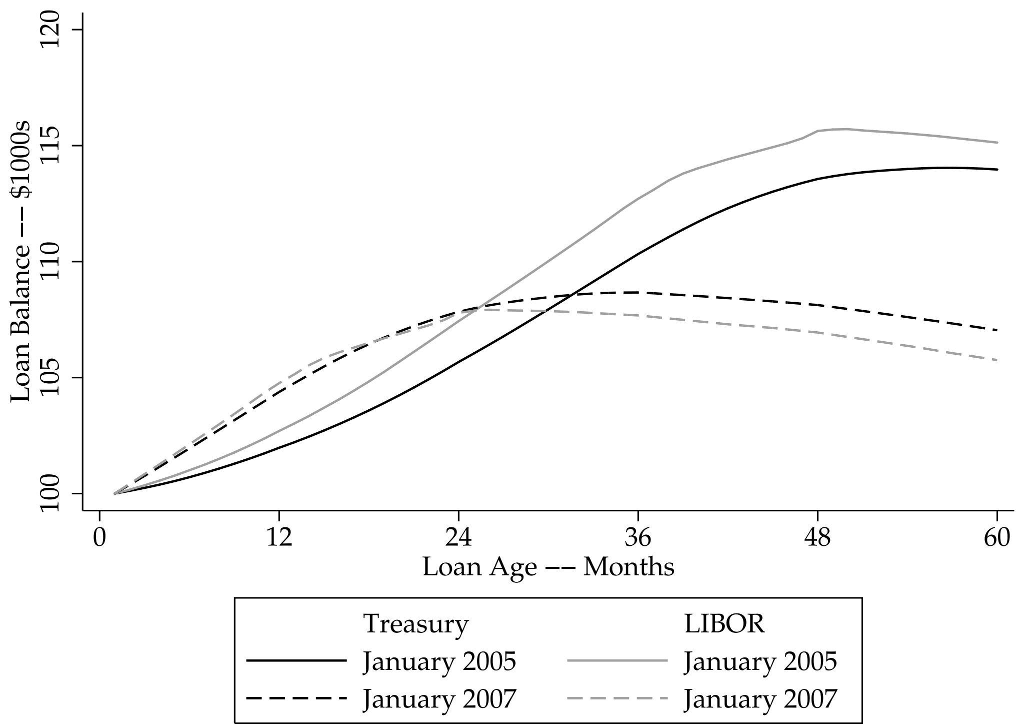
PANEL A: SPREAD BETWEEN LIBOR AND TREASURY INCREASED DRAMATICALLY DURING CRISIS



PANEL B: SPREAD IS MIRRORED IN INTEREST RATES AND DEFAULT PATTERNS FOR ARMS

Top panel shows spread between 1-year LIBOR and 1-year Constant Maturity Treasury (CMT) between 2002 and 2010. The black line in the bottom panel shows the difference in (reset) rates between LIBOR-indexed loans and Treasury-indexed loans resetting in the corresponding month. The lighter line shows the difference in the one year default probability between LIBOR and Treasury indexed 5/1 ARM loans resetting in that month.

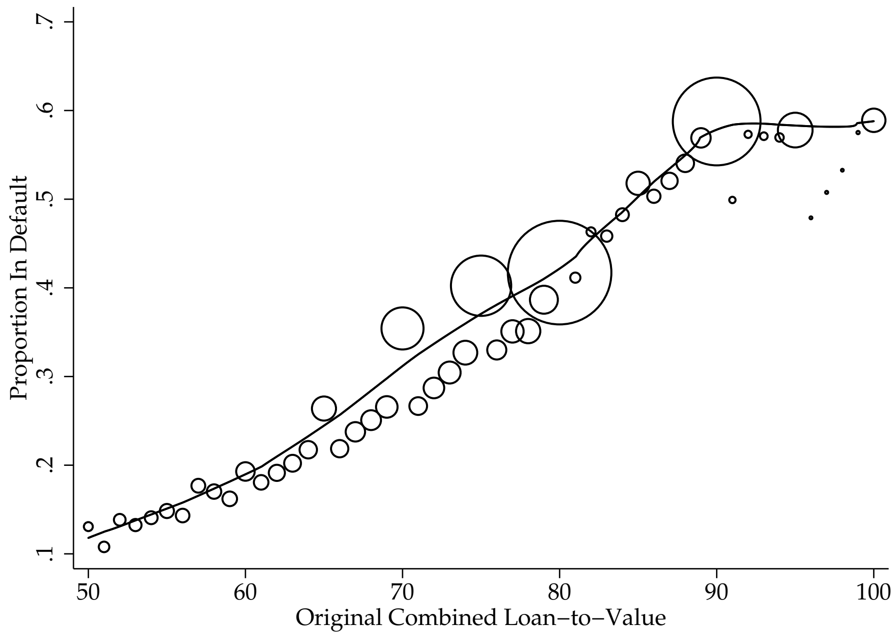
FIGURE III
INDEX × ORIGINATION MONTH GENERATES DIFFERENCE-IN-DIFFERENCE VARIATION IN BALANCE TRAJECTORIES FOR OPTION ARMS



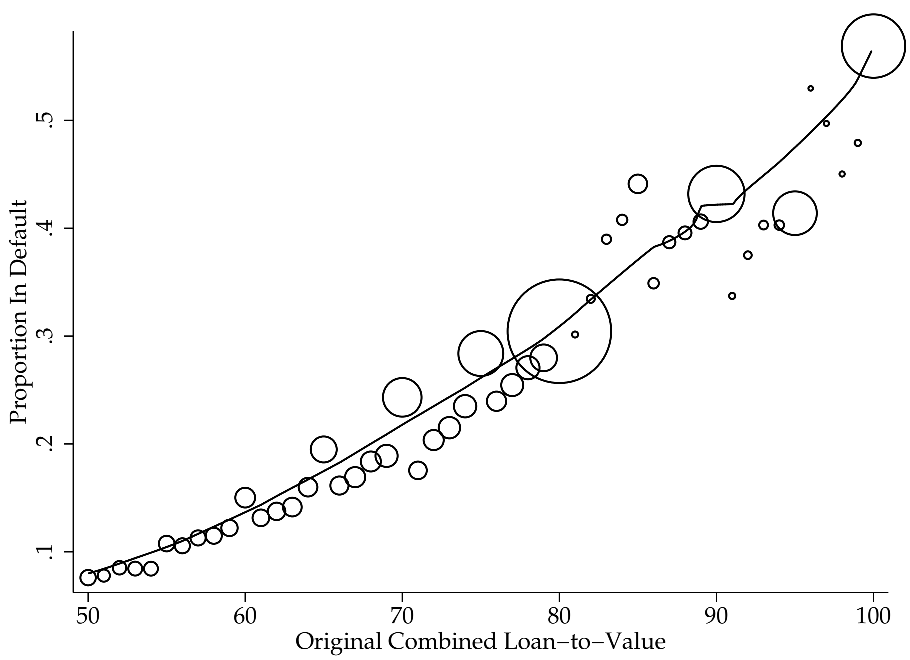
Simulated balance trajectories for $100,000 LIBOR- and Treasury-indexed loans originated in January 2005 or January 2007. Trajectories assume margin of 3.5 percent and initial payment based on 1.75 percent teaser. Treasury refers to 1-year MTA, LIBOR refers to 3-month duration.

FIGURE IV
ORIGINAL LTV IS POSITIVELY CORRELATED WITH DEFAULT WITHIN 60 MONTHS

PANEL A: OPTION ARM SAMPLE

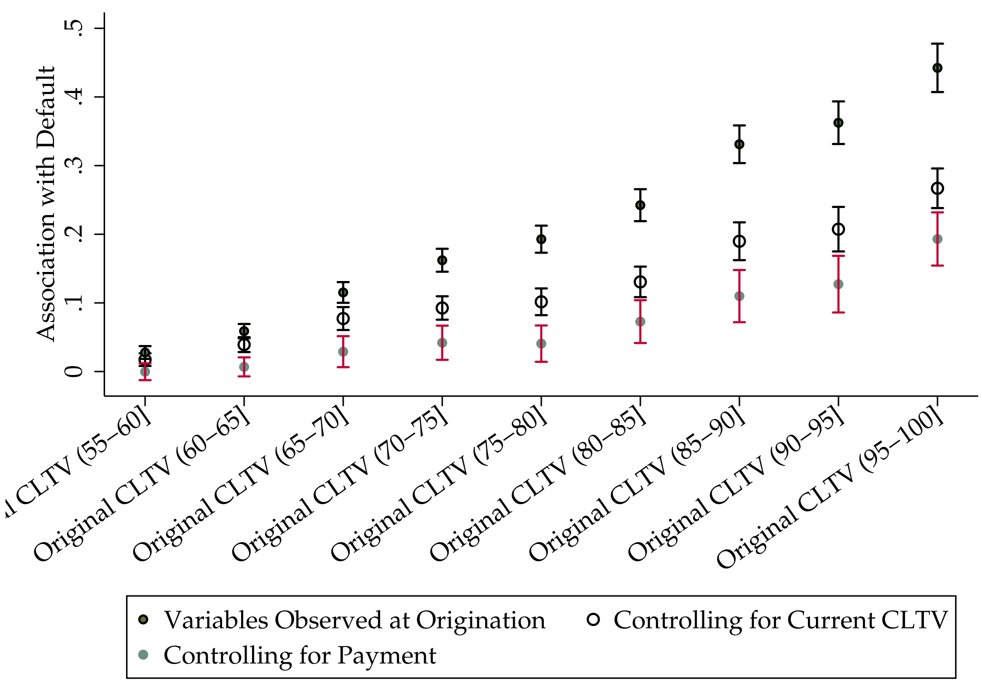


PANEL B: 5/1 ARM SAMPLE



Hollow dots show the average proportion of loans defaulting within the first 60 months for each 1-point bin of original loan-to-value. Size of dots is proportional to number of borrowers within each bin. Default is defined as 60 or more days past due. The solid line shows a local linear smoothing of the raw data. Full sample of Option ARMs is included in Panel A; full sample of 5/1 ARMs is included in panel B.

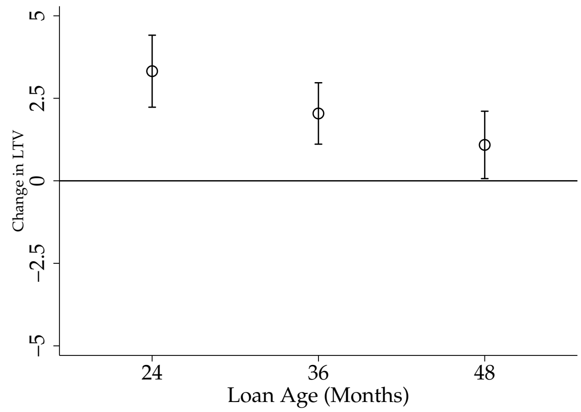
FIGURE V
TOTAL LEVERAGE AT ORIGINATION AGAINST FUTURE DEFAULT, 5/1 ARMS



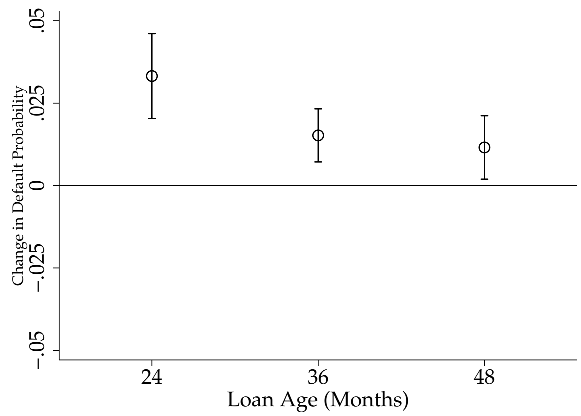
Sample of 5/1 ARMs. Black dots indicate the non-parametric relationship between original leverage and ex-post loan default when controlling for all variables observed by the lender at time of origination. The white dots illustrate this relationship when also controlling for ex-post Current CLTV. Origination leverage includes both first and any second liens taken at time of origination.

FIGURE VI
REGRESSIONS OF DEFAULT AND CREDIT SCORE ON INSTRUMENT FOR HOME EQUITY

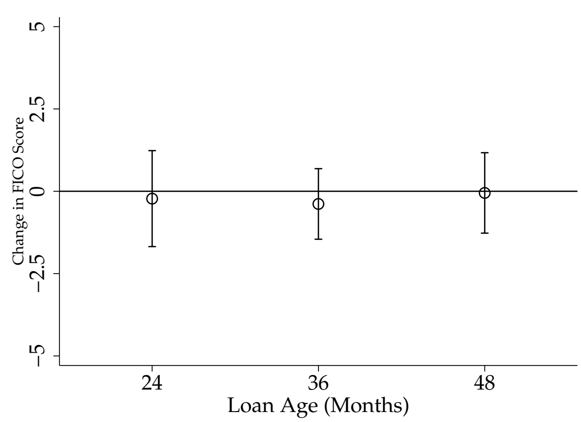
PANEL A: INSTRUMENT RELEVANCE—INSTRUMENT PREDICTS CURRENT LOAN-TO-VALUE



PANEL B: REDUCED FORM—INSTRUMENT PREDICTS DEFAULT ACROSS LIFECYCLE

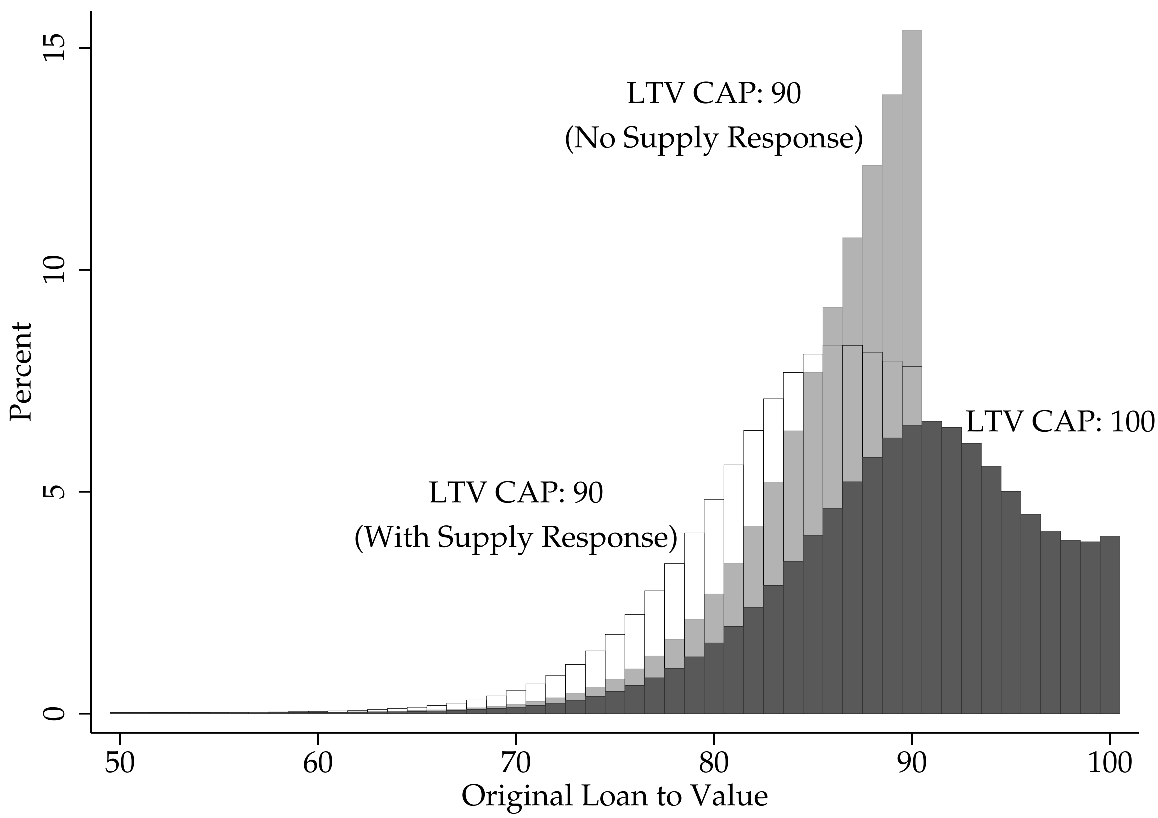


PANEL C: INSTRUMENT EXOGENEITY—INSTRUMENT DOES NOT PREDICT CREDIT SCORE



OLS regressions of outcomes on simulated instrument including origination month and index fixed effects. The simulated instrument is the mechanical calculation of balance based upon the borrowers' index choice and origination month. Margin is fixed to 3.5 for all borrowers, original loan to $100,000 and initial monthly payment is based on 1.75 percent teaser rate. Top panel shows the outcome of default within one year at 24, 36, and 48 months, where default is defined as being 60 or more days past due. Bottom panel shows the outcome of borrowers FICO scores for those remaining at 24, 36 and 48 months.

FIGURE VII
EFFECT OF LTV CAP OF 90 ON LEVERAGE: WITH AND WITHOUT SUPPLY RESPONSE



Bars show simulated proportion of borrowers choosing each original LTV under three regimes. The dark gray bars show equilibrium LTV choices at an LTV cap of 100, the light gray show borrowers' LTV choices after a reduction in the LTV cap to 90, but allowing no changes in contracts below 90. White bars show equilibrium LTV choices with an LTV cap of 90 allowing for the supply response. Figure is based on exaggerated level of adverse selection. Table VI shows appropriately calibrated results.

TABLES

TABLE I
SUMMARY STATISTICS: BALANCE ACROSS INDICIES

	Panel A: Option ARM Sample			
	Treasury		Libor	
	Mean	SD	Mean	SD
FICO Score	706.1	45.9	713.8	45.1
Original Balance	370.5	264.4	346.1	282.1
Loan for Purchase	0.33		0.42	
No/Low Documentation	0.79		0.77	
Primary Residence	0.77		0.68	
Condo, Co-op or Multifamily	0.14		0.16	
Prepayment Penalty	0.99		0.94	
Margin	3.21	0.53	2.85	0.51
Original LTV	76.6	8.40	77.0	8.30
State:				
- California	0.46		0.35	
- Florida	0.14		0.16	
- Arizona	0.043		0.040	
- Nevada	0.037		0.054	
Origination Year:				
- 2004	0.081		0.31	
- 2005	0.41		0.35	
- 2006	0.43		0.24	
- 2007	0.082		0.089	
Observations	490132		45199	
	Panel B: 5/1 ARM Sample			
	Treasury		Libor	
	Mean	SD	Mean	SD
FICO Score	728.7	50.8	718.1	52.3
Origination Balance	483.6	302.7	439.0	313.6
Loan for Purchase	0.24		0.20	
No/Low Documentation	0.52		0.70	
Primary Residence	0.87		0.84	
Prepayment Penalty	0.071		0.18	
Margin	2.77	0.31	2.36	0.39
Original LTV	74.3	9.02	76.2	8.37
State:				
- California	0.48		0.40	
- Florida	0.063		0.093	
- Arizona	0.032		0.041	
- Nevada	0.021		0.029	
Origination Year:				
- 2004	0.25		0.16	
- 2005	0.37		0.25	
- 2006	0.12		0.34	
- 2007	0.051		0.17	
Observations	109214		344594	

Summary statistics for full sample of Option ARMs (Panel A) and 5/1 ARMs (Panel B). Treasury refers to loans indexed to Treasury rates, LIBOR refers to those indexed to LIBOR.

TABLE II

FIRST STAGE: INSTRUMENTS PREDICT REALIZED NEGATIVE EQUITY, LOAN-TO-VALUE, INTEREST RATES, AND PAYMENTSS

	Panel A: Option ARMs—Observed/Imputed Equity on Simulated Instruments							
	Conditional on Survival to 24 Months				Full Sample (Imputed Current Equity)			
	Home Equity		Loan-to-Value		Home Equity		Loan-to-Value	
Simulated Home Equity	1.345***	0.795***			1.349***	0.339**		
($100,000s)	(0.214)	(0.197)			(0.226)	(0.164)		
Simulated Loan-To-Value			3.559***	1.736***			2.632***	0.545
			(0.621)	(0.471)			(0.463)	(0.363)
F (Simulated Instrument)	39.5	16.3	32.8	13.6	35.7	4.2	32.3	2.3
F (Fixed Effects)	10.3	7.1	5.0	11.3	11.3	6.8	8.1	8.5
N	265134	265134	268364	268364	443600	443600	443600	443600
Orig. Month/Index FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
MSA FEs	No	Yes	No	Yes	No	Yes	No	Yes
Full Controls	No	Yes	No	Yes	No	Yes	No	Yes
	Panel B: 5/1 ARMs—Observed/Imputed Payments/Interest Rates on Simulated Instruments							
	Conditional on Survival to 60 Months				Full Sample (Imputed Payments/Interest Rates)			
	Interest Rates		Payments		Interest Rates		Payments	
Instrumented Interest Rate	0.838***	0.843***	195.443***	111.062***	0.949***	0.967***	215.842***	213.500***
	(0.008)	(0.008)	(42.333)	(13.774)	(0.007)	(0.007)	(33.084)	(9.064)
F(Fixed Effects)	11920	12175	65	65	20015	20289	555	555
N	107424	107424	107424	107424	453748	453748	312311	312311
R^2	0.89	0.92	0.067	0.82	0.83	0.88	0.069	0.95
Orig. Month/Index FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
MSA FEs	No	Yes	No	Yes	No	Yes	No	Yes
Full Controls	No	Yes	No	Yes	No	Yes	No	Yes

First stage regressions of measures of borrower equity on instruments for equity based on borrower's index and month of origin. Displayed in each column is the coefficient from regressing borrower's true equity value, measured either as the loan-to-value ratio (in percentage terms) or as the level of negative equity in $100,000s, on the simulated instrument for that equity. The simulated instrument is calculated using the borrowers true index and origination month to determine interest rates but fixing all other loan terms to standard values: a margin of 3.5%, an initial minimum payment based upon a 1.75% teaser rate, home price appreciation equal to the national average, and the assumption that the borrower always makes minimum payments. With these terms, home equity can be calculated mechanically. The F(simulated instrument) is the F-statistic from this regression, while F(Fixed effects) is the F-statistic from regressions that include the full set of interactions between origination month and index type as instruments. Full controls refers to fixed effects for index type, documentation, the loans purpose and occupancy, the existence of prepayment penalties and private mortgage insurance, and single family homes. We also include indicators for each 20-point bin of borrower's FICO credit scores, loan originator and servicer fixed effects, and controls for second liens. We allow individual state time trends. Standard errors are clustered at the MSA level. * denotes 10% significance, ** denotes 5% significance, *** denotes 1% significance.

TABLE III
SEPARATING ADVERSE SELECTION AND MORAL HAZARD: THE IMPACT OF ORIGINAL AND CURRENT LEVERAGE ON 1 YEAR DEFAULT PROBABILITIES

	Panel A: OLS and IV Regressions at 24 Months Including Current Negative Equity					
	Baseline	OLS	IV	Baseline	OLS	IV
Original Loan-to-Value	0.586***	0.252***	0.331***	0.721***	0.407***	0.260***
	(0.046)	(0.054)	(0.118)	(0.026)	(0.037)	(0.047)
Current Negative Equity in $100,000s		0.059***	0.045**		0.061***	0.089***
		(0.006)	(0.021)		(0.005)	(0.010)
Mean of Dep. Var	0.264	0.264	0.264	0.264	0.264	0.264
N	265134	265134	265134	265134	265134	265134
Origination Month FEs	Yes	Yes	Yes	Yes	Yes	Yes
Index FEs	Yes	Yes	Yes	Yes	Yes	Yes
MSA FEs	No	No	No	Yes	Yes	Yes
Full Controls	No	No	No	Yes	Yes	Yes
	Panel B: OLS and IV Regressions at 24 Months Including Current Loan-to-Value					
	Baseline	OLS	IV	Baseline	OLS	IV
Original Loan-to-Value	0.586***	−0.059	−0.241	0.721***	0.244***	0.229***
	(0.046)	(0.056)	(0.234)	(0.026)	(0.053)	(0.050)
Current Loan-to-Value		0.573***	0.735***		0.402***	0.415***
		(0.029)	(0.212)		(0.037)	(0.041)
Mean of Dep. Var	0.264	0.264	0.264	0.264	0.264	0.264
N	265134	265134	265134	265134	265134	265134
Origination Month FEs	Yes	Yes	Yes	Yes	Yes	Yes
Index FEs	Yes	Yes	Yes	Yes	Yes	Yes
MSA FEs	No	No	No	Yes	Yes	Yes
Full Controls	No	No	No	Yes	Yes	Yes

OLS and IV regressions of default between 24 and 36 months on borrowers original loan-to-value and current equity at 24 months, defined as either the level of negative equity in $100,000s (Panel A), or current loan-to-value (Panel B). Default is defined as 60 or more days past due. Baseline refers to OLS regressions omitting current equity. IV regressions include the full set of interactions between index and origination month as instruments for current equity. Full controls refers to fixed effects for index type, documentation, the loans purpose and occupancy, the existence of prepayment penalties and private mortgage insurance, and single family homes. We also include indicators for each 20-point bin of borrower's FICO credit scores, loan originator and servicer fixed effects, and controls for second liens. We allow individual state time trends. Standard errors are clustered at the MSA level. * denotes 10% significance, ** denotes 5% significance, *** denotes 1% significance.

TABLE IV
PAYMENTS, INTEREST RATES, AND DEFAULT

	Panel A: Causal Effect of Payments/Reset Rates on One Year Default Rate					
	Monthly Payments			Interest Rates		
	OLS	IV	IV	OLS	IV	IV
Monthly Payment (100USD)	0.002***	0.012***	0.011***			
	(0.000)	(0.002)	(0.002)			
Reset Rate				0.014***	0.033***	0.032***
				(0.003)	(0.006)	(0.005)
Original Interest Rate			0.016***			0.019***
			(0.003)			(0.003)
Margin			−0.001			−0.049***
			(0.008)			(0.013)
Mean of Dep. Var.	0.068	0.068	0.068	0.068	0.068	0.068
N	107437	107419	107419	107438	107420	107420
Origination Month FEs	Yes	Yes	Yes	Yes	Yes	Yes
Index FEs	Yes	Yes	Yes	Yes	Yes	Yes
MSA FEs	Yes	Yes	Yes	Yes	Yes	Yes
Full Controls	Yes	Yes	Yes	Yes	Yes	Yes
	Panel B: Selection—Relative Payment Sensitivity by Original LTV					
	OLS			IV		
	Orig. LTV< 80	Orig. LTV= 80	Orig. LTV> 80	Orig. LTV< 80	Orig. LTV= 80	Orig. LTV> 80
Monthly Payment (100USD)	0.001***	0.003***	0.005***	0.003**	0.011***	0.020***
	(0.000)	(0.000)	(0.001)	(0.002)	(0.003)	(0.005)
Mean of Dep. Var.	0.048	0.072	0.10	0.048	0.072	0.10
N	47588	34615	25234	47554	34587	25206
Origination Month FEs	Yes	Yes	Yes	Yes	Yes	Yes
Index FEs	Yes	Yes	Yes	Yes	Yes	Yes
MSA FEs	Yes	Yes	Yes	Yes	Yes	Yes
Full Controls	Yes	Yes	Yes	Yes	Yes	Yes
	Panel C: Selection—Relative Interest Rate Sensitititivity by Original LTV					
	OLS			IV		
	Orig. LTV< 80	Orig. LTV= 80	Orig. LTV> 80	Orig. LTV< 80	Orig. LTV= 80	Orig. LTV> 80
Reset Rate	0.005*	0.022***	0.008	0.011*	0.039***	0.069***
	(0.003)	(0.005)	(0.006)	(0.006)	(0.009)	(0.017)
Mean of Dep. Var.	0.048	0.072	0.10	0.048	0.072	0.10
N	47588	34616	25234	47554	34588	25206
Origination Month FEs	Yes	Yes	Yes	Yes	Yes	Yes
Index FEs	Yes	Yes	Yes	Yes	Yes	Yes
MSA FEs	Yes	Yes	Yes	Yes	Yes	Yes
Full Controls	Yes	Yes	Yes	Yes	Yes	Yes

Results from OLS and IV regressions with the binary outcome of default between 60 and 72 months for borrowers with 5/1 ARMs. Default is defined as 60 or more days past due. Panel A includes regressions of default on monthly payments or reset rates, as well as contract terms at origination (the original interest rate and margin). IV specifications instrument for monthly payments or reset rates with a difference-in-difference interaction of origination month and index type. Panels B and C reproduce columns 1/2 and 5/6, respectively, of Panel A separately for borrowers with original LTV below 80, at 80, and above 80. Full controls refers to fixed effects for index type, documentation, the loans purpose and occupancy, the existence of prepayment penalties and private mortgage insurance, and single family homes. We also include indicators for each 20-point bin of borrower's FICO credit scores, loan originator and servicer fixed effects, and controls for second liens. Standard errors are clustered at the MSA level. * denotes 10% significance, ** denotes 5% significance, *** denotes 1% significance.

TABLE V
JOINT ESTIMATES OF THE IMPACT OF ORIGINAL AND CURRENT LEVERAGE ON 1 YEAR DEFAULT PROBABILITIES AND LEVERAGE DEMAND

	Negative Equity			Loan-to-Value		
	24 Months	36 Months	48 Months	24 Months	36 Months	48 Months
Current Negative Equity in \$100,000s	0.529*** (0.048)	0.371*** (0.058)	0.232* (0.136)			
Current Loan-To-Value				1.811*** (0.194)	1.046*** (0.199)	0.420 (0.358)
ρ: Correlation of Errors in Default and Leverage Choice	0.036** (0.017)	0.048** (0.020)	0.050 (0.044)	0.067*** (0.016)	0.071*** (0.019)	0.078** (0.037)
Default Threshold	0.906	1.707	3.822	1.338	1.681	3.144
S.D. of Default Error	1.890	2.697	4.313	0.552	0.956	2.378
N	263177	162103	106921	263177	162103	106921
Origination Quarter FEs	Yes	Yes	Yes	Yes	Yes	Yes
Index FEs	Yes	Yes	Yes	Yes	Yes	Yes
State FEs	Yes	Yes	Yes	Yes	Yes	Yes
Full Controls	Yes	Yes	Yes	Yes	Yes	Yes

Estimates from joint model of leverage demand and default choice. Table shows coefficient on current equity at 24, 36 and 48 months, where current equity is defined as either the level of negative equity in \$100,000s (or current loan-to-value). ρ displays the estimated correlation between the errors in the leverage and default equations, capturing adverse selection. Also shown are the default threshold for a borrower at the mean covariate level, and the standard deviation of the error in the default choice in units of current equity. Full controls refers to fixed effects for index type, documentation, the loans purpose and occupancy, the existence of prepayment penalties and private mortgage insurance, and single family homes. We also include indicators for each 20-point bin of borrower's FICO credit scores, loan originator and servicer fixed effects, and controls for second liens. We allow individual state time trends. Standard errors are clustered at the MSA level. * denotes 10% significance, ** denotes 5% significance, *** denotes 1% significance.

TABLE VI

SIMULATION RESULTS: THE IMPACT OF A REDUCTION IN THE LTV CAP FROM 100 TO 90

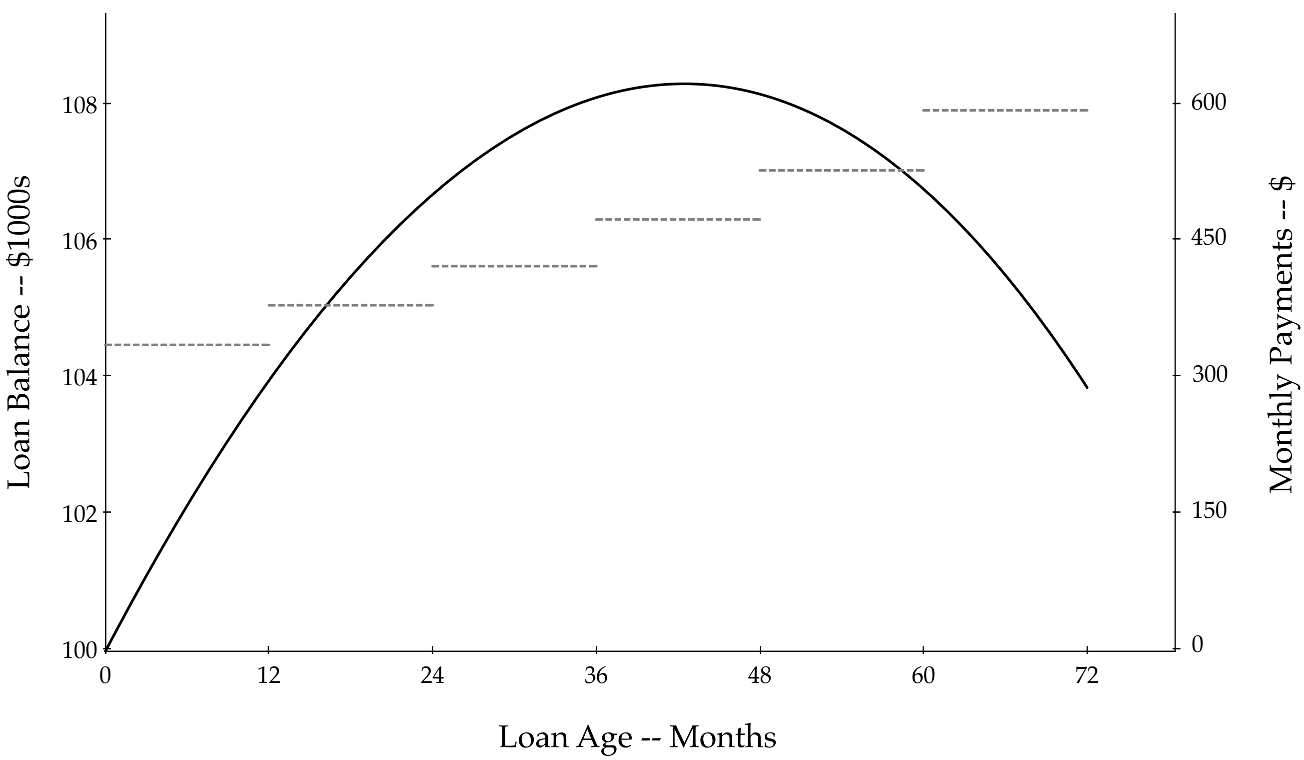
	Col. 1: LTV Cap of 100	Col. 2: LTV Cap of 90 (No Supply Response)	Col. 3: LTV Cap of 90 (With Supply Response)
Average Loan Amount	\$270,055	\$246,265	\$246,002
Average Interest Rate	8.6%	7.5%	7.9%
Average Balance	\$293,359	\$264,863	\$265,476
Defaults	12.0%	9.1%	9.2%
Naive Defaults	-	7.8%	-
Welfare Loss (CV Rel. to Col. 1)	-	\$8,135	\$8,752
		Parameters	
	Initial Price: $H_0 = \$300000$	Final Value: $H \sim N(500000, 100000)$	Proportion Behavioral: 1%
	CARA Coefficient: a=0.000002	Viscosity: $\gamma = \frac{10}{504}$	$\beta = \frac{1}{1+r_f} = 0.95$
	Prop. Recovered in Default: $\delta = 0.9$	$C_i \sim N(90,000, 190,000)$	Borrowers: $N = 1000$

Simulations from structural model described in Section 7. CARA utility assumed, 1000 simulated borrowers, with 1% behavioral. Viscosity set to match estimated $\rho = 0.067$. The first column shows equilibrium outcomes with an LTV cap of 100. The second column shows borrower responses to the removal of all contracts with initial LTV between 90 and 100, holding fixed all contracts with initial LTV less than 90. Naive defaults refer to expected defaults calculated ignoring borrower heterogeneity and extrapolating from default probabilities at each LTV with an LTV cap of 100. The third column shows equilibrium outcomes with an LTV cap of 90. CV calculated based on expected utility prior to realization of EV1 error.

APPENDICIES

A APPENDIX TABLES AND FIGURES

FIGURE A.I
STYLIZED MONTHLY PAYMENT AND BALANCE TRAJECTORY FOR OPTION ARM



The solid line shows the balance trajectory for a stylized Option ARM with an initial loan of $100,000. The balance is initially increasing, demonstrating negative amortization. Monthly payments, shown by the dashed lines, increase by 7.5% per year regardless of balance. As payments grow, the balance begins to decrease, as shown by the parabolic shape of the balance trajectory. At 5 years the monthly payment jumps to the fully amortizing amount.

FIGURE A.II
STYLIZED EXAMPLE OF IMPACT OF INTEREST RATE VARIATION ON OPTION ARM BALANCE

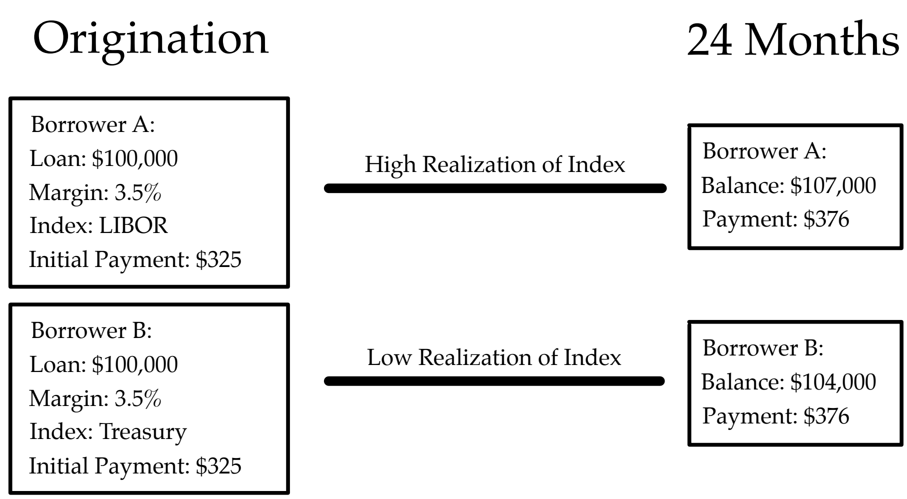
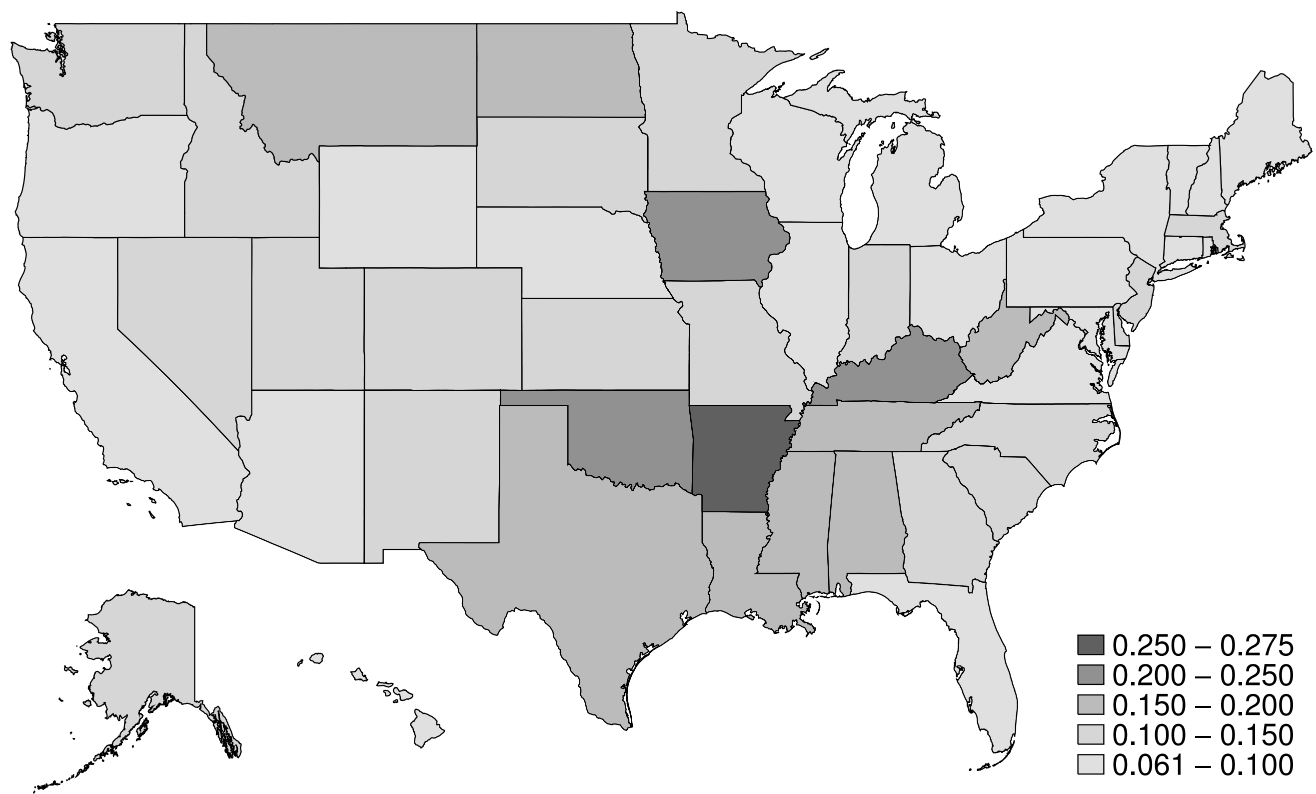


FIGURE A.III
UNIFORM DENSITY OF LIBOR INDEXED OPTION ARMS ACROSS STATES



Plot shows number of LIBOR indexed Option ARMs as a proportion of all LIBOR- or Treasury-indexed Option ARMs. The minimum is 6.1 percent, while the max is 27.5 percent. In the majority of states, between 5 and 15 percent of Option ARMs are indexed to LIBOR.

FIGURE A.IV
INTEREST RATE SCHEDULE IS INCREASING IN ORIGINAL LOAN-TO-VALUE

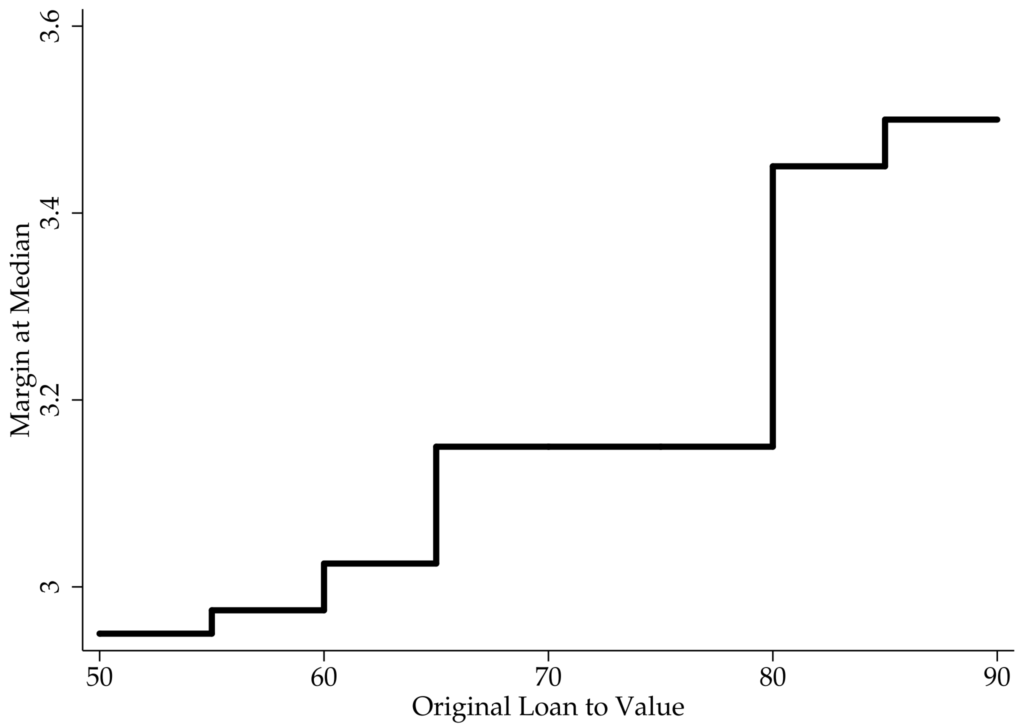
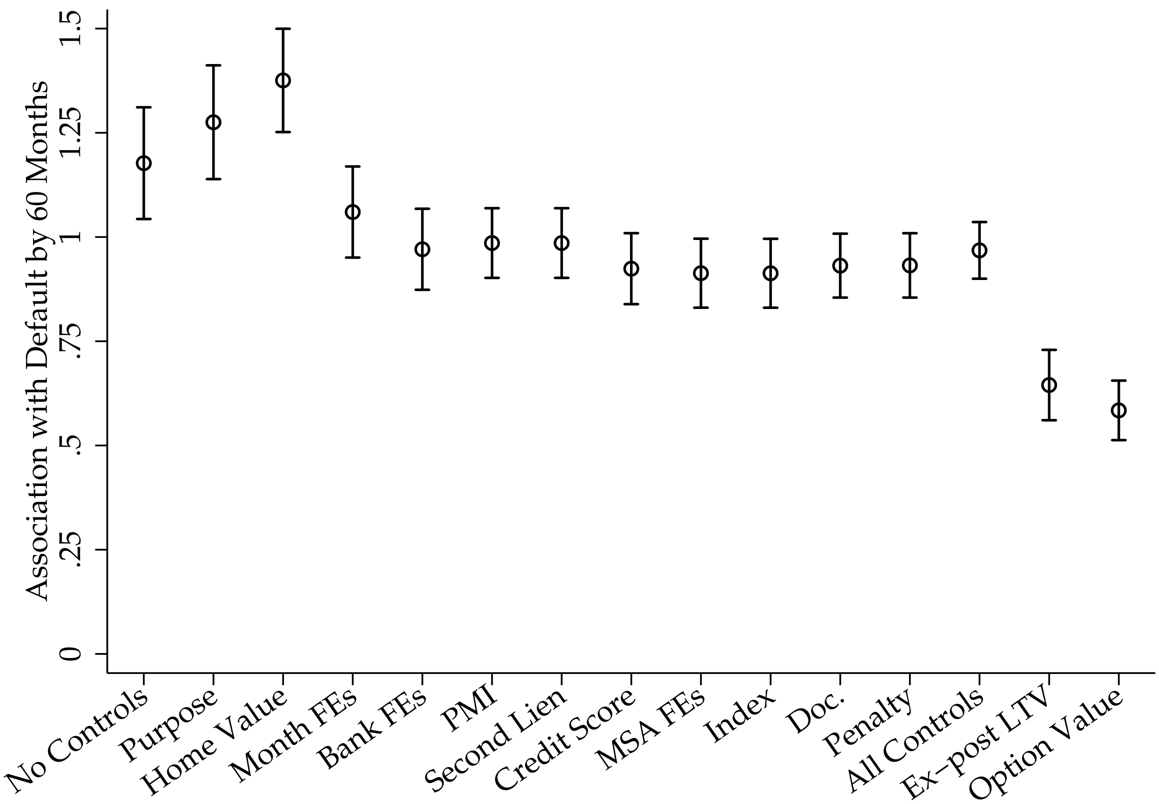


Figure displays the median margin, the fixed portion of each borrower's interest rate, for each 5 point loan-to-value bin. Full sample of Option ARMs is included.

FIGURE A.V
CORRELATION BETWEEN ORIGINAL LTV AND DEFAULT HOLDS CONDITIONAL ON INFORMATION AVAILABLE TO LENDER



Results from OLS regressions of default within the first 60 months on original loan-to-value. Circles show coefficients on original loan-to-value with 95 percent confidence intervals based on standard errors clustered at the MSA level. The leftmost coefficient includes no controls, and each step to the left increases the set of controls included. Purpose refers to dummies for purchase, refinance, or cash out refinance. Bank FEs include originator and servicer fixed effects. Credit score refers to dummies for each 20-point bin of original FICO, with an additional category for missing values. Index is a dummy for LIBOR. Penalty is equal to one if the loan features a prepayment penalty. Full controls additionally includes a dummy for single family home and investor vs. owner occupant. Ex-post LTV refers to the imputed loan-to-value at 60 months based on initial contract terms. Option value provides a more flexible specification of mortgage value, including six leads and lags of home prices and interest rates at 60 months. Full sample of Option ARMs is included.

TABLE A.I
FRACTION OF LIBOR-INDEXED LOANS BY LENDER

Originator	Percent of Loans Indexed to LIBOR
American Home Mortgage	$< 1\%$
Bank United	$< 1\%$
Bank of America	85%
Countrywide	3%
Downey	0%
EMC	0%
Greenpoint	91%
IndyMac	$< 1\%$
MortgageIT	5%
Residential Funding	9%
Servicer	**Percent of Loans Indexed to LIBOR**
American Home Mortgage	$< 1\%$
Bank of America	10%
Central Mortgage	1%
Countrywide	15%
EMC	7%
IndyMac	$< 1\%$
JP Morgan Chase	2%
Nationstar	31%
Ocwen	2%
Washington Mutual	$< 1\%$

Table displays percent of LIBOR-indexed loans for the top 10 originators and servicer in the sample. Servicer is available for 99 percent of loans, while originator is only available for 27 percent of loans.

TABLE A.II
HETEROGENEITY IN THE IMPACT OF ORIGINAL AND CURRENT LEVERAGE ON 1 YEAR DEFAULT PROBABILITY

	Panel A: IV Regressions at 24 Months by State Recourse Status					
	Full Recourse			Limited Recourse		
Original Loan-to-Value	0.546***	0.530***	0.494***	0.741***	0.276***	0.239***
	(0.044)	(0.116)	(0.179)	(0.025)	(0.045)	(0.057)
Current Negative Equity in $100,000s		0.003			0.089***	
		(0.034)			(0.009)	
Current Loan-to-Value			0.044			0.421***
			(0.189)			(0.044)
Mean of Dep. Var	0.198	0.198	0.198	0.272	0.272	0.272
N	28565	28565	28565	236569	236569	236569
Origination Month FEs	Yes	Yes	Yes	Yes	Yes	Yes
Index FEs	Yes	Yes	Yes	Yes	Yes	Yes
MSA FEs	Yes	Yes	Yes	Yes	Yes	Yes
Full Controls	Yes	Yes	Yes	Yes	Yes	Yes
	Panel B: IV Regressions at 24 Months by Original Documentation					
	No/Low Documentation			Full Documentation		
Original Loan-to-Value	0.766***	0.355***	0.336***	0.492***	−0.017	−0.095*
	(0.026)	(0.056)	(0.058)	(0.031)	(0.067)	(0.057)
Current Negative Equity in $100,000s		0.077***			0.113***	
		(0.010)			(0.015)	
Current Loan-to-Value			0.356***			0.538***
			(0.045)			(0.052)
Mean of Dep. Var	0.286	0.286	0.286	0.166	0.166	0.166
N	215366	215366	215366	49768	49768	49768
Origination Month FEs	Yes	Yes	Yes	Yes	Yes	Yes
Index FEs	Yes	Yes	Yes	Yes	Yes	Yes
MSA FEs	Yes	Yes	Yes	Yes	Yes	Yes
Full Controls	Yes	Yes	Yes	Yes	Yes	Yes
	Panel C: IV Regressions at 24 Months by Loan Purpose					
	Purchase			Refinance		
Original Loan-to-Value	0.587***	0.119**	0.076	0.762***	0.313***	0.277***
	(0.033)	(0.056)	(0.050)	(0.026)	(0.050)	(0.059)
Current Negative Equity in $100,000s		0.101***			0.084***	
		(0.013)			(0.009)	
Current Loan-to-Value			0.452***			0.405***
			(0.042)			(0.048)
Mean of Dep. Var	0.252	0.252	0.252	0.270	0.270	0.270
N	93226	93226	93226	171908	171908	171908
Origination Month FEs	Yes	Yes	Yes	Yes	Yes	Yes
Index FEs	Yes	Yes	Yes	Yes	Yes	Yes
MSA FEs	Yes	Yes	Yes	Yes	Yes	Yes
Full Controls	Yes	Yes	Yes	Yes	Yes	Yes

OLS and IV regressions of default between 24 and 36 months on borrowers original loan-to-value and current equity at 24 months, defined as either the level of negative equity in $100,000s (or current loan-to-value). Baseline refers to OLS regressions omitting current equity, all other specifications are IV regressions including the full set interactions between index and origination month as instruments for current equity. States are categorized as full recourse if they are considered to have strong provisions regarding deficiency judgments in Rao and Walsh (2009). Full controls refers to fixed effects for index type, documentation, the loans purpose and occupancy, the existence of prepayment penalties and private mortgage insurance, and single family homes. We also include indicators for each 20-point bin of borrowers' FICO credit scores, loan originator and servicer fixed effects, and controls for second liens. We allow individual state time trends. Standard errors are clustered at the MSA level. * denotes 10% significance, ** denotes 5% significance, *** denotes 1% significance.

TABLE A.III
IMPACT OF ORIGINAL AND CURRENT LEVERAGE ON
1 YEAR DEFAULT PROBABILITY AT 48 MONTHS

	Panel A: OLS and IV Regressions Including Current Negative Equity					
	Baseline	OLS	IV	Baseline	OLS	IV
Original Loan-to-Value	0.283***	−0.005	−0.136	0.452***	0.187***	0.231***
	(0.038)	(0.025)	(0.219)	(0.028)	(0.021)	(0.074)
Current Negative Equity in $100,000s		0.073***	0.106**		0.054***	0.045***
		(0.004)	(0.053)		(0.002)	(0.015)
Mean of Dep. Var	0.213	0.213	0.213	0.213	0.213	0.213
N	107917	107917	107917	107917	107917	107917
Origination Month FEs	Yes	Yes	Yes	Yes	Yes	Yes
Index FEs	Yes	Yes	Yes	Yes	Yes	Yes
MSA FEs	No	No	No	Yes	Yes	Yes
Full Controls	No	No	No	Yes	Yes	Yes
	Panel B: OLS and IV Regressions Including Current Loan-to-Value					
	Baseline	OLS	IV	Baseline	OLS	IV
Original Loan-to-Value	0.283***	0.027	−0.067	0.452***	0.165***	0.371***
	(0.038)	(0.028)	(0.160)	(0.028)	(0.026)	(0.068)
Current Loan-to-Value		0.195***	0.266**		0.180***	0.050
		(0.008)	(0.122)		(0.010)	(0.038)
Mean of Dep. Var	0.213	0.213	0.213	0.213	0.213	0.213
N	107917	107917	107917	107917	107917	107917
Origination Month FEs	Yes	Yes	Yes	Yes	Yes	Yes
Index FEs	Yes	Yes	Yes	Yes	Yes	Yes
MSA FEs	No	No	No	Yes	Yes	Yes
Full Controls	No	No	No	Yes	Yes	Yes

OLS and IV regressions of default between 48 and 60 months on borrowers' original loan-to-value and current equity at 24 months, defined as either the level of negative equity in $100,000s (Panel A), or current loan-to-value (Panel B). Default is defined as 60 or more days past due. Baseline refers to OLS regressions omitting current equity. IV regressions include the full set of interactions between index and origination month as instruments for current equity. Full controls refers to fixed effects for index type, documentation, the loans purpose and occupancy, the existence of prepayment penalties and private mortgage insurance, and single family homes. We also include indicators for each 20-point bin of borrowers FICO credit scores, loan originator and servicer fixed effects, and controls for second liens. We allow individual state time trends. Standard errors are clustered at the MSA level. * denotes 10% significance, ** denotes 5% significance, *** denotes 1% significance.

TABLE A.IV
IMPACT OF ORIGINAL AND CURRENT LEVERAGE ON CUMULATIVE DEFAULT PROBABILITIES

	Panel A: Current Negative Equity					
	36 Months			60 Months: Controlling for Trajectory		
	Baseline	OLS	IV	Baseline	OLS	IV
Original Loan-to-Value	0.857***	0.712***	0.148**	1.041***	0.892***	0.338***
	(0.030)	(0.034)	(0.064)	(0.037)	(0.032)	(0.127)
Imputed Negative Equity at 36 Months in $100,000s		0.026***	0.128***		0.004	−0.157*
		(0.004)	(0.016)		(0.005)	(0.081)
Imputed Negative Equity at 24 Months in $100,000s					−0.006*	0.174***
					(0.004)	(0.050)
Imputed Negative Equity at 48 Months in $100,000s					0.012	0.174**
					(0.008)	(0.089)
Imputed Negative Equity at 60 Months in $100,000s					0.016**	−0.060
					(0.007)	(0.054)
Mean of Dep. Var	0.310	0.310	0.310	0.454	0.454	0.454
N	443600	443600	443600	443600	443600	443600
Origination Month FEs	Yes	Yes	Yes	Yes	Yes	Yes
Index FEs	Yes	Yes	Yes	Yes	Yes	Yes
MSA FEs	No	No	No	Yes	Yes	Yes
Full Controls	No	No	No	Yes	Yes	Yes
	Panel B: Current Loan-to-Value					
	36 Months			60 Months: Controlling for Trajectory		
	Baseline	OLS	IV	Baseline	OLS	IV
Original Loan-to-Value	0.857***	0.509***	0.255***	1.041***	0.583***	0.299**
	(0.030)	(0.037)	(0.066)	(0.037)	(0.049)	(0.124)
Imputed Loan-to-Value at 36 Months		0.231***	0.402***		0.006	−0.341
		(0.016)	(0.043)		(0.022)	(0.228)
Imputed Loan-to-Value at 24 Months					0.217***	0.806***
					(0.048)	(0.187)
Imputed Loan-to-Value at 48 Months					0.088***	−0.109
					(0.032)	(0.356)
Imputed Loan-to-Value at 60 Months					0.019	0.263
					(0.024)	(0.292)
Mean of Dep. Var	0.310	0.310	0.310	0.454	0.454	0.454
N	443600	443600	443600	443600	443600	443600
Origination Month FEs	Yes	Yes	Yes	Yes	Yes	Yes
Index FEs	Yes	Yes	Yes	Yes	Yes	Yes
MSA FEs	No	No	No	Yes	Yes	Yes
Full Controls	No	No	No	Yes	Yes	Yes

The left columns show OLS and IV regressions of default by 36 months on borrowers' original loan-to-value and imputed current equity at 36 months, defined as either the level of negative equity in $100,000s (Panel A) or current loan-to-value (Panel B) at 36 months. Right columns show OLS and IV regressions of default by 60 months on borrowers' original loan-to-value and imputed current equity at 24 months, 36 months, 48 months and 60 months, defined as either the level of negative equity in $100,000s (Panel A) or current loan-to-value (Panel B). Default is defined as 60 or more days past due. Baseline refers to OLS regressions omitting current equity. IV regressions include the full set of interactions between index and origination month as instruments for current equity. Full controls refers to fixed effects for index type, documentation, the loans purpose and occupancy, the existence of prepayment penalties and private mortgage insurance, and single family homes. We also include indicators for each 20-point bin of borrowers FICO credit scores, loan originator and servicer fixed effects, and controls for second liens. We allow individual state time trends. Standard errors are clustered at the MSA level. * denotes 10% significance, ** denotes 5% significance, *** denotes 1% significance.

TABLE A.V
IMPACT OF ORIGINAL LEVERAGE WITH FLEXIBLE CONTROLS FOR CURRENT LEVERAGE AND TIME-VARYING COVARIATES

	Panel A: Current Negative Equity					
	Cubic in Neg. Equity		Current Rates and Payments		Neg. Equity × Covariates	
	OLS	IV	OLS	IV	OLS	IV
Original Loan-to-Value	0.332***	0.296***	0.339***	0.204***	0.372***	0.309***
	(0.041)	(0.053)	(0.035)	(0.050)	(0.040)	(0.055)
Current Negative Equity in $100,000s	0.107***	0.146***	0.061***	0.089***	0.413**	−0.082
	(0.008)	(0.015)	(0.005)	(0.010)	(0.171)	(0.064)
Current Negative Equity^2	0.016***	−0.016				
	(0.002)	(0.019)				
Current Negative Equity^3	0.001***	−0.010***				
	(0.000)	(0.003)				
Minimum Payment in $			0.000***	0.000***		
			(0.000)	(0.000)		
Interest Rate			0.047***	0.047***		
			(0.003)	(0.003)		
Current Negative Equity × Fico Score						−0.000
						(0.000)
Current Negative Equity × Purchase						0.086***
						(0.028)
Mean of Dep. Var	0.264	0.264	0.275	0.275	0.264	0.264
N	265134	265134	240189	240189	265134	265134
Origination Month FEs	Yes	Yes	Yes	Yes	Yes	Yes
Index FEs	Yes	Yes	Yes	Yes	Yes	Yes
MSA FEs	No	No	No	Yes	Yes	Yes
Full Controls	No	No	No	Yes	Yes	Yes

	Panel B: Current Loan-to-Value					
	Cubic in LTV		Current Rates and Payments		LTV × Covariates	
	OLS	IV	OLS	IV	OLS	IV
Original Loan-to-Value	0.168***	0.175***	0.157***	0.127**	0.241***	0.229***
	(0.055)	(0.060)	(0.054)	(0.058)	(0.054)	(0.070)
Current Loan-to-Value	−0.542***	0.556***	0.389***	0.414***	−0.033	0.308***
	(0.144)	(0.067)	(0.038)	(0.043)	(0.751)	(0.049)
Current Loan-to-Value^2	1.128***	0.000				
	(0.176)	(1.866)				
Current Loan-to-Value^3	−0.391***	−0.038				
	(0.059)	(0.170)				
Minimum Payment in $			0.000***	0.000***		
			(0.000)	(0.000)		
Interest Rate			0.043***	0.043***		
			(0.003)	(0.003)		
Current Loan-to-Value × Fico Score						0.000
						(0.001)
Current Loan-to-Value × Purchase						0.001
						(0.189)
Mean of Dep. Var	0.264	0.264	0.275	0.275	0.264	0.264
N	265134	265134	240189	240189	265134	265134
Origination Month FEs	Yes	Yes	Yes	Yes	Yes	Yes
Index FEs	Yes	Yes	Yes	Yes	Yes	Yes
MSA FEs	No	No	No	Yes	Yes	Yes
Full Controls	No	No	No	Yes	Yes	Yes

OLS and IV regressions of default between 24 and 36 months on borrowers' original loan-to-value and current equity at 24 months, defined as either the level of negative equity in $100,000s (Panel A), or current loan-to-value (Panel B). The first two columns include a cubic in current equity. The third and fourth columns include current and original minimum payments, as well as the current interest rate. The 5th column interacts current equity with all control variables in an OLS specification. The final column includes current equity interacted with each borrowers FICO score and an indicator equal to one if the loan was used to purchase a home. Default is defined as 60 or more days past due. IV regressions include the full set of interactions between index and origination month as instruments for all terms including current equity. Full controls refers to fixed effects for index type, documentation, the loans purpose and occupancy, the existence of prepayment penalties and private mortgage insurance, and single family homes. We also include indicators for each 20-point bin of borrowers FICO credit scores, loan originator and servicer fixed effects, and controls for second liens. We allow individual state time trends. Standard errors are clustered at the MSA level. * denotes 10% significance, ** denotes 5% significance, *** denotes 1% significance.

TABLE A.VI
IMPACT OF ORIGINAL AND CURRENT LEVERAGE ON 1 YEAR DEFAULT PROBABILITY: PROBIT ESTIMATES AND ALTERNATIVE INSTRUMENTS

	Panel A: Probit and Control Function				
	Baseline	Probit	Control Function	Probit	Control Function
Original Loan-to-Value	3.282***	2.028***	0.556**	1.602***	1.047***
	(0.100)	(0.134)	(0.260)	(0.169)	(0.296)
Current Negative Equity in $100,000s		0.251***	0.529***		
		(0.020)	(0.051)		
Current Loan-to-Value				1.347***	1.808***
				(0.111)	(0.216)
Mean of Dep. Var	0.264	0.264	0.264	0.264	0.264
N	265128	265128	265128	265128	265128
Origination Month FEs	Yes	Yes	Yes	Yes	Yes
Index FEs	Yes	Yes	Yes	Yes	Yes
State FEs	Yes	Yes	Yes	Yes	Yes
Full Controls	Yes	Yes	Yes	Yes	Yes
	Panel B: OLS and IV Incorporating Simulated Instrument				
	Baseline	OLS	IV	OLS	IV
Original Loan-to-Value	0.721***	−0.641*	0.256***	−0.541	0.229***
	(0.026)	(0.339)	(0.047)	(0.348)	(0.050)
Current Negative Equity in $100,000s		0.216***	0.090***		
		(0.060)	(0.010)		
Current Loan-to-Value				1.002***	0.415***
				(0.314)	(0.041)
Mean of Dep. Var	0.264	0.264	0.264	0.264	0.264
N	265134	265134	265134	265134	265134
Origination Month FEs	Yes	Yes	Yes	Yes	Yes
Index FEs	Yes	Yes	Yes	Yes	Yes
State FEs	Yes	Yes	Yes	Yes	Yes
Full Controls	Yes	Yes	Yes	Yes	Yes

Top panel shows probit and control function specifications of default between 24 and 36 months on borrowers' original loan-to-value and current equity at 24 months, defined as either the level of negative equity in $100,000s or current loan-to-value. Default is defined as 60 or more days past due. Baseline refers to probit regressions omitting current equity. Control Function regressions include the full set of interactions between index and origination month as instruments for current equity, and are estimated following Blundell and Powell (2004). The bottom panel includes OLS regressions as in Table III, but uses the simulated instrument. Full controls refers to fixed effects for index type, documentation, the loans purpose and occupancy, the existence of prepayment penalties and private mortgage insurance, and single family homes. We also include indicators for each 20-point bin of borrowers FICO credit scores, loan originator and servicer fixed effects, and controls for second liens. We allow individual state time trends. Standard errors are clustered at the MSA level. * denotes 10% significance, ** denotes 5% significance, *** denotes 1% significance.

TABLE A.VII
IMPACT OF ORIGINAL AND CURRENT LEVERAGE ON ONE YEAR DELINQUENCY, DEFAULT, AND FORECLOSURE RATES

	30 Days Past Due			90 Days Past Due			Foreclosure		
	Baseline	Equity	Loan-to-Value	Baseline	Equity	Loan-to-Value	Baseline	Equity	Loan-to-Value
Original Loan-to-Value	0.688***	0.379***	0.211***	0.710***	0.407***	0.256***	0.494***	0.315***	0.213***
	(0.026)	(0.034)	(0.049)	(0.026)	(0.037)	(0.051)	(0.019)	(0.029)	(0.038)
Current Negative Equity in $100,000s		0.060***			0.059***			0.035***	
		(0.005)			(0.005)			(0.004)	
Current Loan-to-Value			0.404***			0.381***			0.234***
			(0.034)			(0.035)			(0.022)
Mean of Dep. Var	0.304	0.304	0.304	0.248	0.248	0.248	0.177	0.177	0.177
N	213535	213535	213535	278761	278761	278761	294636	294636	294636
Origination Month FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Index FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
MSA FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Full Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

OLS and IV regressions of default between 24 and 36 months on borrowers' original loan-to-value and current equity at 24 months, defined as either the level of negative equity in $100,000s (Panel A), or current loan-to-value (Panel B). Default is defined as 30/90 or more days past due or as foreclosure. Baseline refers to OLS regressions omitting current equity. IV regressions include the full set of interactions between index and origination month as instruments for current equity. Full controls refers to fixed effects for index type, documentation, the loans purpose and occupancy, the existence of prepayment penalties and private mortgage insurance, and single family homes. We also include indicators for each 20-point bin of borrowers FICO credit scores, loan originator and servicer fixed effects, and controls for second liens. We allow individual state time trends. * denotes 10% significance, ** denotes 5% significance, *** denotes 1% significance.

TABLE A.VIII
FANNIE MAE LOAN-LEVEL PRICING ADJUSTMENTS

Table 1: All Eligible Mortgages (excluding MCM) – LLPA by Credit Score/LTV Ratio

Representative Credit Score	LTV Range								
	Applicable for all mortgages with terms greater than 15 years								
	≤ 60.00%	60.01 – 70.00%	70.01 – 75.00%	75.01 – 80.00%	80.01 – 85.00%	85.01 – 90.00%	90.01 – 95.00%	95.01 – 97.00%	SFC
≥ 740	0.000%	0.250%	0.250%	0.500%	0.250%	0.250%	0.250%	0.750%	N/A
720 – 739	0.000%	0.250%	0.500%	0.750%	0.500%	0.500%	0.500%	1.000%	N/A
700 – 719	0.000%	0.500%	1.000%	1.250%	1.000%	1.000%	1.000%	1.500%	N/A
680 – 699	0.000%	0.500%	1.250%	1.750%	1.500%	1.250%	1.250%	1.500%	N/A
660 – 679	0.000%	1.000%	2.250%	2.750%	2.750%	2.250%	2.250%	2.250%	N/A
640 – 659	0.500%	1.250%	2.750%	3.000%	3.250%	2.750%	2.750%	2.750%	N/A
620 – 639	0.500%	1.500%	3.000%	3.000%	3.250%	3.250%	3.250%	3.500%	N/A
< 620[(1)]	0.500%	1.500%	3.000%	3.000%	3.250%	3.250%	3.250%	3.750%	N/A

Loan-level interest rate increases necessary for different categories of original LTV and credit scores for loans delivered to Fannie Mae.

Table A.IX
Positive Correlation Tests: Original Leverage and Interest Rate Predict Default

	Panel A: Association Between Contract Terms and Delinquency by 60 Months for Option ARMs							
	No Controls	Month FEs	Full Controls	Low/No Doc	No Controls	Month FEs	Full Controls	Low/No Doc
Original Loan-to-Value	1.177***	0.929***	0.992***	1.122***				
	(0.068)	(0.064)	(0.037)	(0.040)				
Margin					0.222***	0.113***	0.068***	0.071***
					(0.007)	(0.005)	(0.004)	(0.005)
Mean of Dep. Var.	0.42	0.42	0.42	0.47	0.42	0.42	0.42	0.47
Raw Correlation	0.20	0.20	0.20	0.22	0.24	0.24	0.24	0.24
N	534909	534909	534909	419645	534909	534909	534909	419645
R^2	0.04	0.15	0.30	0.29	0.06	0.14	0.28	0.27
Origination Month FEs	No	Yes	Yes	Yes	No	Yes	Yes	Yes
Index FEs	No	No	Yes	Yes	No	No	Yes	Yes
MSA FEs	No	No	Yes	Yes	No	No	Yes	Yes
Full Controls	No	No	Yes	Yes	No	No	Yes	Yes
	Panel B: Association Between Contract Terms and Delinquency for 5/1 ARMs							
	No Controls	Month FEs	Full Controls	Low/No Doc	No Controls	Month FEs	Full Controls	Low/No Doc
Original Loan-to-Value	1.040***	0.867***	0.824***	0.963***				
	(0.069)	(0.052)	(0.038)	(0.038)				
Original Interest Rate					0.168***	0.133***	0.082***	0.089***
					(0.005)	(0.006)	(0.003)	(0.004)
Mean of Dep. Var.	0.32	0.32	0.32	0.37	0.32	0.32	0.32	0.37
Raw Correlation	0.191	0.191	0.191	0.210	0.360	0.360	0.360	0.357
N	453808	453808	453808	298142	453808	453808	453808	298142
R^2	0.036	0.13	0.26	0.26	0.13	0.14	0.26	0.26
Origination Month FEs	No	Yes	Yes	Yes	No	Yes	Yes	Yes
Index FEs	No	No	Yes	Yes	No	No	Yes	Yes
MSA FEs	No	No	Yes	Yes	No	No	Yes	Yes
Full Controls	No	No	Yes	Yes	No	No	Yes	Yes

Results from OLS regressions of the binary outcome of default on borrowers' original loan-to-value, margin, or initial interest rate and various controls. Default is defined as 60 or more days past due. Full controls refers to fixed effects for index type, documentation, the loans purpose and occupancy, the existence of prepayment penalties and private mortgage insurance, and single family homes. We also include indicators for each 20-point bin of borrowers' FICO credit scores, loan originator and servicer fixed effects, and controls for second liens. We allow individual state time trends. Raw correlation refers to the pairwise correlation between original loan-to-value or margin and default. The χ^2 test statistic is the test suggested in Chiappori and Salanié (2000), and tests for a correlation between the generalized residual from probit versions of the specifications presented here, and the residual from an OLS regression of original loan-to-value or margin on the listed covariates. Standard errors are clustered at the MSA level. Panel A subsets on Option ARMs, Panel B subsets on 5/1 ARMs. * denotes 10% significance, ** denotes 5% significance, *** denotes 1% significance.

B Positive Correlation Tests

In this appendix, we confirm the motivating relationship of the paper: a positive correlation between leverage and default. We first clarify that borrowers do not choose an amount of leverage in isolation. Instead, they choose a contract that entails both the loan size and the interest rate as a pair. We then explicitly conduct positive correlation tests following Chiappori and Salanié (2000) to demonstrate the existence of asymmetric information. More simply, we show that a positive correlation exists between loan size and default and that this correlation persists conditional on the relevant information available to the bank at the time of contracting.

B.1 The Contract Menu

Mortgage contracts often have many features, but the key choice analyzed here is the tradeoff between the amount of leverage—summarized by the original LTV—and the interest rate.[39] A borrower may select a high LTV contract that requires a high interest rate or a low LTV contract with a lower rate. This menu of different interest rates and leverage pairs represents two dimensions of what Geanakoplos (2014) calls the credit surface. The particular slope and curvature of the surface depends on the current economic climate, the borrower's credit score, and other observable characteristics. For a given lender, contracts are usually summarized in a rate sheet, a series of guidelines indicating the required rates for different mortgage products, features, and borrower characteristics.[40]

Two features of the contract menu are suggestive of the existence of information asymmetries. The first is the very presence of multiple contract options for a given borrower, a standard property of markets with separating equilibria. Of course, these options might reflect market segmentation based on unobserved heterogeneity in preferences that is irrelevant to the lender. The second is that the relationship between leverage and interest rate is increasing: larger loans are offered at a higher unitary price. This shows that lenders account for the increase in default risk that comes when observationally equivalent borrowers take larger loans. Appendix Figure A.IV shows this increasing relationship in the data, plotting the empirical schedule between leverage (original LTV) and the margin—the fixed portion of the interest rate—for Option ARMs. We show the median margin offered within each 5-point bin of LTV from 50 to 90.[41] A clear pattern emerges: borrowers who choose higher original LTVs are also choosing higher interest rates.

[39] Just as in the model, borrowers choose an initial loan L and Balance B.

[40] Customarily, lenders specify explicit margin increases associated with each 5-point bin of LTV. For eligible mortgages delivered to Fannie Mae, these increases are explicitly codified. Appendix Table A.VIII shows an example of pricing adjustments necessary for mortgages purchased by Fannie Mae.

[41] This figure presents raw data, unconditional on the borrower's credit score or other characteristics, and hence may not represent the actual contract menu offered to any specific borrower.

B.2 A Positive Correlation Between Leverage and Default

Appendix Figure IV shows the raw positive correlation between leverage and default. For Option ARMs, borrowers who choose large original LTVs are also more likely to default within the first 60 months of the loan. The relationship is nearly monotonic: those with original LTVs close to 50 default less that 10 percent of the time, while those with original LTVs near 90 default more than 50 percent of the time. The black line represents a local linear smoothing through the raw data, while black circles show the proportion of defaults for each 1-point point bin of original LTV.

By itself this raw correlation is not conclusive evidence of an information asymmetry. In principle, the correlation could be driven by selection on the basis of characteristics that are observed by the lender and appropriately priced into the contract. As a result, a crucial feature of the tests for information asymmetries suggested by Chiappori and Salanié (2000) are comprehensive controls for the lender's information set. If *observationally equivalent* borrowers who select larger loans default at higher rates, it can only be because (i) those borrowers are more likely to default on the basis of some unobservable (adverse selection), (ii) the larger loans actually *cause* more defaults (moral hazard), or (iii) some combination of the two.

Appendix Figure A.V shows that the positive correlation between original LTV and default holds conditional on the information available to the lender, providing an affirmative test for the existence of asymmetric information. Each dot in the plot shows the coefficient on original LTV from OLS regressions of a binary indicator of default by 60 months on original LTV, successively controlling for more comprehensive subsets of the information available to the lender. The leftmost coefficient, from a regression with no controls, displays the raw relationship: a 1-point increase in the borrower's original LTV is associated with an approximately 1.2 percentage point increase in defaults. The coefficient labeled *full controls* shows the relationship with the most comprehensive set of controls available. The inclusion of *full controls* drops the coefficient slightly, from just under 1.2 to just under 1.0. It remains large and significant. Note that only the inclusion of month fixed effects causes a meaningful drop, while controlling for the loan purpose and home value actually causes the coefficient to increase. The left-hand side of Panel A in Appendix Table A.IX exhibits the information in Appendix Figure A.V in table form.

While we would ideally be able to condition exactly on the information available to the lender, the Moody's data is missing two features typically known by mortgage originators. These are the borrower's income as well as soft personal information about a borrower's risk that is not recorded. Fortunately, because of the preponderance of low or no documentation Option ARMs, lenders also did not have information about borrowers' income for the majority of loans in the sample. The fourth column of Panel A displays results limiting the sample only to these loans. The coefficient remains significant, and in fact increases slightly. The problem of soft information is more difficult to deal with. However, any missing soft information is likely to bias the coefficient on the original LTV towards 0. If lenders are aware that borrowers are bad credit risks in some way that is unobservable in the Moody's data, they will be less likely to offer desirable terms for high leverage contracts.

The right-hand side of Table A.IX shows that whether one considers the borrower's leverage or interest rate as the defining feature of the contract is not crucial. There is a robust positive correlation between the borrower's margin and default. Finally, Panel B shows that the positive correlation holds consistently when looking at defaults by 12, 24, 36, or 48 months.

The final two coefficients shown in Figure A.V preview the remainder of the empirical analysis. The first, labeled *Ex-post LTV,* shows the coefficient on original LTV when controlling not just for the information of the lender, but also the (imputed) LTV at 60 months. The drop in the coefficient when including *Ex-post LTV* roughly represents the moral hazard effect. This is the portion of the correlation that is due not to selection, but to the incentives to default provided by the loan liability. The residual coefficient on original LTV represents selection. The final plotted coefficient, labeled *Option Value*, repeats this exercise using a more flexible set of controls in addition to the *Ex-post LTV*, including 6 months of leads and lags in interest rates and zip code level home prices. Note that there is not a significant drop in the coefficient when including this more flexible specification.

C Robustness

In this appendix, we describe a series of robustness checks intended to supplement the primary analysis.

Table A.II considers how the results in Table III change across three relevant subgroups: (i) in states with full recourse versus those with limited recourse, (ii) for borrowers providing full documentation versus those providing limited or no documentation, and (iii) for home purchases versus refinances. In each panel, we show the baseline relationship between original LTV and default for the relevant subgroup, then IV regressions with E_{ijt} defined first as negative equity and next as current LTV. All specifications include the full set of controls.

C.0. State Recourse Status

The most notable difference between states with full versus limited recourse[42] is in the strength of the estimated moral hazard effect. Both categories show a significant baseline correlation between original LTV and default. However, the impact of E_{ijt} on default—defined either as current negative equity or LTV—is large and statistically significant in limited recourse states, and near zero in full recourse states. This pattern is intuitive: in states where borrowers are responsible for the loan balance even in default, the marginal incentive to default generated by an increase in the current balance is low. Perhaps more surprising is that both types of states show strong evidence of adverse selection across OLS and IV specifications. In both cases, original LTV is strongly associated with default, controlling for current incentives to default. It should be noted that the sample size is much smaller in full recourse states, and the estimates are correspondingly less precise.

C.0. Documentation

Dividing borrowers by documentation provided, shown in Panel B of Table A.II, suggests that income verification may be an important factor in screening borrowers. The results for the low or no documentation sample largely match the full sample. In contrast, in the sample providing full documentation, the entirety of the raw correlation between leverage and default is explained by moral hazard. The optimistic view of this result is that documentation solves the adverse selection problem: the additional information on income allows lenders to distinguish an individual's riskiness before offering a set of contracts. However, because we do not observe income, we are also not perfectly

[42] By state recourse status, we refer to a state's provisions regarding a lender's ability to recover any balance that exceeds the value of the home in the case of default. We categorize states as full or limited recourse on the basis of that in Rao and Walsh (2009), with full recourse referring to states with strong provisions regarding deficiency judgments and limited recourse referring to those with mixed, weak, or nonexistent provisions.

able to control for the information set of the lender in the full documentation sample. As a result, the coefficient on original LTV in the full documentation sample pools an adverse selection effect with any steering of borrowers by lenders on the basis of income.

C.0. Purchases vs. Refinances

The differences between those purchasing homes versus those refinancing existing mortgages, shown in Panel C of Table A.II, are less severe than those in Panels A and B. While the baseline correlation between original LTV and default is higher in the refinance sample, both show comparable moral hazard effects: a 10 point increase in the current LTV causes an average of just over 4 percent more defaults within a year on average in both samples. However, the estimated adverse selection effects are slightly smaller in the purchase sample and only significant when E_{ijt} is defined as current negative equity.

C.0. Loans at 48 Months

The results for loans at 48 are similar to those at 24 months, if somewhat muted. Appendix Table A.III presents identical regressions to those in Table III, except with current E_{ijt} defined at 48 months and the dependent variable defined to be default between 48 and 60 months. With full controls, the baseline relationship between original LTV and default is somewhat lower than at 24 months, and the proportion of the correlation due to adverse selection somewhat higher (greater than 50 percent in the IV specifications). Further, the estimated moral hazard effects are smaller, and insignificant when E_{ijt} is defined to be current LTV. Given the weakness of the instrument at 48 months, these estimates should be interpreted cautiously, but they largely support the results found in Table III. Results at other cross-sections are similar.

C.0. Cumulative Default Probabilities

The regressions in Table III take an indicator for default within one year as the dependent variable. Doing so poses two potential issues. First, considering the default probability between 24 and 36 months limits the sample to borrowers who are still active at 24 months. This generates a potential source of bias, as borrowers who default or prepay in the early years of the loan may differ from the larger population, or may be responding endogenously to new knowledge of their anticipated future balance. Second, lenders may be more concerned with whether a borrower defaults at all, rather than a borrower's hazard rate, particularly with loans that feature negative amortization.

To address these issues, Appendix Table A.IV considers the impact of the original LTV and current E_{ijt} on cumulative default outcomes in the full sample. This approach avoids sample selection issues, but requires a slight reinterpretation of the treatment. The moral hazard effect no longer captures a response to the realized balance but rather the borrower's response to the anticipated balance trajectory. Furthermore, because E_{ijt} is not observed directly for those defaulting prior to t, we use the imputed version of the E_{ijt}, based on original contract terms and realized interest rates.

I first estimate specifications meant to mimic those in Table III, this time utilizing the outcome of cumulative default by 36 months. These are shown on the left-hand side of Appendix Table A.IV. We include imputed E_{ijt} measured at 36 months. For these estimates the baseline relationship between the original LTV and default is higher than in Table III. However, the portion owing to adverse selection—approximately 17 percent when E_{ijt} is defined as current negative equity, and 29 percent when defined as current LTV—is somewhat lower. Regardless, there is strong evidence that both moral hazard and adverse selection are present.

As a more robust test of the adverse selection effect, the right-hand side of Appendix Table A.IV considers the outcome of default by 60 months. For these regressions, we include a comprehensive set of controls for E_{ijt}, not just at a given point in time, but across the life of the loan. These controls are meant to account for the full impact of the non-linear loan trajectory throughout the first 60 months. Even controlling for the full trajectory of E_{ijt}, the initial leverage choice is strongly predictive of default. In these specifications, adverse selection remains responsible for approximately 30 percent of the baseline relationship between original LTV and default.

C.0. Alternate Functional Forms

A potential concern is that the observed effect of original LTV on default when controlling for E_{ijt} does not truly reflect selection, but rather some more complicated functional form relating E_{ijt} to default that is not captured by a linear specification. Appendix Table A.V examines whether there is still evidence of adverse selection across three more complex specifications: (i) including a cubic specification in current E_{ijt}, (ii) controlling for current and past minimum payments and interest rates, and (iii) interacting E_{ijt} with covariates.[43] The estimated adverse selection effect is persistent across all specifications.

C.0. Further Robustness

Appendix Tables A.VI and A.VII explore further robustness. The results are robust to (i) probit and control function specifications, which are potentially more realistic than the linear probability model,

[43]In column 5 of Appendix Table A.V, the OLS specification, we fully interact E_{ijt} with all covariates. However, because we do not have sufficient instruments to do so in an IV specification, in column 6 we simply interact E_{ijt} with two covariates: the borrower's credit score and whether the loan was to purchase a home or refinance an existing mortgage.

(ii) the use of the simulated instrument rather than the full set of fixed effects, and (iii) alternative definitions of default, ranging from mild (30 days past due) to extreme (foreclosure).