A Model of Mortgage Default

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Abstract

This paper solves a dynamic model of a household's decision to default on its mortgage, taking into account labor income, house price, inflation, and interest rate risk. Mortgage default is triggered by negative home equity, which results from declining house prices in a low inflation environment with large mortgage balances outstanding. Not all households with negative home equity default, however. The level of negative home equity that triggers default depends on the extent to which households are borrowing constrained. High loan-to-value ratios at mortgage origination increase the probability of negative home equity. High loan-to-income ratios also increase the probability of default by making borrowing constraints more severe. Interest-only mortgages trade off an increased probability of negative home equity against a relaxation of borrowing constraints.

1 Introduction

Many different factors contributed to the global financial crisis of 2007-09. One such factor seems to have been the growing availability of subprime mortgage credit in the mid-2000s. Households were able to borrow higher multiples of income, with lower required downpayments, often using adjustable-rate mortgages with low initial "teaser" rates. Low initial interest rates made the mortgage payments associated with large loans seem affordable for many households.

The onset of the crisis was characterized by a fall in house prices, an increase in mortgage defaults and home foreclosures, and a decrease in the value of mortgage-backed securities. These events initially affected residential construction and the financial sector, but their negative effects spread quickly to other sectors of the economy. Foreclosures appear also to have had negative feedback effects on the values of neighboring properties, worsening the decline in house prices (Campbell, Giglio, and Pathak 2010). The crisis has emphasized the importance of understanding household incentives to default on mortgages, and the way in which these incentives vary across different types of mortgage contracts. This paper studies the default decision using a theoretical model of a rational utility-maximizing household.

We solve a dynamic model of a household who finances the purchase of a house with a mortgage, and who must in each period decide how much to consume and whether to default on the loan. Several sources of risk affect household decisions and the value of the option to default on the mortgage, including house price risk, labor income risk, inflation risk, and real interest rate risk. We use labor income and house price data from the Panel Study of Income Dynamics (PSID), and interest rate and inflation data published by the Federal Reserve to parameterize these sources of risk.

The existing theoretical literature on mortgage default has emphasized the role of house prices and home equity accumulation for the default decision. Deng, Quigley, and Van Order (2000) propose a model, based on option theory, that predicts that the default option is exercised if it is in the money by some specific amount. That is, in their model agents do not default as soon as home equity becomes negative; they prefer to wait since default is irreversible and house prices may increase. Earlier empirical papers by Vandell (1978) and Campbell and Dietrich (1983) also emphasized the importance of home equity for the default decision.

In our model also, mortgage default is triggered by negative home equity which tends to occur for a particular combination of the several shocks that the household faces: house price declines in a low inflation environment with large nominal mortgage balances outstanding. Households do not default as soon as home equity becomes negative. A novel prediction of our model is that the default trigger level depends on the extent to which households are borrowing constrained; some households with more negative home equity than defaulting households, but who are less borrowing constrained than the defaulters, choose not to default. The degree to which borrowing constraints bind depends on the realizations of income shocks, the endogenously chosen level of savings, and the level of interest rates. This effect increases default rates for adjustable-rate mortgages (ARMs), because high interest rates imply larger mortgage payments on ARMs, tightening borrowing constraints and triggering defaults.

We use our model to investigate the extent to which the loan-to-value (LTV) and loan-to-income (LTI) ratios at mortgage origination affect default probabilities. The LTV ratio measures the equity stake that households have in the house. Naturally, a lower equity stake at mortgage initiation (i.e. a higher LTV ratio) increases the probability of negative home equity and default. This effect has been documented empirically by Schwartz and Torous (2003) and more recently by Mayer, Pence, and Sherlund (2009). Regulators in many countries, including Austria, Poland, China and Hong Kong, ban high LTV ratios in an effort to control the incidence of mortgage default.

The contribution of the LTI ratio to default is less well understood. LTI is a measure of mortgage affordability that is commonly used by mortgage providers throughout the world to determine the maximum loan amount and the interest rate. It has also drawn the attention of regulators. Some countries, such as the Netherlands and Hong Kong, have a regulatory mortgage affordability threshold in place.

A clear understanding of the relation between LTV and LTI ratios and mortgage defaults is particularly important in light of the recent US experience. Figure 1 plots aggregate LTV and LTI ratios for the US over the last couple of decades.[3] This figure shows that there was an increase in the average LTV in the years before the crisis, but to a level that does not seem high by historical standards. What is particularly striking is the large increase in the LTI ratio,

[3] The LTV data are from the monthly interest rate survey, and the LTI series is calculated as the ratio of average loan amount obtained from the same survey to the median US household income obtained from census data.

from an average of 3.3 during the 1980's and 1990's to a value as high as 4.5 in the mid 2000s. This pattern in the LTI ratio is not confined to the US; in the United Kingdom the average LTI ratio increased from roughly two in the 1970's and 1980's to above 3.5 in the years leading to the credit crunch (Financial Services Authority, 2009).

Our model allows us to understand the channels through which LTV and LTI ratios affect mortgage default. A smaller downpayment increases the probability of negative home equity, and reduces borrowers' incentives to meet mortgage payments. The unconditional default probabilities predicted by the model become particularly large (over ten percent) for LTV ratios in excess of ninety percent. The LTI ratio affects default probabilities through a different channel. A higher LTI ratio does not increase the probability of negative equity; however, it reduces mortgage affordability making borrowing constraints more likely to bind. The level of negative home equity that triggers default becomes less negative, and default probabilities accordingly increase. Thus our model suggests that mortgage providers and regulators should think about combinations of LTV and LTI and should not try to control these parameters in isolation.

During the recent crisis, interest-only and other alternative mortgage products have been criticized for their higher delinquency and default rates compared to traditional principal-repayment mortgages (Mayer, Pence, and Sherlund, 2009). Interest-only (IO) mortgages defer principal repayments to late in the life of the loan, so the loan amount outstanding at each date is larger, increasing the probability that the household will be faced with negative home equity. This increases the probability of default. On the other hand, IO mortgages have lower cash outlays which may relax borrowing constraints and reduce default probabilities. Our model shows that for IO mortgages with principal repayment at maturity, the latter effect dominates early in the life of the mortgage, but default rates become larger than for principal-repayment mortgages late in the life of the mortgage due to the considerably higher probability of negative home equity. Thus default rates for IO mortgages are less sensitive to drops in house prices in the early years of the loan, but more sensitive to the longer-term evolution of house prices.

Although IO mortgages with principal repayment at maturity are available in some countries, such as the UK, commonly available IO mortgages in the US have an interest-only period that ends after a few years, at which point the mortgage resets and households start repaying the principal. After mid-2011, $400 billion worth of US IO mortgage loans are expected to reset.[4] This implies for many households a large increase in mortgage payments which could lead them to default. We use our model to investigate the likelihood that this will be the case. We find that the reset of mortgage loans at a time when home equity is negative does indeed lead to a jump in default rates. The results of the model suggest that taking steps to alleviate households' liquidity constraints (for example by extending the IO period or increasing loan maturity) may help to reduce the size of such jump.

Households are heterogenous in many respects, for example their human capital characteristics, expected house price appreciation, and risk and time preferences. We use our model to investigate how such heterogeneity impacts mortgage default rates. For instance, we consider two households who differ in terms of the expected growth rate of their labor income, and find that the higher the growth rate the smaller the probability that a household will default on the mortgage. Interestingly, this reduction is larger for IO mortgages than for repayment mortgages.

Several recent empirical papers study mortgage default. Foote, Gerardi, and Willen (2008) examine homeowners in Massachusetts who had negative home equity during the early 1990s and find that fewer than ten percent of these owners eventually lost their home to foreclosure, so that not all households with negative home equity default. Bajari, Chu, and Park (2009) study empirically the relative importance of the various drivers behind subprime borrowers' decision to default. They emphasize the role of the nationwide decrease in home prices as the main driver of default, but also find that the increase in borrowers with high payment to income ratios has contributed to increased default rates in the subprime market. Mian and Sufi (2009) emphasize the importance of an increase in mortgage supply in the mid-2000s, driven by securitization that created moral hazard among mortgage originators.

The contribution of our paper is to propose a dynamic and unified microeconomic model of rational consumption and mortgage default in the presence of house price, labor income, and interest rate risk. Our goal is not to try to derive the optimal mortgage contract (as in Piskorski and Tchistyi, 2008, 2009), but instead to study the determinants of the default decision within an empirically parameterized model, and to compare outcomes across different types of mortgages. In this respect our paper is related to the literature on mortgage choice (see for example Brueckner (1994), Stanton and Wallace (1998, 1999), Campbell and Cocco

[4] The New York Times, September 9, 2009.

(2003), and Koijen, Van Hermert, and Van Nieuwerburgh (2010) among others).

Our paper is also related to interesting recent work by Corbae and Quintin (2010). They solve an equilibrium model to try to evaluate the extent to which low downpayment and delayed amortization mortgages were responsible for the increase in foreclosures in the late 2000s, and find that such mortgages account for 40% of the observed foreclosure increase. Our paper does not attempt to solve for mortgage market equilibrium, and therefore can examine household risks and mortgage terms in more realistic detail.

The paper is organized as follows. In section 2 we set up the model, building on Campbell and Cocco (2003) with extensions to study the mortgage default decision. We present results for standard principal-repayment mortgages, both fixed- and adjustable-rate, in section 3. Section 4 studies interest-only mortgages and compares their default characteristics to principal-repayment mortgages. Section 5 focuses on household heterogeneity, and section 6 carries out some robustness exercises. The final section concludes.

2 The Model

2.1 Setup

2.1.1 Time parameters and preferences

We model the consumption and default choices of a household with a time horizon of T periods, who uses a mortgage to finance the purchase of a house of fixed size H. We assume that household preferences are separable in housing and other consumption, and are given by:

$$\max E_0 \sum_{t=0}^{T} \beta^t \frac{C_t^{1-\gamma}}{1-\gamma} + \beta^{T+1} b \frac{W_{T+1}^{1-\gamma}}{1-\gamma}, \tag{1}$$

where β is the time discount factor, C_t is non-durable consumption, and γ is the coefficient of relative risk aversion. Since we have assumed that housing and non-durable consumption are separable and that H is fixed, we can drop the latter from the preferences. The household derives utility from terminal real wealth, W_{T+1}, which can be interpreted as the remaining lifetime utility from reaching age $T+1$ with wealth W_{T+1}. Terminal wealth includes both financial and housing wealth. The parameter b measures the relative importance of the utility derived from terminal wealth.

Naturally, in reality, H is not fixed and depends on household preferences and income, among other factors. We simplify the analysis here by abstracting from housing choice, but we do study mortgage default for different values of H. Later in the paper, in section 6.2, we consider a simple model of housing choice to make sure that our main results are robust to this consideration.

2.1.2 Interest and inflation rates

Nominal interest rates are variable over time. This variability comes from movements in both the expected inflation rate and the ex-ante real interest rate. We use a simple model that captures variability in both these components of the short-term nominal interest rate.

We write the nominal price level at time t as P_t, and normalize P_0=1. We adopt the convention that lower-case letters denote log variables, thus $p_t \equiv \log(P_t)$ and the log inflation rate $\pi_t = p_{t+1} - p_t$. To simplify the model, we abstract from one-period uncertainty in realized inflation; thus expected inflation at time t is the same as inflation realized from t to $t+1$. While clearly counterfactual, this assumption should have little effect on our results since short-term inflation uncertainty is quite modest. We assume that expected inflation follows an AR(1) process. That is,

$$\pi_t = \mu(1 - \phi) + \phi\pi_{t-1} + \epsilon_t, \tag{2}$$

where ϵ_t is a normally distributed white noise shock with mean zero and variance σ_ϵ^2. We assume that the ex-ante real interest rate is time-varying and serially uncorrelated. The expected log real return on a one-period bond, $r_{1t} = \log(1 + R_{1t})$, is given by:

$$r_{1t} = \overline{r} + \psi_t, \tag{3}$$

where $\overline{r}$ is the mean log real interest rate and ψ_t is a normally distributed white noise shock with mean zero and variance σ_ψ^2.

The log nominal yield on a one-period nominal bond, $y_{1t} = \log(1 + Y_{1t})$, is equal to the log real return on a one-period bond plus expected inflation:

$$y_{1t} = r_{1t} + \pi_t. \tag{4}$$

2.1.3 Labor income

The household is endowed with stochastic gross real labor income in each period, L_t, which cannot be traded or used as collateral for a loan. As usual we use a lower case letter to denote the natural log of the variable, so $l_t \equiv \log(L_t)$. The household's log real labor income is exogenous and is given by:

$$l_t = f(t, Z_t) + v_t + \omega_t, \tag{5}$$

where $f(t, Z_t)$ is a deterministic function of age t and other individual characteristics Z_t, and v_t and ω_t are random shocks. In particular, v_t is a permanent shock and assumed to follow a random walk:

$$v_t = v_{t-1} + \eta_t, \tag{6}$$

where η_t is an i.i.d. normally distributed random variable with mean zero and variance σ_η^2. The other shock represented by ω_t is transitory and follows an i.i.d. normal distribution with mean zero and variance σ_ω^2. Thus log income is the sum of a deterministic component and two random components, one transitory and one persistent.

We let real transitory labor income shocks, ω_t, be correlated with innovations to the stochastic process for expected inflation, ϵ_t, and denote the corresponding coefficient of correlation φ. In a world where wages are set in real terms, this correlation is likely to be zero. If wages are set in nominal terms, however, the correlation between real labor income and inflation may be negative.

We model the tax code in the simplest possible way, by considering a linear taxation rule. Gross labor income, L_t, and interest earned are taxed at the constant tax rate τ. We allow for mortgage interest deductibility at this rate.

2.1.4 House prices

The price of housing fluctuates over time. Let P_t^H denote the date t real price of housing, and let $p_t^H \equiv log(P_t^H)$. We normalize $P_0^H = 1$ so that H also denotes the value of the house that the household purchases at the initial date. The real price of housing is a random walk with drift, so real house price growth can be written as:

$$\Delta p_t^H = g + \delta_t, \tag{7}$$

where g is a constant and δ is an i.i.d. normally distributed random shock with mean zero and variance σ_δ^2. We assume that the shock δ is uncorrelated with inflation, so in our model housing is a real asset and an inflation hedge. It would be straightforward to relax this assumption.

We assume that innovations to real house prices are perfectly positively correlated with innovations to the permanent component of the household's real labor income. Therefore states with high house prices are also states with high permanent labor income. While there is evidence that labor income and house prices are positively correlated, the assumption of perfect correlation is counterfactual. We make this assumption since it allows us to reduce the dimensionality of the household's optimization problem.

2.1.5 Mortgage contracts

The household finances the purchase of a house of size H with previous accumulated savings and a nominal mortgage loan of $(1-\delta)H$, where δ is the required down-payment. (Recall that we have normalized, without loss of generality, P_0^H and P_0 to one.) Therefore the LTV and LTI ratios at mortgage origination are given by:

$$LTV = (1-\delta) \tag{8}$$

$$LTI = \frac{(1-\delta)H}{L_0}, \tag{9}$$

where L_0 denotes the level of household labor income at the initial date.

Required mortgage payments depend on the type of mortgage. We consider several alternative types, including FRM, ARM, and IO mortgages.

Let Y_T^{FRM} be the interest rate on a FRM with maturity T. It is equal to the expected interest rate over the life of the loan plus an interest rate premium. The date t real mortgage payment, M_t^{FRM}, is given by:

$$M_t^{FRM} = \frac{(1-\delta)H\left[\frac{1}{Y_T^{FRM}} - \frac{1}{Y_T^{FRM}(1+Y_T^{FRM})^T}\right]^{-1}}{P_t}. \tag{10}$$

For simplicity we abstract from the refinancing decision. In many countries FRMs do not include an option to refinance. In addition, most households with negative home equity are unable to refinance, so default decisions are little affected by this option.

Let Y_{1t}^{ARM} be the one-period nominal interest rate on an ARM, and let D_t^{ARM} be the nominal principal amount outstanding at date t. The date t real mortgage payment, M_t^{ARM}, is given by:

$$M_t^{ARM} = \frac{Y_{1t}^{ARM} D_t^{ARM} + \Delta D_{t+1}^{ARM}}{P_t}, \tag{11}$$

where ΔD_{t+1}^{ARM} is the component of the mortgage payment at date t that goes to pay down principal rather than pay interest. We assume that for the ARM the principal loan repayments, ΔD_{t+1}^{ARM}, equal those that occur for the FRM. This assumption simplifies the solution of the model since the outstanding mortgage balance is not a state variable.

A household with an IO mortgage pays interest each period but only repays the principal at maturity. Therefore the date $t < T$ real mortgage payment is given by:

$$M_t^{IO} = \frac{Y_{1t}^{IO}(1-\delta)H}{P_t}, \tag{12}$$

and the principal amount outstanding is constant in nominal terms over the life of the loan. This type of mortgage is available in some countries, such as the UK. But in the US the most common type of IO mortgages involve an interest-only period that varies in length, after which the loan resets, and borrowers start paying the principal in addition to the interest. We will also study default for this type of mortgage.

The date t nominal interest rate for both ARM and IO mortgages is equal to the short rate plus a constant premium:

$$Y_{1t}^i = Y_{1t} + \psi^i. \tag{13}$$

where the mortgage premium ψ^i, for $i = ARM, IO$, compensates the lender for default risk. For the FRM the interest rate is fixed over the life of the loan, and equals the average interest rate over the loan maturity plus a premium ψ^{FRM}.

2.1.6 Mortgage default

In each period the household decides whether or not to default on the mortgage loan. The household may be forced to default because it has insufficient cash to meet the mortgage payment. However, the household may also find it optimal to default, even if it has the cash to meet the payment.

We assume that in case of default the household is not liable in terms of financial savings or future labor income for any losses incurred by mortgage providers. The mortgage provider seizes the house, the household is excluded from credit markets, and since it cannot borrow the funds needed to buy another house it is forced into the rental market for the remainder of the time horizon.[5] The rental cost of housing equals the user cost of housing plus a constant rental premium, ψ^R. That is, the date t real rental cost Z_t for a house of size H is given by:

$$Z_t = [Y_{1t} - E_t[(exp(\Delta p^H_{t+1} + \pi_t) - 1] + \psi^R]P^H_t H, \tag{14}$$

where Y_{1t} is the one-period nominal interest rate, $E_t[exp(\Delta p^H_{t+1} + \pi_{1t}) - 1]$ is the expected one-period proportional nominal change in the house price, and $P^H_t H$ is the date t real value of the house.

Relative to owning, renting is costly for several reasons. First, there is a rental premium ψ^R that households must pay. This may be motivated by moral hazard considerations, that renters may not have as great an incentive as homeowners to take care of the property. Second, owning provides insurance against future house price fluctuations (Sinai and Souleles, 2005). When renting households must pay a rent that is proportional to house prices. However, in our model permanent income shocks are positively correlated with house price shocks, so households do have an economic hedge against house price fluctuations even if they are not homeowners. Third, following the US tax rules, we allow for mortgage interest deductibility.

We assume that in case of default the household is guaranteed a lower bound of $\underline{C}$ in per-period non-durable consumption, which can be viewed as a subsistence level. It can be motivated by the existence of social welfare programs that put a lower bound on the consumption that households are able to achieve. In terms of our model it implies that consumption and default decisions are not driven by the probability of marginal utility being equal to infinity,

[5] This is a simplification. In the US households who default are excluded from credit markets for seven years.

which would be the case for power utility if there was a positive probability of zero (or very small) consumption.

2.2 Solution Technique

This problem cannot be solved analytically. The numerical techniques that we use for solving it are standard. We discretize the state-space and the variables over which the choices are made. The state variables of the problem are age (t), cash-on-hand (X_t), whether the household has defaulted on the mortgage or not (Def_t^S, equal to one if previous default and zero otherwise), real house prices (P_t^H), the price level (P_t), inflation (π_t), and the real interest rate (r_{1t}). The choice variables are consumption (C_t) and whether to default on the mortgage loan if no default has occurred before (Def_t^C, equal to one if the household chooses to default in period t and zero otherwise). Terminal real wealth is given by:

$$W_{T+1}^i = X_{T+1} + P_{T+1}^H H, \quad \text{for } i = ARM, FRM \text{ and } Def_{T+1}^S = 0 \tag{15}$$

$$W_{T+1}^{IO} = X_{T+1} + P_{T+1}^H H - \frac{(1-\delta)H}{P_{T+1}}, \quad \text{for } Def_{T+1}^S = 0, \tag{16}$$

$$W_{T+1}^{Rent} = X_{T+1}, \quad \text{for } Def_{T+1}^S = 1. \tag{17}$$

For the ARM and FRM contracts, if the household has not previously defaulted, real wealth is the sum of real financial wealth and housing wealth. For the IO mortgage we need to subtract the loan principal repayment (in real terms) to obtain real terminal wealth. In the default state households derive utility solely from real financial wealth.

In the periods before the last, the equation describing the evolution of cash-on-hand in the no default state is:

$$X_{t+1}^i = (X_t - C_t)(1 + R_{1t}(1-\tau)) - M_t^i + L_{t+1}(1-\tau) + \frac{Y_{1t}^i D_t \tau}{P_t}, \tag{18}$$

for $i = ARM, IO, FRM$. Savings earn real interest that is taxed at rate τ. Next period's cash-on-hand is equal to the latter minus mortgage payments (made at the end of the period), plus next period's labor income and the tax deduction on nominal mortgage interest paid.[6]

The evolution of cash-on-hand in the default state is given by:

$$X_{t+1}^{Rent} = (X_t - C_t)(1 + R_{1t}(1-\tau)) - Z_t + L_{t+1}(1-\tau). \tag{19}$$

where Z_t denotes the date t real rental payment.

We have solved this problem by backwards induction starting from period $T+1$. The shocks are approximated using Gaussian quadrature. For inflation and house prices we assume that there are two possible outcomes. This simplifies the numerical solution of the problem since for each period t we only need to keep track of the number of past high/low inflation and house price shocks to determine the date t price level and house prices. For each combination of the state variables, we optimize with respect to the choice variables. We use cubic spline interpolation to evaluate the value function for outcomes that do not lie on the grid for the state variables.

2.3 Parameterization

2.3.1 Time and preference parameters

In order to parameterize the model we assume that each period corresponds to one year. We assume that the initial age in our model is 30 and that age T is 50. Thus mortgage maturity is 20 years. In the baseline parameterization we set the discount factor β equal to 0.98 and the coefficient of relative risk aversion γ equal to 2. But we recognize that there is household heterogeneity with respect to preference and other parameters, and we study the role that such heterogeneity plays in mortgage default. The parameter that measures the relative importance of terminal wealth, b, is assumed to be equal to 400. This is large enough to ensure that households have an incentive to save. The time and preference parameters that we use in the baseline case are reported in the first panel of Table 1.

[6] This equation can be adapted to allow taxation of nominal interest, or a mortgage deduction only for real mortgage interest. We are currently exploring these alternatives.

2.3.2 Labor income

We use data from the Panel Study of Income Dynamics (PSID) for the years 1970 to 2005 to calibrate the labor income process. Our income measure is broadly defined to include total reported labor income, plus unemployment compensation, workers compensation, social security transfers, and other transfers for both the head of the household and his spouse. We use such a broad measure to implicitly allow for the several ways that households insure themselves against risks of labor income that is more narrowly defined. Labor income was deflated using the consumer price index.

It is widely documented that income profile varies across education attainment. To control for this difference, following the existing literature, we partition the sample into three education groups based on the educational attainment of the head of the household. For each education group we regress the log of real labor income on age dummies, controlling for demographic characteristics such as marital status and household size, and allowing for household fixed effects. We use this smoothed income profile to calculate, for each education group, the average household income for an head with age 30 and the average annual growth rate in household income from ages 30 to 50. The estimated real labor income growth rate for households with a high-school degree is 0.8 percent, and we use this value in the benchmark case. The assumption of a constant income growth rate is a simplification of the true income profile that makes it easier to carry out comparative statics and to investigate the role of future income prospects on the default decision.

We use the residuals of the above panel regressions to estimate labor income risk. In order to mitigate the effects of measurement error on estimated income risk, we have winsorized the income residuals at the 5th and 95th percentiles. We follow the procedure of Carroll and Samwick (1997) to decompose the variance of the winsorized residuals into transitory and permanent components. The estimated values are reported in Table 1.

2.3.3 House prices

We use house price data from the PSID to estimate the parameters of the house price process. In each wave, individuals are asked to assess the current market value of their houses. We obtain real house prices by dividing self-reported house prices by the consumer price index.

House price changes are calculated as the first difference of the logarithm of real house prices, for individuals who are present in consecutive annual interviews, and who report not having moved since the previous year.

In order to address the issue of measurement error, and similarly to labor income, we have winsorized the logarithm of real house price changes at the 5th and 95th percentiles (-36.6 and 40.3 percent, respectively). We use the winsorized data to calculate the expected value and the standard deviation of real house price changes, which are equal to 1.66% and 16.2%, respectively. This fairly large standard deviation probably is due, in part, to measurement error in the data. In the baseline value we use these estimated values, but we consider alternative parameterizations.[7]

2.3.4 Interest and inflation rates

In order to parameterize the stochastic process for the real interest rate we use data on the US Treasury yield with 1-year maturity, published by the Federal Reserve. We calculate the real interest rate by deflating the nominal yield by the inflation rate. The estimated parameters for the process for the real interest rate and the AR(1) process for the inflation rate are reported in Table 1.

In the baseline case we set the credit risk premium on each of the mortgage loans, ψ^i, for $i = FRM, ARM, IO$ equal to 1%. This allows us to compare the determinants of mortgage default across the different types of mortgage loans, for a given premium. Naturally, to the extent that some of these mortgage types have higher default rates than others, the credit risk premium should also be larger. We investigate this issue in a later section. Finally, we set the rental premium ψ^R equal to 2%.

[7] The fact that house values in PSID are self assessed and do not correspond to real transactions may raise some concerns. We have obtained data on median US house prices from the Monthly Interest Rate Survey for the years of 1991 to 2007. The average growth rate in real (nominal) house prices over this period was 1.2 (3.9) percent, with a standard deviation of 4.8 percent. This lower standard deviation is due to the fact that it is calculated using an aggregate house price index.

2.3.5 Correlations

We use household level data to estimate the correlation between income and house price shocks. We find that house price shocks are positively correlated with labor income shocks, but the estimated correlation is only 0.037, which is in part due to measurement error in the data. In order to compute the correlations between house prices and income shocks and inflation and real interest rate shocks, we compute, for each year, their average across households. In the baseline parameterization we set the correlation between the different shocks equal to zero (except for labor income and house prices), but it would be feasible to consider other values for these correlations.

3 Default Rates for Principal-Repayment Mortgages

In order to study the determinants of mortgage default we solve for the policy functions, generate realizations for house price, income and interest rate shocks, and then simulate the optimal consumption and default choices for ten thousand agents. The results that we report in this section are based on these simulations. Therefore, they are unconditional results, based on the different possible realizations for the shocks weighted by their respective probabilities.

3.1 Mortgage default triggers

To illustrate the determinants of mortgage default, we begin by reporting some results for a standard ARM. Figure 2 plots the age profiles of cross-sectional average real consumption and mortgage default rates which are the two choice variables in the model. The consumption profile is increasing with age reflecting the fact that households in the model are borrowing constrained. Most of the default that occurs takes place between the ages of 33 and 38, or between three and eight years into the life of the loan. Schwartz and Torous (2003) have found in regressions aimed at explaining default rates that the age of the mortgage plays an important role. Figure 2 shows that our model is consistent with this empirical finding, with almost no default taking place in the second decade of the mortgage life.

We are interested in determining what triggers default in our model. A natural candidate is home equity. The empirical literature on mortgage default has emphasized the importance of this variable (see for example Deng, Quigley, Van Order (2000), or more recently Foote, Gerardi, and Willen (2008), and Bajari, Chu, and Park (2009)). We calculate for each household and for each date t the current house value as a fraction of currently outstanding debt:

$$Equity_t = \frac{P_t P_t^H H}{D_t} \tag{20}$$

where D_t denotes the loan principal amount outstanding at date t, P_t denotes the price level, and P_t^H the real price of housing. The latter two are a function of the realization of the inflation and house price shocks between dates 1 and t, respectively. Taking natural logarithms of the above:

$$\ln(Equity_t) = \ln(P_t) + \ln(P_t^H) + \ln(H) - \ln(D_t). \tag{21}$$

When households are underwater (that is, when they have negative home equity) then $Equity_t$ is less than one and $\ln(Equity_t)$ is less than zero.

Figure 3 plots the date t price level, house prices, and remaining debt against $\ln(Equity_t)$. The right hand graph shows the data for the households who choose to default at date t, whereas the left hand graph shows the data for the agents who choose not to do so. The figure clearly illustrates that defaulting households have negative home equity ($\ln(Equity_t) < 0$).

Comparing the left and right hand side graphs we see that negative home equity tends to occur for a particular combination of the realization of the shocks: declines in house prices (which result in a low P_t^H) in a low inflation environment (which results in a low price level) at times when there are large mortgage balances outstanding (early in the life of the loan). Since the mortgage loan is nominal, high inflation realizations and the corresponding increases in the price level lead to a reduction in the real value of the outstanding loan, and to a reduction in the likelihood that the household is faced with negative home equity.

Most interestingly, not all households with negative equity choose to default. The left hand graph of Figure 3 shows that indeed there are households who are underwater but who choose not to default. We focus on these households and construct a variable that measures the ratio of current mortgage payments to household income (MTI):

$$MTI_t = \frac{M_t}{L_t} \tag{22}$$

In Figure 4 we plot this variable, by default decision, for households with negative home equity. The figure shows that households do not default at low levels of negative home equity. It is only when equity becomes sufficiently negative that default occurs. Thus households only exercise the put option when it is in the money by some amount. This is also a prediction of models that take an option theory approach to the mortgage default decision, such as Deng, Quigley, and Van Order (2000). But in our model the ratio of mortgage payments to household income also plays an important role; it is those households with a larger value for this ratio that tend to default. Large mortgage payments relative to household income, in the presence of borrowing constraints, force a choice between severe consumption cutbacks and mortgage default.

Table 2 reports the means of several variables for households with large negative home equity ($\ln(Equity) < -0.1$) by default decision and mortgage type. This table confirms that the households who choose to default are those with low income and large mortgage payments relative to income. The MTI ratio averages 0.443 for households who default versus 0.348 for households who do not default. The next two rows of this table report real rental payments and the difference between mortgage and rent payments scaled by household income. Rental payments are on average much lower than mortgage payments. This is of course due to the fact that mortgage payments cover both interest and principal repayments. For households significantly underwater who choose to default, that decision allows for a reduction in current housing expenditure of 37 percent of income. For those that choose not to default the reduction would only be 27 percent of income.

The results in Table 2 also highlight some interesting differences between default decisions for ARMs and FRMs. For ARMs default tends to occur when interest rates are high, since then ARM payments are high relative to income. On the other hand there is little difference in real mortgage payments relative to income between households who default and who not default on FRMs. For these mortgages default tends to occur when interest rates are low since it is at such times that rental payments are lower. The difference between mortgage and rent payments (as a percentage of income) is 39 percent for defaulting households versus 36 percent for non-defaulting households.

3.2 The effects of LTV and LTI on default

We are interested in evaluating how LTV and LTI ratios at mortgage origination relate to subsequent default, so we solve our model for different values for these parameters. We are particularly interested in LTI since Figure 1 shows a significant increase in average LTI during the 2000s. One important advantage of using a model to study the effect of LTI is that we can compare outcomes across LTI for a common set of shocks to the households in the model.

With the previously discussed results on mortgage default triggers in mind, we decompose the probability of default into the probability that the household is faced with negative equity times the probability of default conditional on negative home equity:

$$\Pr(Default) = \Pr(Equity < 0) \times \Pr(Default/Equity < 0). \tag{23}$$

The results are reported in Table 3. Panel A shows the results for ARMs: in the top panel we vary the LTV (for a given LTI) and in the bottom panel we vary the LTI (for a given LTV). Unsurprisingly, for higher LTV the probability of negative home equity is also higher. On the other hand, the probability of default conditional on negative equity actually *decreases* with the LTV ratio. For higher LTV ratios households are more likely to be faced with negative equity early in the life of the loan, and are more likely to wait before defaulting. This tends to counteract the increased probability of negative equity. The former effect dominates for the values we consider, so the probability of default increases significantly with LTV: from 6.6 percent for 80 percent LTV to 17.1 percent for 95 percent LTV.

In the bottom part of Panel A we vary LTI for a given LTV. Default rates increase with LTI because there is an increase in the probability of default conditional on negative equity. The higher the initial LTI the higher are mortgage payments relative to household income, which makes liquidity constraints more severe, and induce default. The probability of negative home equity does not depend on the LTI.

Panel B of Table 3 shows the results for FRMs. For every combination of the parameters considered, unconditional default probabilities are smaller for FRMs than for ARMs. The qualitative patterns are similar to those in Panel A, but there are some interesting quantitative differences. Default rates for FRMs increase much less with LTI than those for ARMs: from 8.6 percent to 12.6 percent for the former compared to from 9.8 percent to 17.9 percent for the latter (for an increase in LTI from 3.5 to 5.5). Thus default probabilities for ARMs are more sensitive to LTI than default probabilities for FRMs. This effect comes solely from a higher probability of default in case of negative home equity since the two types of mortgages have identical outstanding principal at each point of time, and are subject to identical house price shocks. The reason is that high interest rates tighten borrowing constraints on ARM borrowers, a point emphasized by Campbell and Cocco (2003).

4 Alternative Mortgage Products

During the recent financial crisis, mortgage delinquency and default rates have been particularly large for alternative mortgage products. These come in many different forms, but generally share the feature that they postpone principal repayments to later in the life of the loan. We use our model to study these mortgages and to compare them to the more traditional principal-repayment mortgages.

We consider two different types of interest-only (IO) mortgages. The first is an IO mortgage for which loan principal repayment takes place only at maturity. Although this type of mortgage is available in some countries, it is not the most common in the US. Therefore, we also study another type of IO mortgage, with interest-only payments for a given number of years, that then resets to a principal-repayment mortgage. In the US a large number of these mortgages, originated during the mid-2000s, will reset within the next few years, and at the time of the reset there will be a large increase in mortgage payments. The concern is that such an increase will lead households to default on their mortgages.

Table 4 decomposes default probabilities into the probability of negative equity and the probability of default conditional on negative equity. Panel A repeats our earlier results for standard ARMs and Panel B shows results for an IO mortgage with principal repayment at maturity. Comparing Panels A and B, we see that default rates for IO mortgages are significantly higher than for ARMs. The main reason is that IO mortgages have much higher probabilities of negative home equity. The difference is particularly large for lower levels of the LTV; for LTV of 0.80 the probability of negative home equity is 0.378 for IO mortgages compared to 0.195 for ARMs.

An interesting finding is that the probabilities of default, and of default conditional on negative equity, are less sensitive to LTI for IO mortgages than for ARMs. For an increase in LTI from 3.5 to 5.5, the default probability conditional on negative equity increases from 0.344 to 0.397 for IO mortgages compared to from 0.228 to 0.396 for ARMs. IO mortgages have much lower mortgage payments relative to income than ARMs do, so their default rates conditional on negative home equity are much less sensitive to the initial LTI.

The last panel of Table 4 reports the results for IO mortgages that reset after two years. The default probabilities (as well as their components) have values in between those of the ARM and the IO with repayment of principal only at maturity. The probabilities reported in Table 4 are calculated over the life of the loan, and hide interesting time variation in default probabilities. In order to investigate this time variation in Figure 5 we plot the per year probability of negative home equity and cumulative default rates for the different types of mortgages.

Comparing first ARMs to IO mortgages with principal repayment at maturity we see that early in the life of the loan default rates are actually higher for the former, in spite of the fact that the probability of negative home equity is higher for the latter. The reason is that mortgage payments are higher for repayment than for IO mortgages, borrowing constraints are more likely to bind, and it is more costly for households to exercise the option to wait. Later in the life of the mortgage, the dominant force becomes the fact that households with an IO mortgage are much more likely to have negative home equity, and their default rates become larger than those for ARMs. In fact for IO mortgages default occurs until maturity, whereas for ARMs default becomes negligible in the second half of the loan. Thus default rates for IO mortgages are more sensitive to the longer-term evolution of house prices.

Naturally, default rates for IO mortgages with a reset period are less sensitive to the longer-term evolution of house prices, since households start paying down the principal prior to maturity. Figure 5 shows the results for two alternative reset periods, two and five years. Interestingly, for both of these cases, and for each period, cumulative default rates are higher than for ARMs. IO mortgages with a reset period have lower mortgage payments than ARMs before the reset period, but higher payments after (the loan principal is repaid at a faster rate after the reset period). The period of lower mortgage payments is the initial period, when households are less likely to have negative home equity (due to the downpayment), and less likely to default. And the increase in mortgage payments after the reset period leads them to default on the mortgage. This means that IO mortgages with a short reset period (up to 5 years) may lead to, in the shorter term, higher default rates than for either ARMs or IO mortgages with a longer reset period.

5 Household Heterogeneity

In the previous sections we have studied mortgage default for different initial LTV and LTI ratios, and for different mortgage types, but for given household preference parameters and human capital. In this section we recognize that households are heterogeneous in their preference parameters and in the characteristics of their labor income. Such heterogeneity may affect the type of mortgage that households choose. For example, an individual who faces a steep income profile may be more likely to choose an interest-only mortgage since this helps to relax borrowing constraints early in life. With this in mind, we investigate the effects of household characteristics on default rates.

5.1 Labor income growth

Households differ in their expected growth rate of labor income. We investigate the impact of this parameter on default probabilities. More precisely, in the second panel of table 5 we report results for an average income growth equal to 1% (compared to 0.8% in the baseline case). Compared to the baseline case we see that the probability of default is now lower, both for the ARM and the IO mortgage with reset. Although the probability of negative equity is not affected by household income growth, the probability of default given negative equity is reduced. Interestingly, this reduction is larger for the IO than for the ARM: a reduction of 6% in default probabilities for the former compared to a reduction of 4% for the latter. When income growth is higher, the reset of the mortgage interest rate is less likely to lead households to default, since at the time of the reset their income is likely to be higher.

5.2 House price growth

In the second panel of Table 5 we investigate the effects of a higher expected growth rate of house prices, equal to 2% (compared to 1.6% in the baseline case). Higher house price growth reduces the probability of negative home equity and the probability of default given negative equity. Both these channels contribute to a reduction of the overall default probability.

5.3 Stigma from mortgage default

In a recent empirical paper Guiso, Sapienza, and Zingales (2009) find that moral and social considerations play an important role in the default decision. Ceteris paribus, people who consider it immoral to default are 77% less likely to declare their intention to do so. We can adapt our model to investigate how such considerations affect default rates for different mortgage types. We assume that in case of default the household incurs a utility loss, $Stigma$. The household will choose to default, setting $Def_t^C = 1$, whenever the continuation utility with default less the stigma cost is higher than the utility without default:

$$V_t(State_t \mid Def_t^c = 1) - Stigma > V_t(State_t \mid Def_t^C = 0). \tag{24}$$

The main difficulty with this extension of our model is determining an appropriate value for $Stigma$. In the fourth panel of Table 5 we report the results for $Stigma = 0.05$. In order to give the reader an idea of what this means we have translated this value into an equivalent per-period consumption loss. For the ARM mortgage, $Stigma = 0.05$ is equivalent to a decrease in the constant equivalent consumption stream of 3.43% per period. The results in table 5 show that this level of $Stigma$ has a large effect on default probabilities, both for ARM and the mortgages.

5.4 Utility of terminal wealth

For tractability, we have truncated our baseline model at age 50, but we have allowed the agent to derive utility from terminal wealth, which can be viewed as the remaining lifetime utility from reaching age 50 with a given wealth level. This also insures that agents in our model have an incentive to save. In the baseline parameterization we have set the parameter b that measures the relative importance of terminal wealth equal to 400. One way to asses how reasonable this value is to study the wealth accumulation generated by the model. For the ARM contract, and at age 50, agents have on average US \$195,000 of accumulated financial wealth. This value should be compared to the financial wealth held by households in checking and saving accounts, mutual funds, and retirement accounts. We have solved our model for alternative values for b, equal to 200 and 100, and we report the default probabilities in the last two panels of Table 5. The average financial wealth at age 50 under the ARM contract is \$159,000 for the first alternative and \$94,000 for the second. The higher are the incentives for individuals to save, the smaller are the default probabilities predicted by the model.

6 Robustness

6.1 Horizon Effects

A potential concern is that our model may be artificially generating horizon effects. For a household who defaults early in the life of the mortgage, the horizon is long and so is the period during which the rental premium must be paid. On the other hand, later in the life of the mortgage, there are fewer periods left during which the individual must pay the rental premium, so the penalty in case of default is smaller. This may have a differential impact in the default rates for different mortgage types.

In order to investigate the extent to which this should be a concern, we have solved our model for a different default penalty. More precisely, in this alternative model, we let the rental premium be equal to 2% in the first seven years after the agent defaults, after which it drops to 1% (the same value as the mortgage premium). If the household defaults in the last seven years of the model, then it pays a lump-sum rental premium at the terminal date equal to the present value of the rental premiums not yet paid, discounted at the riskless interest rate. Our choice of 7 years reflects the number of years for which mortgage default information is kept in the credit history of households in the US. In a recent paper, Demyanyk, Koijen, and Hemert (2010) empirically study the consequences of mortgage default on a borrower's credit score. The solution of this model requires an additional state variable in the default state, that measures the number of periods that have passed since the agent has defaulted.

The results are shown in Table 6. The first panel shows the baseline results for comparison. Naturally, for this alternative model, the predicted default probabilities are higher than for the baseline model, since the penalty in case of default is lower. Table 6 shows that the increases are particularly large for the ARM and the IO mortgage with a reset period. Figure 6 shows the evolution with age of default rates and the probability of negative home equity. As expected, there is a smaller increase in default for the IO mortgages in the latter years of the mortgage. For this mortgage type, in the baseline case, the increase in default that occurs in the last seven years of the loan is 4.9 percent (25 percent of the total), whereas for the alternative model the increase is 4.1 percent (19 percent of the total). However, the general patterns are very similar to the baseline case (shown in Figure 5).

6.2 Housing choice

In the baseline model we have assumed for tractability that housing and other goods preferences are separable, and that housing is fixed. This was done for tractability. Existing theoretical models of mortgage default also make this assumption. But there may be interesting interactions between default choice and housing choices. We extend our model to allow for housing choice in the event of default.[8]

More precisely, we allow defaulting households to freely choose between three different levels of housing. These levels are the same as in the baseline case (initial LTI=3.5), a smaller house with initial LTI of 2.5, and a larger house with initial LTI of 4.5. We assume separable preferences between housing and other consumption so as to be consistent with the baseline model. Thus household preferences are given by:

$$U(C_t, H_t) = \frac{C_t^{1-\gamma}}{1-\gamma} + \theta \frac{H_t^{1-\gamma}}{1-\gamma}. \tag{25}$$

In this extended model there is one more choice variable in the default state, but no additional state variables are needed. The results for two alternative values for θ are reported in the last two panels of Table 7. In each of these panels, the last two columns report the proportion of households who chose to increase/decrease/maintain house size in the period in which they default. The first panel reports the baseline results, for which there is no housing choice in the default state, so that by definition all households maintain house size.

As we would expect, default rates are higher when households are allowed to choose house size in the default state. Of course this effect comes solely from the probability of default

[8] It would be considerably more complicated to allow for housing choice in the no-default state, since this would require additional state variables. In addition it is likely that most households considering default cannot change house size without default, since they are likely to have negative home equity.

conditional on negative equity. Most households that choose to default reduce house size. But when housing is sufficiently important (θ is larger) there are some households who choose to increase house size. Households default when they are underwater, which occurs when house prices are lower, so that housing is relatively cheaper relative to other consumption. The importance of this effect depends on the degree of substitutability between housing and other goods consumption in household preferences. But overall the results in Table 7 show that the default probability patterns that we have emphasized in this paper are robust to this alternative model in which we allow for house size choice.

7 Future Research

7.1 Credit risk premium

We have investigated the determinants of mortgage default for exogenously given credit risk premia, similar across mortgage types. However, such premia should in equilibrium reflect the probability of default and the losses given default for mortgage providers. We can use our model to determine what such premia should be.

The first step is to calculate the expected profits of banks. In periods in which the household chooses not to default, the nominal dollar profit of mortgage providers is equal to the interest rate premium charged times the debt outstanding:

$$\Pi_t^i = \psi_i D_t^i \tag{26}$$

where $i = ARM, FRM, IO$ denotes mortgage type, D_t^i is the principal amount of the loan outstanding at date t and Π denotes dollar profit.

The nominal profit of mortgage providers for periods in which the household defaults on the loan is:

$$\Pi_t^i = P_t P_t^H H - D_t^i. \tag{27}$$

This formula assumes that when there is default, mortgage providers sell the house for nominal value $P_t P_t^H H$. It does not take account of any negative effect of foreclosure on house value, of the sort documented by Campbell, Giglio, and Pathak (2010), but it would be straightforward to extend the model to allow for this.

The ex-ante expected profit of mortgage providers is given by:

$$E_0[\sum_{j=1}^{J}\sum_{t=1}^{T+1}\frac{\Pi_t^{ij}}{(1+Y_{1t})^t}] \tag{28}$$

where j denotes the household. We can compare the profits of mortgage providers for different contracts and for different parameter values. We can investigate the increase in mortgage credit risk premia that different LTI and LTV ratio and mortgage contracts warrant. This assumes that mortgage providers are risk neutral, but it would be straightforward to consider a higher discount rate for the profits. We can also compare the premia generated from our model to actual data on the premia charged by mortgage providers for different mortgage types.

7.2 Unemployment risk

An important source of income risk is unemployment, or the probability of a large drop in income. In our baseline model, unemployment risk is not separately modeled but simply contributes to a higher variance of labor income shocks. Alternatively, we can use an income process that explicitly models the possibility of unemployment. We have used PSID data to parameterize this source of risk. The probability of unemployment is equal to 4.9 percent. To assess the impact of unemployment on the level of labor income, we calculate the ratio of the average reported household income for unemployed heads to the average reported income for employed heads of household. We find that unemployment implies a drop in income to 57 percent of its value.

This estimated drop in labor income in the event of unemployment may seem small. However, it is important to remember that we are using a broad measure of labor income, that includes not only wages, but also social security and other transfers that households receive. In addition, we use annual income measure, and the average duration of unemployment is less than one year. Finally, we measure household income and not individual income. In many households, even if the head becomes unemployed, the spouse may remain employed and receive wage income. Our parameterization takes into account all these different ways that households have to insure themselves against unemployment of the head of households.

8 Conclusion

We have proposed a model of mortgage default, in the presence of labor income, house price, inflation and interest rate risk, to show how these different shocks contribute to the default decision. We have decomposed our model's predicted default rates into the probability that households face negative home equity and the probability that they choose to default conditional on negative equity. Negative home equity tends to occur for a particular combination of the shocks: house price declines in a low-inflation environment, early in the life of the mortgage when outstanding balances are large. Not all households with negative equity choose to default. Those who face large mortgage payments relative to income, a result of high interest rates and low labor income, are more likely to do so.

We have modelled different mortgage types, including adjustable-rate, fixed-rate, and interest-only mortgages. The predicted default rates differ across these types, as do the determinants of the default decision. Interest-only mortgages are characterized by a higher probability of negative home equity, but not necessarily a higher probability of default in case of negative home equity. Since mortgage payments are lower relative to income, for a given level of negative home equity, households are more likely to exercise the option to wait before defaulting. This also makes default rates for interest-only mortgages more sensitive to the longer term evolution of house prices.

In the credit boom of the mid-2000s average loan-to-value (LTV) ratios were relatively stable, but loan-to-income (LTI) ratios increased. We have used our model to calculate default rates, by mortgage type, for different values for these mortgage parameters. Our decomposition of the default rate into the probability of negative home equity and the probability of default given negative home equity shows that a high LTV ratio increases the former whereas a high LTI ratio increases the latter. The model's predicted default rates become particularly large when both LTV and LTI ratios are high. Finally, we have used our model to explore the effects of household heterogeneity, including a stigma effect of default, on default rates. In future research it would be interesting to use data on mortgage default to structurally estimate our model parameters and to test the predictions of the model across households and mortgage types.

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Table 1: Baseline Parameters

Time and Preference Parameters	
Discount factor	0.98
Risk aversion	2
Intial age	30
Number of periods	20
Bequest motive	20^2
Lower bound on cons	$1,000
Loan Parameters	
Loan to income	3.5
Loan to value	0.90
Credit risk premium	0.01
Rental premium	0.02
Labor income	
Income growth	0.008
Stdev permanent income shocks	0.063
Stdev temporary income shocks	0.225
House prices	
Expect house price return	0.016
Stdev house price return	0.162
Real Interest Rate	
Mean	0.018
Stdev of the real rate	0.017
Inflation Rate	
Mean	0.041
Stdev of the inflation rate	0.028
AR(1) coefficient	0.723

Note to Table 1: This table reports the parameter values used in the baseline case.

Table 2: Means for different variables for observations with Ln(Equity)<-0.10 by mortgage type and household default decision.

	ARM		FRM	
Variable	Default	No default	Default	No default
Age	36.36	34.44	36.59	34.64
Real net income	29.49	33.11	29.51	32.47
Real consumption	15.28	16.50	14.76	15.90
Ln(Current loan-to-value)	0.250	0.164	0.266	0.164
Ln(Nominal interest rate)	0.054	0.037	0.031	0.047
Real mortgage payment	12.42	10.97	12.33	13.82
Mortgage Payment/Income	0.443	0.348	0.439	0.446
Real rental payment	1.960	2.454	1.315	2.551
(Mortgage-Rent)/Income	0.373	0.271	0.392	0.363
Number of observations	962	2598	848	2844

Note to Table 2: This table reports the mean for several variables for ARM and FRM by default decision for households with

Table 3: Probability of default predicted by the model.

Panel A: Adjustable-Rate Mortgage			
Loan-to-income = 4.5	ltv = 0.80	ltv = 0.9	ltv = 0.95
Prob(Default)	0.066	0.130	0.171
Prob(Home equity<0)	0.195	0.431	0.556
Prob(Default/Home equity<0)	0.341	0.300	0.308
Loan-to-value = 0.90	lti = 3.5	lti = 4.5	lti = 5.5
Prob(Default)	0.098	0.130	0.179
Prob(Home equity<0)	0.431	0.431	0.426
Prob(Default/Home equity<0)	0.228	0.300	0.396

Panel B: Fixed-Rate Mortgage			
Loan-to-income = 4.5	ltv = 0.80	ltv = 0.9	ltv = 0.95
Prob(Default)	0.057	0.107	0.136
Prob(Home equity<0)	0.195	0.431	0.556
Prob(Default/Home equity<0)	0.293	0.249	0.244
Loan-to-value = 0.90	lti =3.5	lti = 4.5	lti = 5.5
Prob(Default)	0.086	0.107	0.126
Prob(Home equity<0)	0.431	0.431	0.431
Prob(Default/Home equity<0)	0.200	0.249	0.292

Note to Table 3: This table decomposes the probability of default into probability of negative equity times the probability of default conditional on negative home equity for the FRM and ARM mortgage contracts for different values for LTV and LTI.

Table 4: Probability of default predicted by the model for Interest-Only Mortgages

Panel A: Adjustable-Rate Mortgage			
Loan-to-income = 4.5	ltv = 0.80	ltv = 0.90	ltv = 0.95
Prob(Default)	0.066	0.130	0.171
Prob(Home equity<0)	0.195	0.431	0.556
Prob(Default/Home equity<0)	0.341	0.300	0.308
Loan-to-value = 0.90	lti = 3.5	lti = 4.5	lti = 5.5
Prob(Default)	0.098	0.130	0.179
Prob(Home equity<0)	0.431	0.431	0.426
Prob(Default/Home equity<0)	0.228	0.300	0.396
Panel B: Interest-Only Mortgage			
Loan-to-income = 4.5	ltv = 0.80	ltv = 0.90	ltv = 0.95
Prob(Default)	0.150	0.209	0.240
Prob(Home equity<0)	0.378	0.561	0.669
Prob(Default/Home equity<0)	0.397	0.372	0.359
Loan-to-value = 0.90	lti =3.5	lti = 4.5	lti = 5.5
Prob(Default)	0.193	0.209	0.223
Prob(Home equity<0)	0.561	0.561	0.561
Prob(Default/Home equity<0)	0.344	0.372	0.397
Panel C: Interest-Only Mortgage With Reset			
Loan-to-income = 4.5	ltv = 0.80	ltv = 0.90	ltv = 0.95
Prob(Default)	0.089	0.167	0.208
Prob(Home equity<0)	0.249	0.449	0.591
Prob(Default/Home equity<0)	0.356	0.372	0.352
Loan-to-value = 0.90	lti =3.5	lti = 4.5	lti = 5.5
Prob(Default)	0.127	0.167	0.208
Prob(Home equity<0)	0.449	0.449	0.449
Prob(Default/Home equity<0)	0.282	0.372	0.463

Note to Table 4: This table reports decomposes the probability of default into the probability of negative equity times the probability of default conditional on negative home equity for ARM and the Interest-Only mortgage contracts for different values for LTV and LTI.

Table 5: Probability of default predicted by the model for different parameters

Baseline	ARM	IO Reset
Prob(Default)	0.098	0.127
Prob(Home equity<0)	0.431	0.449
Prob(Default/Home equity<0)	0.228	0.282
Higher income growth = 1%	ARM	IO Reset
Prob(Default)	0.094	0.119
Prob(Home equity<0)	0.431	0.449
Prob(Default/Home equity<0)	0.219	0.266
Higher house price growth = 2%	ARM	IO Reset
Prob(Default)	0.090	0.118
Prob(Home equity<0)	0.428	0.445
Prob(Default/Home equity<0)	0.211	0.265
Stigma= 0.05	ARM	IO Reset
Prob(Default)	0.035	0.045
Prob(Home equity<0)	0.431	0.449
Prob(Default/Home equity<0)	0.082	0.100
b = 200	ARM	IO Reset
Prob(Default)	0.135	0.184
Prob(Home equity<0)	0.431	0.449
Prob(Default/Home equity<0)	0.314	0.410
b = 100	ARM	IO Reset
Prob(Default)	0.156	0.210
Prob(Home equity<0)	0.431	0.449
Prob(Default/Home equity<0)	0.362	0.469

Note to Table 5: This table reports decomposes the probability of default into the probability of negative equity times the probability of default conditional on negative home equity for ARM and the Interest-Only mortgage contracts for different values for income growth, house price returns, Stigma, and for the importance of the utility of terminal wealth.

Table 6: Default probabilities for a different penalty in case of default

Probabilities	ARM	FRM	IO	IO Reset
Base Model				
Prob(Default)	0.098	0.086	0.193	0.127
Prob(Home equity<0)	0.431	0.431	0.561	0.449
Prob(Default/Home equity<0)	0.228	0.200	0.344	0.282
Model with 7 year penalty				
Prob(Default)	0.133	0.112	0.214	0.169
Prob(Home equity<0)	0.431	0.431	0.561	0.449
Prob(Default/Home equity<0)	0.307	0.260	0.382	0.375

Note to Table 6: The first panel reports the results for the baseline model. In the second panel the penalty is such that the individual pays a rental premium equal to 2% in the seven years after default and 1% in subsequent years. When default occurs within seven years of the terminal date, the remaining penalty is paid at the terminal date, discounted at the riskfree rate.

Table 7: Default probabilities and housing size choice when default

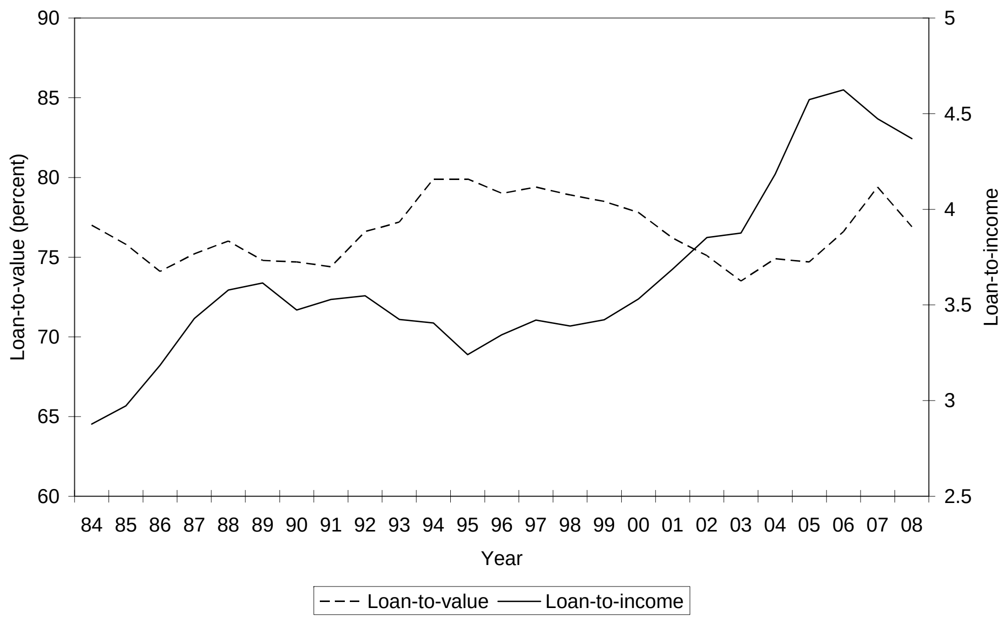
Probabilities	ARM	IO Reset	House choice	ARM	IO Reset
Base Model, LTI = 3.5					
Prob(Default)	0.098	0.127	$\Delta H < 0$	n.a.	n.a.
Prob(Home equity<0)	0.431	0.449	$\Delta H = 0$	n.a.	n.a.
Prob(Default/Home equity<0)	0.228	0.282	$\Delta H > 0$	n.a.	n.a.
LTI = 3.5, $\theta = 0.3$					
Prob(Default)	0.162	0.195	$\Delta H < 0$	0.531	0.525
Prob(Home equity<0)	0.431	0.449	$\Delta H = 0$	0.366	0.329
Prob(Default/Home equity<0)	0.376	0.435	$\Delta H > 0$	0.104	0.147
LTI = 3.5, $\theta = 0.2$					
Prob(Default)	0.168	0.202	$\Delta H < 0$	0.678	0.632
Prob(Home equity<0)	0.431	0.449	$\Delta H = 0$	0.322	0.368
Prob(Default/Home equity<0)	0.388	0.449	$\Delta H > 0$	0.000	0.000

Note to Table 7: The house size data reports the percentage of households who decrease, increase and do not change house size in periods when they default on the mortgage. The preferences are:

$$U(C_t, H_t) = \frac{C_t^{1-\gamma}}{1-\gamma} + \theta \frac{H_t^{1-\gamma}}{1-\gamma}. \tag{1}$$

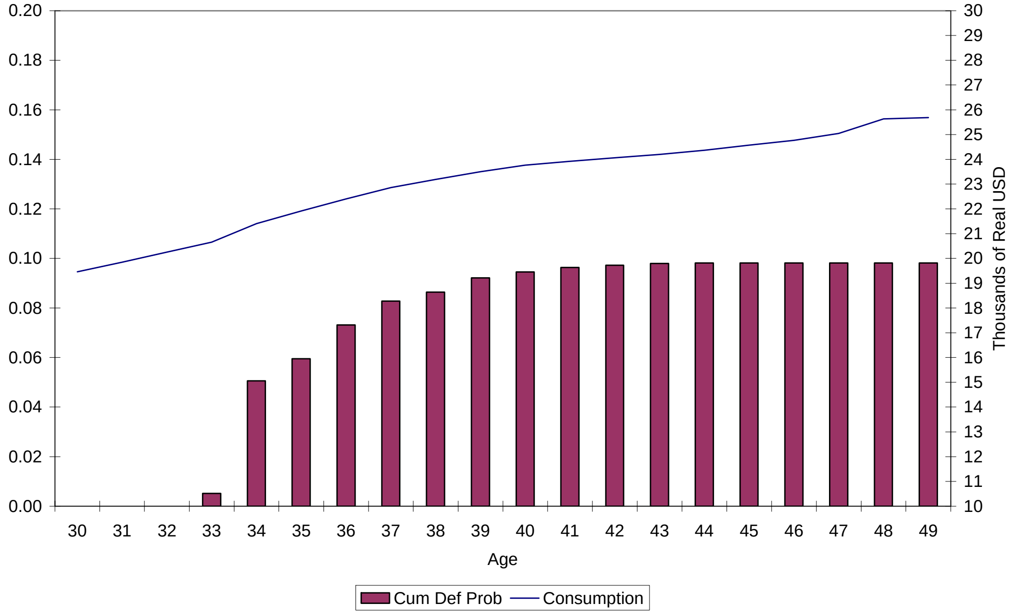
The first panel reports the baseline results for which there is no housing choice.

Figure 1: Loan-to-value and loan-to-income over time for the US.



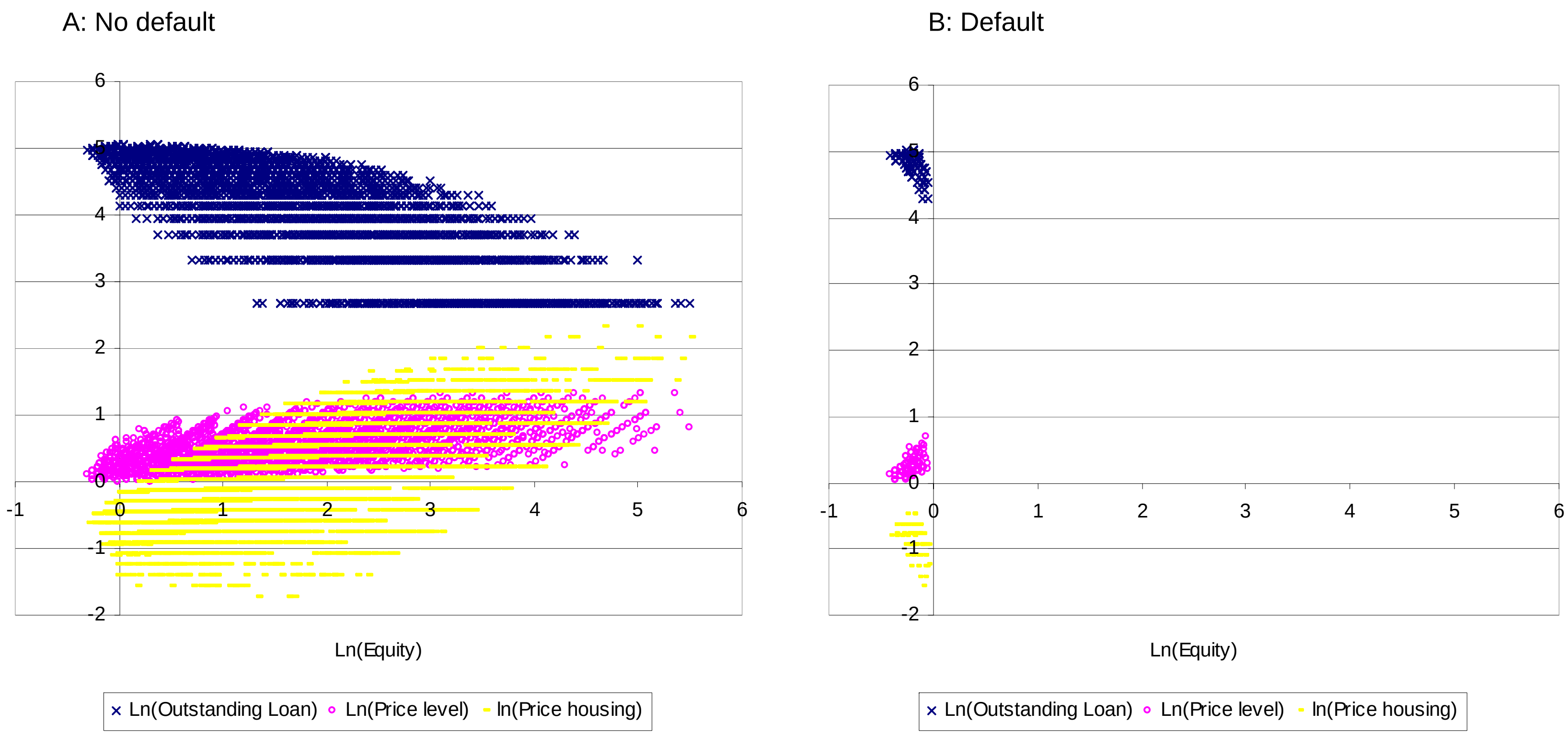
Note to Figure 1: The LTV data are from the Monthly Interest Rate Survey and the LTI data are calculated as the ratio of the average loan amount obtained from the same survey to the median US household income obtained from Census data.

Figure 2: Mean consumption and cumulative default rates predicted by the model



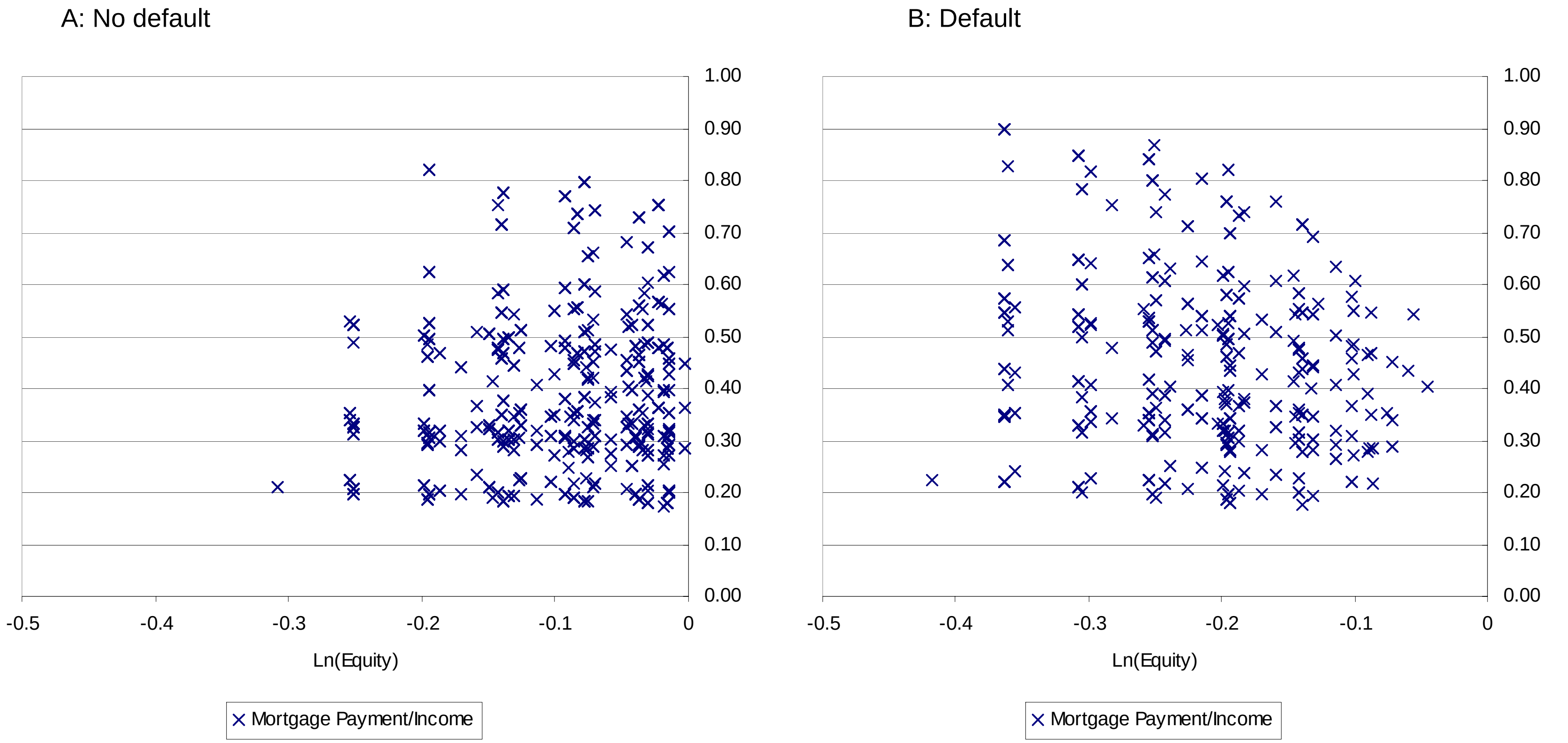
Note to Figure 2: The data is generated from simulating the model for the ARM with the parameters in Table 1.

Figure 3: Logarithm of Home Equity as a function of the logarithm of house prices, price level and outstanding principal by default decision.



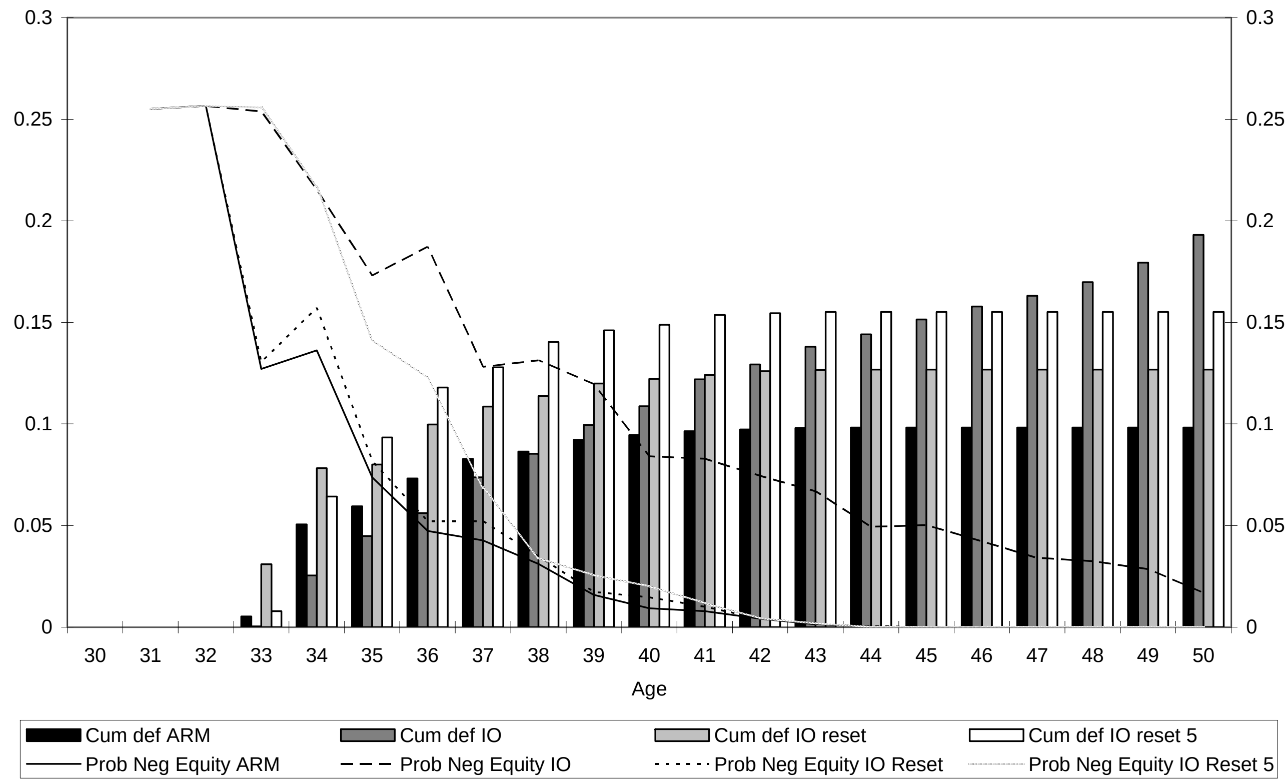
Note to Figure 3: The data is generated from simulating the model for the ARM with the parameters in Table 1.

Figure 4: Logarithm of Home Equity as a function of the ratio of mortgage payments to household income by default decision for households with ln(equity)<0.



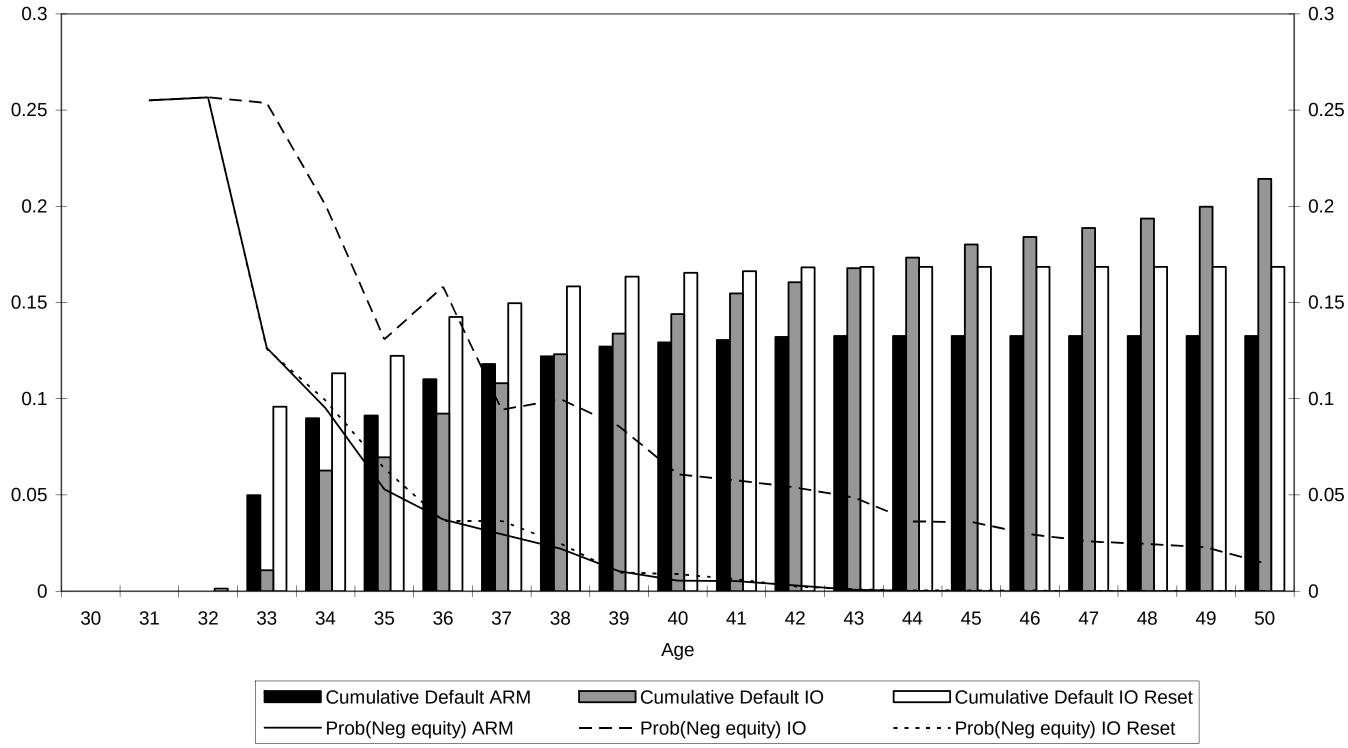
Note to Figure 4: The data is generated from simulating the model for the ARM with the parameters in Table 1.

Figure 5: Probability of negative home equity and cumulative default rates with age for different mortgage contracts.



Note to Figure 5: The data is generated from simulating the model.

Figure 6: Probability of negative home equity and cumulative default rates for different penalty in case of default.



Note to Figure 6: The data is generated from simulating the model with a rental premium equal to 2% in the first seven years subsequent to default, and 1% afterwards.