



Innovations in information technology and the mortgage market[☆]



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ABSTRACT

In this paper I analyze the effects of innovations in information technology on the mortgage and housing markets using a life-cycle model with incomplete markets and idiosyncratic income, as well as moving and house price shocks. I explicitly model the housing tenure choices of households. Lenders offer individual-specific mortgage contracts to home buyers, and the terms of these contracts are endogenously determined. I find that, as lenders have better information about the households, the average mortgage premium, foreclosure rate, and homeownership rate all increase while average down payment decreases. Hence, improvements in information technology can rationalize the relaxation of mortgage credit terms, which has been suggested as one of the main reasons for the latest financial crisis.

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1. Introduction

The U.S. housing market has witnessed some remarkable changes in the last two decades. Between 1995 and 2006, it went through an expansionary period during which homeownership rate, house price, and mortgage originations reached historically high levels. However, beginning in 2006, the housing market experienced the most severe downturn in U.S. history, which initiated the worst recession since the Great Depression. Many researchers point to the relaxation of mortgage lending terms for the boom and bust cycle of the housing market.¹ However, to the best of my knowledge, there is no study that models the reason behind the relaxation of the mortgage credit terms. Therefore, in this paper, I fill this gap by studying the effects of advances in the information technology used by mortgage originators on the relaxation of mortgage terms.

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¹ For example, see Ortalo-Magne and Rady (2006), Mian and Sufi (2009), Corbae and Quintin (2013), Dell'Ariccia et al. (2012), Favilukis et al. (2011), Ferrero (2012), Landvoigt et al. (2012), and Demyanyk and Van Hemert (2011).

Table 1
Summary statistics.

Statistic ^a	1992–1995	2002–2006
Homeownership	64.2%	68.6%
Foreclosure rate	0.7%	0.9%
Down payment fraction	25%	20%
Mortgage premium	1.3%	1.7%

^a Homeownership data is from Census. Foreclosure data is from Mortgage Bankers Association with the correction suggested by [Herkenhoff and Ohanian \(2013\)](#); Foreclosure completions are half of the foreclosure starts. Down payment data is from [Chomsisengphet and Pennington-Cross \(2006\)](#). They are calculated as the ratio of total mortgage loan at the time of origination and house price at the time of origination using Loan Performance data. Mortgage interest rate data is from Monthly Interest Rate Survey of Federal Housing Finance Agency and calculated for 30-year fixed rate mortgages. Mortgage premium is measured as the difference between the 30-year fixed rate mortgage and the 10-year treasury constant maturity rate.

Arguably, the most prominent technological change for the mortgage market in the last few decades is the emergence of automated underwriting systems (AUS), which have allowed for a better assessment of the credit risks of home buyers. In particular, advances in information technology (e.g., the rapid decline in the cost of storing and transmitting credit information) have enabled access to more comprehensive data on households, which, in turn, have increased the predictive power of credit scores, thereby allowing lenders to assess the credit risk of home buyers more precisely.² Accompanying these improvements in information technology, the housing market experienced important changes along several key dimensions. As reported in [Table 1](#), a comparison of the periods between 1992 and 1995, and 2002 and 2006 reveals that (i) the foreclosure rate increased, (ii) the average mortgage premium went up, (iii) the average down payment decreased, and (iv) the homeownership rate rose.

In this paper, I explore the effect of innovations in information technology—specifically, the increased ability of lenders to assess the credit risk of home buyers—on the housing and mortgage markets. I develop a standard life-cycle model with incomplete markets and idiosyncratic labor income, as well as moving and house price shocks. I also model the housing tenure choice explicitly. Households are born as renters. Every period, renters decide whether to purchase a house. The purchase of the house can be done through long-term mortgages offered by a continuum of risk-neutral lenders. A mortgage contract consists of a mortgage interest rate, loan amount, mortgage repayment schedule, and maturity. Mortgages are fully amortizing (i.e., homeowners have to pay the mortgage back in full until the end of the mortgage contract, as specified by the maturity date).

Homeowners can transition to renting either exogenously or endogenously. They can receive a moving shock with a fixed probability in every period, and become a renter in the next period. In that case, during the transition from homeownership to renting, they have two options: they either sell their houses or default on the mortgage if they have one.³ Selling a house is different from defaulting, because a seller has to pay back the outstanding mortgage balance to the lender, whereas a defaulter has no obligation. Therefore, default occurs in equilibrium as long as the sale price, net of transaction costs, is lower than the outstanding mortgage debt, which can happen due to the transaction costs of the housing sale or idiosyncratic house price shocks. However, default is not without cost. It involves periodic utility loss, and, upon default, the household becomes a renter again, and then is only eligible to purchase a house with a certain probability. There are two types of households: those with a high utility cost of default (i.e., the “low-risk” type) and those with a low utility cost of default (i.e., the “high-risk” type).⁴

There is free entry into the credit market, so in equilibrium lenders make zero profit on each contract. Since mortgages are long-term contracts, it is essential for the lenders to infer the default probability of each household throughout the life of the mortgage, which depends on the income and house price risks as well as on the type of the household. In this study, I explore two information structures. In one economy, lenders can observe all the characteristics of the household except its type, which creates asymmetric information between the lenders and households. I call this economy the asymmetric information (AI) economy. In the other economy, lenders can observe all of the characteristics of the household, and, therefore, the information is symmetric. Hence, I call it the symmetric information (SI) economy.⁵

I interpret the AI economy as representing the U.S. economy before the emergence of the AUS (before the mid-1990s), and the SI economy as representing the more recent period with AUS (mid-2000s). I calibrate the model to the mid-2000s in order to recover the underlying parameters of the model. Then, I solve the model with asymmetric information representing the mid-1990s. As these two time periods also differ with regard to average interest rates and house prices, I use the

² See [Appendix A.3](#) for more empirical and anecdotal evidence on the effect of innovations in information technology on the mortgage market.

³ I use the terms “default” and “foreclosure” interchangeably. They correspond to the same activity in the model.

⁴ In the rest of the paper, “type” refers to this heterogeneity in the utility cost of default.

⁵ The source of unobserved heterogeneity among households that creates informational asymmetry between lenders and households is somewhat arbitrary. Although this assumption has been used in the previous literature (e.g. [Narajabad, 2012](#) and [Athreya, 2002](#)), it is a difficult task to identify the unobservable type in the data. However, I also experimented with other sources of unobserved heterogeneity, such as income, moving propensity and the discount factor. The qualitative results are similar.

risk-free interest rate and house price of the mid-1990s to solve for the AI economy. The results indicate that the transition from the AI economy to the SI economy decreases the down payment, and increases the mortgage premium, foreclosure rate and homeownership rate, which are all consistent with the corresponding changes in the mortgage market in the specified time period.

Since the AI and SI economies also differ in the risk-free interest rate and house price, I conduct the following (counterfactual) experiment in order to isolate the role of information technology. I simulate the SI economy with the same set of parameters used in the AI economy, and interpret the difference between this economy (which I call the SI-2 economy) and the AI economy as the contribution of the improvements in information technology. The results show that information structure can explain 87% of the increase in the foreclosure rate, 64% of the increase in the mortgage premium, as well as 51% of the decrease in the down payment. Changes in the risk-free interest rate and house price are more important with regard to explaining the increase in the homeownership rate. A higher foreclosure rate does not mean that lenders and households are worse off in the SI-2 economy. When I measure the welfare gain of being born into the SI-2 economy as opposed to the AI economy, the gain, in consumption equivalent terms, is 0.3%. Furthermore, the zero-profit restriction on the contracts ensures that, ex-ante, lenders are indifferent between the two economies. However, the foreclosure rate becomes more sensitive to an unexpected house price shock. The SI-2 economy generates 25% more foreclosures than the AI economy in response to a 20% unexpected drop in the house price.

In the AI economy, lenders cannot observe the types, and face an adverse selection problem. The presence of this asymmetric information puts additional constraints on the contracts offered in the AI economy. The transition from the AI economy to the SI-2 economy renders the credit terms both in the intensive and extensive margins more relaxed. In the extensive margin, those low-income households that are rationed out in the AI economy due to the adverse selection problem face more affordable mortgages in the SI-2 economy. Since these households are comprised of low-income and low-wealth individuals, they demand a lower down payment, which requires a higher mortgage premium. In the intensive margin, since low-risk households are now perfectly observed, they receive more affordable mortgage contracts, which have a lower down payment, at the cost of a higher mortgage premium. As a result, the average down payment decreases, while the average mortgage premium increases. Since the new home buyers are low-income and low-wealth households, and the average down payment decreases together with an increase in the mortgage premium, the default risk in the mortgage market increases. Thus, the foreclosure rate increases.

There is a growing empirical literature that suggests that innovations in the mortgage market are among the main reasons for the recent changes in the housing market.⁶ However, the literature has paid little attention to the modeling of this link.⁷ My own approach is similar to that of [Campbell and Cocco \(2003\)](#), [Li and Yao \(2007\)](#), and [Fernandez-Villaverde and Krueger \(2011\)](#), which feature the life-cycle model of housing with idiosyncratic income shocks.⁸ I model the housing tenure choice of the households (i.e., owning versus renting) as in [Gervais \(2002\)](#), [Chambers et al. \(2009\)](#), and [Sommer et al. \(2012\)](#). I also model the mortgages as individual specific contracts by treating the default option explicitly, as in [Corbae and Quintin \(2013\)](#), [Chatterjee and Eyigungor \(2011\)](#), [Campbell and Cocco \(2012\)](#), and [Jeske et al. \(2013\)](#).

The equilibrium model of mortgage credit and default used in this paper is related to the equilibrium models of unsecured borrowing and bankruptcy.⁹ Closely related to my paper are [Athreya et al. \(2012\)](#), [Drozd and Nosal \(2008\)](#), [Livhits et al. \(2011\)](#), [Narajabad \(2012\)](#), and [Sanchez \(2012\)](#), who explore the effects of innovations in the unsecured credit market. These papers show that improvements in information technology regarding the credit risk of households result in an increase in consumer bankruptcies and debt which is consistent with the trends in the data. These papers analyze the unsecured credit market. Different from these models, I analyze the mortgage market, and offer an explanation for the relaxation of the mortgage contract terms, which is expressed as one of the main reasons behind the latest financial crisis.

This paper is organized as follows. Section 2 describes the environment and sets up the model. Section 3 presents the main results of the model. Section 4 analyzes the counterfactual experiment that separates the impact of the change in the information structure. Finally, Section 5 concludes the paper and offer suggestions for future research. [Appendix A](#) outlines the computational algorithm used to solve the model, and presents a simpler model that can be used to analyze the potential existence problem.

2. Model

2.1. Environment

The economy is populated by J period lived households, a continuum of risk-neutral competitive lenders, and a continuum of competitive real estate agents. Each generation has a continuum of households. Time is discrete and households have

⁶ For example, see [Gerardi et al. \(2010\)](#), [Mian and Sufi \(2009\)](#), and [Doms and Krainer \(2007\)](#).

⁷ Some notable exceptions are [Campbell and Hercowitz \(2006\)](#), [Iacoviello \(2005\)](#), [Kiyotaki et al. \(2011\)](#), [Favilukis et al. \(2011\)](#) and [Landvoigt et al. \(2012\)](#), [Ortalo-Magne and Rady \(2006\)](#), [Chambers et al. \(2009\)](#), and [Corbae and Quintin \(2013\)](#). However, these papers take the innovations in the mortgage market as given, and explore their effects on the housing market. They do not offer an explanation for the relaxation of mortgage terms.

⁸ There are several other studies that incorporate housing into an infinite horizon framework, including [Davis and Heathcote \(2005\)](#), [Rios-Rull and Sanchez-Marcos \(2008\)](#), and [Diaz and Luengo-Prado \(2010\)](#).

⁹ [Chatterjee et al. \(2007\)](#) and [Livhits et al. \(2007\)](#) are some prominent examples of such models.

a deterministic finite life-time. There is mandatory retirement at age $J_r < J$. Households derive utility from the consumption of goods and housing services. Preferences are represented by

$$E_0 \left[\sum_{j=1}^{J_r} \beta^{j-1} u_k(c_j) + \beta^{J_r+1} W(w_{J_r}, y_{J_r}) \right]$$

where $\beta < 1$ is the discount factor, c is consumption, and k is the housing status: inactive renter, active renter, or homeowner. Inactive renters are renters who have a default flag in their credit history, and, therefore, are excluded from purchasing a house, whereas active renters are free to purchase a house. W represents the value function of the household at the retirement age given wealth w_{J_r} and income y_{J_r} .¹⁰ The house size is fixed, and the utility from housing services is summarized in three different utility functions: one for the homeowner, u_h ; one for the active renter, u_r ; and one for the inactive renter, u_e . A homeowner receives a higher utility than a renter, while a renter receives a higher utility than a defaulter from the same consumption: $u_h(c) > u_r(c) \geq u_e(c)$.¹¹

Ex-ante households are only different with respect to the utility cost of defaulting. This heterogeneity is permanent, and will be the source of the informational friction between the lenders and the households in the economy. There is no aggregate uncertainty, but households face three types of idiosyncratic shocks: labor income, house price, and moving shocks. Markets are incomplete so that these shocks are not fully insurable.

The log of the income before retirement is a combination of a deterministic and a stochastic component, whereas after retirement it is a fraction λ of the income at age J_r plus a fraction η of the average income in the economy, \bar{y} :

$$y_j(j, z_j) = \begin{cases} \exp(f(j) + z_j) & \text{if } j \leq J_r \\ \lambda y_{J_r}(J_r, z_{J_r}) + \eta \bar{y} & \text{if } j > J_r \end{cases}$$

$$z_j = \rho_e z_{j-1} + e_j$$

where y_j is the income at age j , $f(j)$ is the age-dependent deterministic component of the log income, and z_j is the stochastic component of the log income. The stochastic component is modeled as an AR(1) process with ρ_e as the persistency level. The innovation to the stochastic component, e_t , is assumed to be i.i.d. and normally distributed with mean zero and variance σ_e^2 . Households can save in order to smooth their consumption at the constant risk-free interest rate r , but no unsecured borrowing is allowed.

The log of the house prices follows an AR(1) process:

$$\log p_{j+1} = \mu_p(1 - \rho_p) + \rho_p \log p_j + \varepsilon_j,$$

where p_j is the house price at age j , and ε_j is the innovation to the house price, which is i.i.d. and normally distributed with mean zero and variance σ_p^2 . ρ_p is the persistency and μ_p is the log-mean of the process. House price shocks are idiosyncratic and independent. At the aggregate level, thanks to the law of large numbers, they wash out, so there is no aggregate uncertainty in the house price. However, the presence of idiosyncratic house price shocks calls for caution about the house purchase price. I assume that all housing transactions are done through competitive, identical, risk-neutral real estate agents. These agents purchase the houses from homeowners and lenders (in case of default), and sell them to new home buyers. Since homeowners sell their houses endogenously, the selling house price is endogenous, and potentially different than the mean of the house price process. As a result, real estate agents set the house purchase price \bar{p}_h so that their expected profit from housing transactions is zero. I also assume that all of the housing transaction costs are paid by the seller, not the real estate agent.

At the beginning of each period, all three shocks are realized. Then, the household first makes the next period housing tenure choice (i.e., renter or homeowner), and then makes its consumption and saving choices. Households start out as renters, and can purchase a house and become an owner at any period. House purchases can be done through securitized borrowing, that is, mortgages. The critical component of the model is that the terms of these mortgages are endogenously determined. A purchaser chooses among a menu of feasible mortgage contracts, each specified with a loan amount and interest rate.¹² I assume that lenders offer only fixed-payment mortgages so that the payment is constant throughout the life of the mortgage.¹³ Therefore, the contract, together with the maturity, which is assumed to be the remaining time until retirement, determines the periodic mortgage payments.

¹⁰ Since I focus on the behavior of the households before retirement, I keep the retirement problem simple. After retirement there are no housing tenure choices and income shocks. Therefore, households are forced to sell their houses at the time of retirement, and live as renters until the time of their deaths. Thus, the problem of the retirees becomes a deterministic consumption/saving problem, and I can derive the analytical solution to this problem.

¹¹ Note that the size of the houses is fixed. Therefore, having separate utility functions for renter and homeowners implies that they receive different amount of housing services from the same house. A fixed house size is a limitation of the model. However, allowing for different house sizes has two drawbacks. First, obviously, it makes the computation of the model harder. Second, and more importantly, it complicates the signaling problem in the AI economy.

¹² Not every combination of mortgage interest rate and loan amount is feasible for the household. The characteristics of the household and competition among lenders restrict the contracts offered to the household in the equilibrium.

¹³ I assume a constant interest rate. Therefore, traditional fixed rate and adjustable rate mortgages would have fixed payments throughout the life of the mortgage and they both fall into this category. These mortgages are not necessarily optimal contracts. A more convenient formulation should also include

A homeowner can be either with or without a mortgage. I do not allow mortgage holders to save, but they can refinance or prepay their mortgage at any period. This way, it is possible for them to smooth their consumption even though they are not allowed to save. Moreover, this allows them to become an outright owner (i.e., a homeowner without a mortgage balance) at any period. Thus, although maturity is ex-ante exogenously set, the observed maturity becomes endogenous. I also allow outright homeowners to borrow using their houses as collateral, but, again, they cannot simultaneously hold mortgage debt and assets.

Homeowners can quit ownership by two means. They have the option to sell their house. However, selling a house is costly for two reasons. First, there are costs (specifically, transaction costs, including real estate and maintenance costs) associated with selling the house. A seller incurs a proportional cost, φ_h , of the house price. Secondly, a seller with a mortgage has to pay back the outstanding mortgage debt to the lender.

The other option for quitting ownership is by defaulting on the mortgage, if the homeowner has one. A defaulter has no obligation to the lender. Upon default, the lender seizes the house, sells it, and pays the amount, net of the outstanding mortgage debt and transaction costs, back to the defaulter.¹⁴ The lender's cost of selling the house is a fraction φ_l of the house price ($\varphi_l > \varphi_h$). What makes defaulting appealing for the household is the fact that a defaulter has no obligation to the lender, whereas a seller has to pay back the debt in full. The same fact places a risk of loss upon the lender. The lender incurs a loss if the net value of the house is smaller than the outstanding debt upon default. Default is not without cost to the household. A defaulter incurs a periodic utility cost, becomes a renter, and is allowed to purchase a house with probability δ . Since default is costly and the selling price of the house to the homeowner is at least equal to the selling price to the lender, the homeowner who decides to leave her house only defaults if the outstanding mortgage balance is strictly higher than the selling price. Otherwise it is always optimal to sell the house rather than defaulting. At the beginning of each period, homeowners receive a moving shock with probability ψ , and are forced to leave the house. Upon receiving the moving shock, movers again have two choices: sell the house or default on the current mortgage, if there is one.

There is a continuum of lenders. Financial markets are perfectly competitive, and there is no cost for entry. Lenders are risk-neutral.¹⁵ The economy is assumed to be an open economy and the risk-free interest rate, r , is fixed exogenously. Lenders have full commitment to the contract. Each contract is characterized by a loan amount, d , and interest rate, r_m . Since households can default on their mortgage at any time, and house price shocks and transaction costs render a loan not fully securitized, lenders face a risk of loss on the mortgage loans.

2.2. Decision problems

2.2.1. Household's problem

The value function at the time of retirement can be calculated analytically. At the beginning of each period, the household is either an inactive renter, active renter, or a homeowner. After the realization of the moving, house price and income shocks, the household makes its housing tenure choice. Denote $V_j^i(\theta, s)$ as the value function of the type- i household with age j , current state variable θ , and housing status $s \in (r, h, e)$, where r denotes an active renter, h denotes a homeowner, and e denotes an inactive renter.

2.2.1.1. Inactive renter The inactive renter does not have a housing tenure choice, and so is forced to be a renter in the current period. The only decisions she has to make are the consumption and saving allocations. She starts the next period as an active renter with probability δ and an inactive renter with probability $(1 - \delta)$. The value function of a type- i inactive renter ($s = e$) with age j , beginning of period saving $a > 0$, and income z becomes:

$$V_j^i(a, z, s = e) = \max_{c, a' \geq 0} \{u_e(c) + \beta E[\delta V_{j+1}^i(a', z', s' = r) + (1 - \delta)V_{j+1}^i(a', z', s' = e)]\} \quad (1)$$

subject to

$$c + a'/(1 + r) = y(j, z) + a$$

where c is the consumption and a' is the next period saving.

2.2.1.2. Active renter Unlike an inactive renter, an active renter must make a housing tenure choice. After the realization of the income shock, an active renter has to decide whether to continue as a renter, named *renter* ($s = rr$), or purchase a house, named *purchaser* ($s = rh$), in the current period. The problem for an active renter who chooses to remain as a renter ($s = rr$) is very similar to the inactive renter's problem apart from the fact that she starts the next period as an active renter for sure:

the mortgage payment as part of the contract and be determined in equilibrium. However, for simplicity, I only focus on fixed payment mortgage contracts, which are the dominant type of mortgage in U.S. history.

¹⁴ In equilibrium, when there is positive home equity, selling is always better than defaulting. Thus, in case of defaulting it means the homeowner has negative home equity, and the defaulter gets nothing from the lender.

¹⁵ Securitization of mortgages helps lenders diversify the risks they face and liquidate their asset holding. The risk-neutrality assumption corresponds to perfect securitization.

$$V_j^i(a, z, s = rr) = \max_{c, a' \geq 0} \{u_r(c) + \beta EV_{j+1}^i(a', z', s' = r)\} \quad (2)$$

subject to

$$c + a'/(1 + r) = y(j, z) + a.$$

The second possible choice for an active renter is to purchase a house. Purchasing a house can be done with or without a mortgage. Lenders design mortgage contracts conditional on the household's observables. Due to the perfect competition in the financial market, lenders make zero-profit on these mortgage contracts. Therefore, only the contracts that make zero-profit are feasible and offered to the household. I denote the set of feasible contracts for a household with observable θ as $\mathcal{Y}(\theta)$. A mortgage contract is specified with a loan amount $d = -a'$ and interest rate, r_m . Thus, a typical element of the feasible contract set is $(d, r_m) \equiv \ell \in \mathcal{Y}(\theta)$. I leave the construction of $\mathcal{Y}(\theta)$ to the next section where I define the lender's problem. Out of the total financial wealth, net of the mortgage payment and down payment, the household consumes the rest and starts the next period as a homeowner. Therefore, I can formulate the problem of the purchaser ($s = rh$) in the following way:

$$V_j^i(a, z, s = rh) = \max_{\substack{c \geq 0 \\ (-a', r_m) \in \mathcal{Y}(\theta)}} \{u_h(c) + \beta EV_{j+1}^i(a', z', p'_h, r_m, s' = h)\} \quad (3)$$

subject to

$$c + a'/(1 + r_m) + \bar{p}_h = y(j, z) + a$$

where \bar{p}_h is the house purchase price. Notice that this formulation also encompasses purchasing the house by paying the total purchase price. In that case, I have $a' > 0$ and $r_m = r$.

The value function for the active renter becomes:

$$V_j^i(a, z, s = r) = \max_{s'_r \in \{rr, rh\}} V_j^i(a, z, s'_r), \quad (4)$$

where s'_r is the policy function for the housing tenure of an active renter.

2.2.1.3. Homeowner A homeowner has two housing tenure options: stay a homeowner or switch to being a renter. If she wants to stay a homeowner, she has two options: stay on the current mortgage contract, named *stayer* ($s = hh$), if there is one, or refinance the mortgage, named *refinancer* ($s = hf$). Apart from the usual state variables (a, z, j) , a stayer is also defined by the interest rate on the mortgage, r_m , if there is any, and the current value of the house, p_h . A stayer has to pay at least the minimum mortgage payment, $m(-a, r_m, j)$, specified in Eq. (12) and implied by the contract terms. However, she can also make additional payments to reduce the principal and still use the same mortgage interest rate. This option allows the mortgage holder to pay the mortgage balance in full and become an outright owner at any time. The problem of the stayer becomes the following:

$$V_j^i(a, z, p_h, r_m, s = hh) = \max_{c \geq 0, a' \geq \bar{a}} \{u_h(c) + \beta EV_{j+1}^i(a', z', p'_h, \tilde{r}_m, s' = h)\} \quad (5)$$

subject to

$$\begin{aligned} c + a'/(1 + \tilde{r}_m) &= y(j, z) + a \\ \bar{a} &= \begin{cases} (a + m(-a, r_m, j))(1 + r_m) & \text{if } a < 0 \\ 0 & \text{if } a \geq 0 \end{cases} \\ \tilde{r}_m &= \begin{cases} r_m & \text{if } a' < 0 \\ r & \text{if } a' \geq 0 \end{cases}. \end{aligned}$$

Notice that this problem also contains the problem of an outright owner ($a \geq 0$) who chooses to continue as a homeowner for the next period. The borrowing limit \bar{a} implies that the stayer has to pay at least the implied mortgage payment, $m(-a, r_m, j)$, to the lender.

The second option for the homeowner is to refinance the mortgage. Refinancing the mortgage is subject to a refinancing cost ϑ , which is assumed to be proportional to the new debt and requires a new set of mortgage contract terms. The recursive formulation of the refinancer's problem becomes:

$$V_j^i(a, z, p_h, r_m, s = hf) = \max_{\substack{c \geq 0 \\ (-a', \tilde{r}_m) \in \mathcal{Y}(\theta)}} \{u_h(c) + \beta EV_{j+1}^i(a', z', p'_h, \tilde{r}_m, s' = h)\} \quad (6)$$

subject to

$$c + a'/(1 + \tilde{r}_m) - \vartheta a' = y(j, z) + a.$$

Refinancing serves two important purposes in the model. It allows mortgage holders to borrow against adverse income shocks and allows mortgage holders with high mortgage costs to reduce their payments.

The third possible choice for a homeowner is to sell the house and become a renter, a *seller* ($s = hr$). The seller incurs some transaction and maintenance costs. These costs are assumed to be fraction φ_h of the selling price. Moreover, a seller has to pay the outstanding mortgage debt, $-a$, in full to the lender. The recursive formulation of her problem is the following:

$$V_j^i(a, z, p_h, r_m, s = hr) = \max_{c, a' \geq 0} \{ [u_r(c) + \beta EV_{j+1}^i(a', z', s' = r)] \} \quad (7)$$

subject to

$$c + a'/(1+r) = y(j, z) + p_h(1 - \varphi_h) + a.$$

The fourth possible choice for a homeowner is to default on the mortgage, if she has any, known as a *defaulter* ($s = he$). A defaulter has no obligation to the lender. The lender seizes the house, sells it in the market, and pays any positive amount from the sale of the house, net of the outstanding mortgage debt and transaction costs, back to the defaulter. For the lender, the sale price of the house is assumed to be $(1 - \varphi_l)p_h$. Therefore, the defaulter receives $\max\{(1 - \varphi_l)p_h + a, 0\}$ from the lender. The defaulter starts the next period as an active renter with probability δ . With probability $(1 - \delta)$, she becomes an inactive renter. The problem of a defaulter becomes the following:

$$V_j^i(a, z, p_h, r_m, s = he) = \max_{c, a' \geq 0} \{ u_e(c) + \beta E[\delta V_{j+1}^i(a', z', s' = r) + (1 - \delta)V_{j+1}^i(a', z', s' = e)] \} \quad (8)$$

subject to

$$c + a'/(1+r) = y(j, z) + \max\{(1 - \varphi_l)p_h + a, 0\}.$$

Notice that the problem of a defaulter is different than the problem of a seller in three ways. First, the defaulter receives $\max\{(1 - \varphi_l)p_h + a, 0\}$ from the housing transaction whereas a seller receives $p_h(1 - \varphi_h) + a$, which means that the defaulter has no obligation to the lender and receives the proceedings of the sale of the house from the lender. However, the seller has to pay the remaining mortgage debt to the lender and receives the proceedings from the sale. Since $\varphi_l > \varphi_h$, the defaulter receives less than the seller as long as $p_h(1 - \varphi_h) + a \geq 0$ (i.e., the home equity net of the transaction costs for the homeowner is positive). The second difference is the current period utility difference between the defaulter and seller. Since $u_e(c) \leq u_r(c)$, compared to a seller, a defaulter receives lower utility from the same consumption. Finally, a defaulter does not have access to the mortgage in the next period with some probability. Such an exclusion lowers the continuation utility for a defaulter. In sum, since defaulting is costly, a homeowner will choose to sell the house instead of defaulting if

$$p_h(1 - \varphi_h) + a \geq 0, \quad (9)$$

(i.e., net home equity is positive). Hence, negative equity is a necessary condition for default in the model. Therefore, in equilibrium, a defaulter gets nothing from the lender.

The homeowner's ex-ante value function can be characterized as follows:

$$V_j^i(a, z, p_h, r_m, s = h) = (1 - \psi) \max_{s'_h \in \{hh, hf, hr, he\}} V_j^i(a, z, p_h, r_m, s'_h) + \psi \max_{s'_m \in \{hr, he\}} V_j^i(a, z, p_h, r_m, s'_m), \quad (10)$$

where s'_h is the policy function for the housing tenure conditional on not receiving the moving shock and s'_m is the policy function for the housing tenure conditional on receiving the moving shock.

2.2.2. Real estate agents

There is a continuum of risk-neutral, identical and competitive real estate agents in the economy. They purchase the houses from the homeowners or lenders and sell them to the home buyers. Perfect competition forces them to make zero-profit on the housing transactions. Homeowners tend to sell their homes when they receive positive house price shocks and keep them when they receive negative house price shocks.¹⁶ Therefore, the average sale price is higher than the mean of the house price process. In order to break-even, real estate agents set the purchase price above the mean of the house price process. I assume that all of the housing transaction costs are incurred by the households. Then, the condition which pins down the house purchase price, \bar{p}_h , becomes the following:

$$\int \bar{p}_h I(s' = rh) d\Gamma(\theta; s = r) = \int p_h ((1 - \psi) I(s'_h \in \{hr, hd\}) + \psi I(s'_m \in \{hr, hd\})) d\Gamma(\theta, p_h; s = h), \quad (11)$$

¹⁶ There is obviously the option of default, which causes some houses in the market to be valued below the average. However, the majority of the housing transactions are generated by sellers. In the model simulations, the fraction of sellers is twenty times the fraction of defaulters.

where I is the indicator function, θ denotes the current state variables for the household, and Γ is the distribution of the households. The left-hand side of this equation is the revenue real estate agents generate by selling the houses to the home buyers at the fixed price \bar{p}_h . The right-hand side is the cost of purchasing the houses from the homeowners who sell their houses or from the lenders who sell the houses upon the default of the homeowners.

2.2.3. Lender's problem

Since mortgages are long-term contracts, the lender's problem is also a dynamic problem. The lender has to design a menu of contracts, $\Upsilon(\theta)$, conditional on the observable, θ , of the purchaser. A mortgage contract is a combination of a loan amount and an interest rate: $(d, r_m) \in \Upsilon(\theta)$.

2.2.3.1. Mortgage payments Mortgages are due by the retirement period, which is deterministic, so that the household's age captures the maturity of the mortgage contract. In addition, since I focus only on fixed payment mortgages, the choice of the loan amount and interest rate, together with the age of the household, determines the amount of the mortgage payments, m . They are directly computed from the present value condition for the contract. This condition says that given the loan amount and the mortgage interest rate, the present discounted value of the mortgage payments should be equal to the loan amount. Since the lender has full commitment to the contract, she calculates the payments on the assumption that the contract ends by the maturity date. Assuming that the interest rate on the mortgage is r_m and the current age of the household is j , the following formulation gives the per-period minimum payments of a mortgage loan with outstanding debt d :

$$d = m + \frac{m}{1+r_m} + \frac{m}{(1+r_m)^2} + \dots + \frac{m}{(1+r_m)^{J-r-j}} \\ m(d, r_m, j) = \frac{1-\alpha}{1-\alpha^{J-r-j+1}}d, \quad \text{where } \alpha = \frac{1}{1+r_m}. \quad (12)$$

2.2.3.2. Mortgage interest rates Next, given the mortgage payments and loan amount, the lender has to determine the mortgage interest rate. This rate is pinned down by the no-arbitrage condition. This condition says that given the expected mortgage payments, the lender should be indifferent between investing in the risk-free market, which is the only outside investment option for the lender, and extending the mortgage loan. Note that the expected payments are not necessarily the above calculated mortgage payments. If the household defaults when the outstanding mortgage debt is d , then the lender receives $\min\{(1-\varphi_l)p_h, d\}$.¹⁷

I denote the value of a mortgage contract with outstanding debt $d = -a$ and interest rate r_m , offered to a household with current period characteristics (z, j, i, p_h) as $V_{i,j}^\ell(a, z, p_h, r_m)$. Note that this function represents not only the value of the contract at the origination, but also the continuation value of the contract at any time period through the mortgage life. Conditional on the homeowner's tenure choices, the realized payments might change. If the household stays in its current house, then the lender receives some mortgage payment and the continuation value from the contract with the updated characteristics of the household and loan amount. If the household defaults, then the lender receives $\min\{(1-\varphi_l)p_h, d\}$. If the household sells the house or refinances, then the lender receives the outstanding loan amount, d .

Given that the opportunity cost of the contract is the risk-free interest rate, r , and that the lender is risk-neutral, then the continuation value of a mortgage contract becomes the following:

$$V_{i,j}^\ell(a, z, p_h, r_m, s) = \left\{ \begin{array}{ll} \frac{a'}{1+r_m} - a + \frac{1}{1+r}EV_{i,j+1}^\ell(a', z', p'_h, r_m) & \text{if stays} \\ -a & \text{if sells or refinances} \\ \min\{p_h(1-\varphi_l), -a\} & \text{if defaults} \end{array} \right\} \quad (13)$$

where a' is the policy function in the problem (5).

At the time of the origination of the contract, the lender may not be able to observe all of the household's characteristics. Therefore, I need to state the no-arbitrage condition conditional on the information structure, which is different for the SI and AI economies.

2.2.3.3. Symmetric information In the SI economy, the lender observes all of the characteristics of the household. So, mortgage contracts are individualized and independent from all of the other households in the economy. The lender can solve the household's problem and obtain the necessary policy functions (i.e., saving and housing choices) in order to evaluate the value of the contract at the origination. Therefore, the no-arbitrage condition for a mortgage contract offered to a household with current period income, age and type (a, z, j, i) , current house price p_h , and a loan amount $d = -a \leq p_h$ becomes:

$$V_{i,j}^\ell(-d, z, p_h, r_m) = d \quad (14)$$

¹⁷ Since default is costly, as long as $p_h(1-\varphi_h) \geq d$, the household sells the house rather than defaulting. Therefore, in equilibrium, when the household defaults, the lender receives $p_h(1-\varphi_l) \leq p_h(1-\varphi_h) < d$ and incurs some loss.

Note that the initial loan amount also implies the down payment for the household ($p_h - d$). I also assume that the initial loan amount cannot exceed the house price: $d \leq p_h$.

2.2.3.4. Asymmetric information In the AI economy, the lender cannot observe the household's type, but can observe the other characteristics: current period wealth, income, age, current house price and housing tenure (a, z, j, p_h, s). Therefore, the lender faces a pool of households with the same wealth level, income, age, house price and housing tenure, but possibly with different default costs. As such, a contract offered to a certain type is also available for the other type in the pool. This creates the well-known *adverse selection* problem. The lender has to either pool different types into a pooling contract or screen different types by offering separating contracts. I leave the discussion of potential problems of existence and other theoretical issues related to the comparison of these contracts to Appendix A.1, and, for now, assume that the separating contract is supportable as an equilibrium.

A separating contract should satisfy two properties. First, it should yield zero-profit to the lender if the targeted type takes the contract. Secondly, it should be incentive compatible for the targeted household. This last property means that the contract designed for the other type in the same pool should not grant a higher utility to the targeted household. Formally, the no-arbitrage condition can be written as follows:

$$V_{i,j}^{\ell}(\theta; \ell_i(\theta; d, r_m)) = d \quad (15)$$

subject to

$$V_j^i(\theta; \ell_i(\theta; d, r_m)) \geq V_j^i(\theta; \ell_{i'}(\theta; d', r'_m)), \quad \forall i' \text{ such that } \Gamma(\theta; i') > 0$$

where $\ell_i(\theta; d, r_m) \equiv (d, r_m)$ is the contract designed for type i household with observable $\theta \equiv (a, z, j, p_h, s)$ and $\Gamma(\theta; i)$ is the distribution of type i households with observable θ .

2.3. Equilibrium

In the SI economy, the markets are fully individualized and the problem of the lender is trivial. I define the set of state variables for the household as Ω with a typical element (a, z, j, i, p_h, s) and let $\theta \in \Theta \subseteq \Omega$ be the observable characteristics of the household by the lender.

Definition 1 (*Symmetric information equilibrium*). A symmetric information equilibrium to the SI economy is a set of value functions $\{V, V^I\}$, policy functions $\{c^*, a^*, s^*\}$, a contract set \mathcal{Y} , the distribution of households Γ , and house purchase price \bar{p}_h such that

- (i) given the house purchase price \bar{p}_h and the feasible contract set $\mathcal{Y}(\Theta)$, value function V , and policy functions $\{c^*, a^*\}$ solve Eqs. (1)–(3) and (5)–(8), s^* is a policy indicator function that solves Eqs. (4), and (10);
- (ii) given the policy functions, value function V^I and each contract $\ell \in \mathcal{Y}(\Theta) \subset \mathbb{R}^2$ solve Eqs. (12)–(14);
- (iii) no lender finds it profitable to offer another contract, which is not in the contract set, \mathcal{Y} , (i.e., $\nexists (d, r_m) \in \mathcal{Y}_s$ such that $V^{\ell}(\theta; d, r_m) > d$ for $\forall \theta \in \Theta$, with V^{ℓ} defined as in Eq. (13));
- (iv) the distribution of households Γ is generated by the policy functions; and
- (v) the house purchase price \bar{p}_h solves Eq. (11).

However, in the AI economy, the lender's problem is more complicated. The nature of the equilibrium depends upon the environment, definition of the equilibrium, and the type of equilibrium. I particularly focus on the separating equilibrium and support the existence of the equilibrium by modifying the equilibrium concept as described in Appendix A.1:

Definition 2 (*Asymmetric information separating equilibrium*). An asymmetric information separating equilibrium to the AI economy is a set of value functions $\{V, V^I\}$, policy functions $\{c^*, a^*, s^*\}$, a contract set \mathcal{Y} , the distribution of households Γ , and house purchase price \bar{p}_h , such that

- (i) given the house purchase price \bar{p}_h and the feasible contract set $\mathcal{Y}(\Theta)$, value function V and policy functions $\{c^*, a^*\}$ solve Eqs. (1)–(3) and (5)–(8), s^* is a policy indicator function that solves Eqs. (4) and (10);
- (ii) given the policy functions value function V^I and each contract $\ell \in \mathcal{Y}(\Theta) \subset \mathbb{R}^2$ solve Eqs. (12), (13) and (15);
- (iii) no lender finds it profitable to offer another contract even after the other competitors can react by adding new contracts;
- (iv) the distribution of households Γ is generated by the policy functions; and
- (v) the house purchase price \bar{p}_h solves Eq. (11).

In the AI economy, the equilibrium is separating, as it is in the SI economy. That is, the market for each household is individualized. However, in the AI economy, the lender has to take into account all of the incentive compatibility constraints,

which are summarized by Eq. (15). This equation states that each type picks the contract designed for her, and the contract designed for the other type with the same observable gives no better utility. This constraint puts an extra restriction on the equilibrium contracts when compared to those offered in the SI economy. In general, low-risk types qualify for “better” terms compared to high-risk types since high-risk types carry a higher risk of default. Therefore, high-risk types might choose the contracts designed for the low-risk types if only the equilibrium contracts in the SI economy are offered. This potential adverse selection forces the low-risk types to differentiate themselves from the high-risk types. In the model they differentiate themselves using the down payment fraction.¹⁸ The low-risk types demand smaller loans (i.e., higher down payments), which are not attractive for high-risk types. However, these loans give lower utility for the low-risk types compared to the SI equilibrium contracts, which means it is costly for the low-risk types to differentiate themselves. The equilibrium contract in the AI economy has the following feature. The high-risk type in a pool receives the contract offered to her in the SI economy, and the low-risk type receives the contract such that the high-risk type is indifferent between the contract offered to her and this contract. This equilibrium contract is called the least-cost separating contract, because it is the contract in which low-risk types differentiate themselves with minimum cost.

3. Quantitative results

3.1. Calibration

The model period is one year. Households live for 36 periods until retirement and 18 periods after retirement. The utility function for the households is the standard CRRA utility function with a slight modification to account for the benefit of homeownership: $u_k(c) = \frac{\gamma_k c^{1-\sigma}}{1-\sigma}$, $k \in \{e, r, h\}$ and γ_k is the utility advantage of being an inactive renter ($k = e$), an active renter ($k = r$) or a homeowner ($k = h$). I normalize $\gamma_r = 1$. The ex-ante difference across the households comes from the utility cost of defaulting, γ_e . I set $\gamma_e = \gamma_r = 1$ for the high-risk types, and $\gamma_e = 0.8$ for the low-risk types. I set the risk-aversion parameter, σ , to 2.

For the income process before retirement, I take the parameters from Storesletten et al. (2004) and set the income persistency, ρ_e , to 0.94 and the standard deviation of the innovation to the AR(1) process, σ_e , as 0.36. I approximate this income process with an 11-state first-order Markov process using the discretization method outlined in Adda and Cooper (2003). For income after-retirement, I assume $\lambda = 0.35$ and $\eta = 0.2$, meaning that the retiree receives 35% of the income at the time of retirement plus 20% of the mean income in the economy. The probability of becoming an active renter, while the household is an inactive renter, is set to $\delta = 0.14$, in order to capture the fact that a default flag stays for approximately seven years in the credit history of a household. The loss in the sale price of the house for the household is set to $\varphi_h = 10\%$.¹⁹ In the case of foreclosure, lenders need to sell the house, and I assume that they incur a larger cost. Following the estimates of Campbell et al. (2011), I set $\varphi_l = 27\%$.

The annual risk-free interest rate is set to $r^{\text{SI}} = 1.5\%$ for the SI economy, which corresponds to the average real interest rate for a 10-year Treasury constant maturity in the 2002–2006 period. For the house price process, I use the estimates of Nagaraja et al. (2011), which set the persistency of the house price at $\rho_p = 0.96$ and the variance of the house price shocks at $\sigma_p = 0.1$. I approximate this house price process with a 5-states first-order Markov process, using the method of Adda and Cooper (2003).

I jointly calibrate the remaining parameters (i.e., discount factor (β), utility premium for an owner (γ_h), moving probability (ψ), measure of the high-risk type (μ), refinancing cost (ϑ) and log-mean of the house price process (μ_p^{SI})) to match six related statistics on the housing market for the period between 2002 and 2006: wealth–income ratio, homeownership rate, moving rate for owners, foreclosure rate, refinancing share among mortgage originations, and average house purchase price. Table 2 presents the results of the calibration.

The structure of the model places a strong discipline on the calibrated parameters. The estimate of the discount factor, β , is 0.87, which is quite low compared to the usual estimates. Given that β mainly determines the wealth–income ratio, this result might seem surprising. However, forcing the real estate agents to break-even in the model results in the purchase price of the houses, $\bar{p}_h^{\text{SI}} = 4.05$, being significantly higher than the average of the stochastic house price process, which is 3.2. Such a large difference between the purchase price and the mean of the house price process makes ownership less appealing. As a result, in order to match the homeownership rate of 68.6%, the estimate of the ownership premium, $\gamma_h = 1.77$, becomes quite large, which means that, when compared to being a renter, being an owner gives one 77% higher utility from the same consumption. Moreover, such a high ownership premium also results in a strong desire to save for the down payment. Remember that mortgage terms are endogenous. Lower down payments result in higher mortgage premiums, which increase mortgage costs. Therefore, households tend to save more in order to put higher down payment

¹⁸ One of the main reasons that I avoid intensive choice in house size is precisely this signaling problem. If I allow different house sizes in the model, then, households can also use this dimension to signal their types. More precisely, low-risk types can signal their types by demanding larger houses in addition to the selection of down payments. This option further complicates the signaling problem and potentially weakens the effect of advances in information technology on the changes in the mortgage market.

¹⁹ Given that this cost includes both selling costs, estimated to be around 7% by Martin (2003) using CEX data, and depreciation costs estimated to be around 3.5% by Garriga et al. (2009) and Corbae and Quintin (2013), 10% is a reasonable total transaction cost for selling. Li and Yao (2007) and Halket and Vasudev (2014) also use similar numbers.

Table 2
Calibration.

Parameter	Explanation	Value
σ	risk aversion	2
ρ_e	persistence of income	0.94
σ_e	std of income shock	0.36
ρ_p	persistence of house price	0.96
σ_p	std of house price shock	0.1
φ_h	selling cost–household	10%
φ_l	selling cost–lender	27%
r^{SI}	risk-free interest rate	1.5%
δ	prob. of being an active renter	0.14
β	discount factor	0.87
γ_h/γ_r	utility advantage of ownership	1.77
ψ	moving probability	0.05
μ	relative measure of good type	0.22
μ_p^{SI}/\bar{y}	mean price/income ratio	1.16
ϑ	refinancing cost	0.015

on a house. This strong desire for saving results in an even lower β to match the wealth–income ratio of 2.5. Moreover, a lower β is important with regard to matching the foreclosure rate of 0.9%. As the discount factor decreases, the incentive for default increases.

The measure of the high-risk type mainly identifies the foreclosure and homeownership rates. High-risk types have lower homeownership rates and higher foreclosure rates when compared to low-risk types. As a result, their measure is important to pin down the foreclosure and homeownership rates. The calibration results in the measure of high-risk types as, $\mu = 0.22$, which means that 22% of the households in the model are of the high-risk type. The moving probability plays a crucial role in pinning down the moving probability of the homeowners, which is reported as 8% by the Census data. This parameter is estimated as $\psi = 0.05$. Therefore, around 5% of homeowners are exogenously forced to move. However, notice that the total moving rate of the homeowners in the model is 8%, which means almost 40% of the moves by homeowners are due to endogenous reasons (i.e. selling the house or defaulting on the mortgage). The refinancing cost is obviously crucial to matching the refinancing share among the mortgage originations, which is around 60% as reported by Mortgage Bankers Association. This parameter is estimated as $\vartheta = 0.015$, meaning that refinancing costs 1.5% of the new debt. Finally, the log-mean of the house price process, μ_p^{SI} mainly targets the purchase price. The Joint Center for Housing Studies reports the ratio of purchase price to income as 4.1 for the 2002–2006 period. Our calibration results $\mu_p^{SI} = 1.16$, which means that the mean of the house price process is 3.2, consistent with the average self-reported house price in the Survey of Consumer Finance (SCF) in 2004.

I solve the SI economy with these parameters. The AI economy represents the period before the introduction of AUS. Since these systems first began to be used in the mid-1990s, I choose the period 1992–1996 to represent the AI economy. This period was different from the period 2002–2006 not only in the information structure, but also in house prices and risk-free interest rates. Therefore, for the AI economy, I set the risk-free interest rate to its 1992–1996 period counterpart ($r^{AI} = 3.6\%$), and solve for the mean of the house price process (μ_p^{AI}) in order to match the homeownership rate in 1992–1996 period. This calibration results $\mu_p^{AI} = 1.1$, implying that the mean of the house price process is 3.05 and the corresponding purchase price is $\bar{p}_h^{AI} = 3.90$.²⁰

3.2. Inspection of the model

I numerically solve the model using backward induction. Since the lifetime is finite for the households, I start by solving the problem of an age- J_r household, which is straightforward to solve given the terminal conditions. Given the last period value functions, I can again solve the problem of an age- $J_r - 1$ household. Iterating this process results in all the necessary value functions and policy functions. The details of the computational algorithm are in Appendix A.2.

Table 3 presents the fit of the model with the data along several dimensions. Since I calibrate the model in order to match the homeownership rate, foreclosure rate, wealth–income ratio, moving rate of homeowners, refinancing share among mortgage originations and purchase price-to-income ratio in the 2002–2006 period, the model produces statistics on these variables that are very close to their data counterparts. In fact, the statistics are also very close along several other dimensions, which the model is not calibrated to match. The average down payment in the data is 20%, whereas the model generates 22.9% for the same statistic. The debt–service ratio, which is the ratio of mortgage debt to income, is 17.1% in the model which is almost the same as its data counterpart. The combined loan-to-value ratio, which is the ratio of the

²⁰ One interpretation of this result is that the decrease in the risk-free interest rate together with the change in the information structure can generate a 4% increase in the house price, given the change in the homeownership rate. Arslan et al. (2013) show that the transitional dynamics of this model can generate larger movements in the house price and foreclosure rate.

Table 3
Benchmark results—symmetric information.

Statistic ^a	Model—SI	Data (2002–2006)
Homeownership rate	68.6%	68.6%
Foreclosure rate	0.90%	0.98%
Moving rate—owners	8.0%	8.0%
Wealth/income ratio	2.5	2.5
Refinancing share	60%	60%
Purchase price	4.05%	4.1%
Mortgage premium	0.67%	1.7%
Average down payment fraction	22.9%	20.0%
Debt-service ratio	17.1%	17.2%
Combined loan-to-value ratio	53.9%	58.4%

^a Homeownership rate, foreclosure rate, moving rate, wealth–income ratio, refinancing share, and purchase price are matched to the data. Homeownership and moving data are from Census. Foreclosure rate and refinancing share are from Mortgage Bankers Association. Wealth–income ratio is from [Kaplan and Violante \(2010\)](#), and purchase price–income ratio is from Joint Center for Housing Studies. Debt–service ratio is from Federal Reserve Board, and combined loan-to-value ratio is from flow of funds account. Average down payment is from survey of consumer finance.

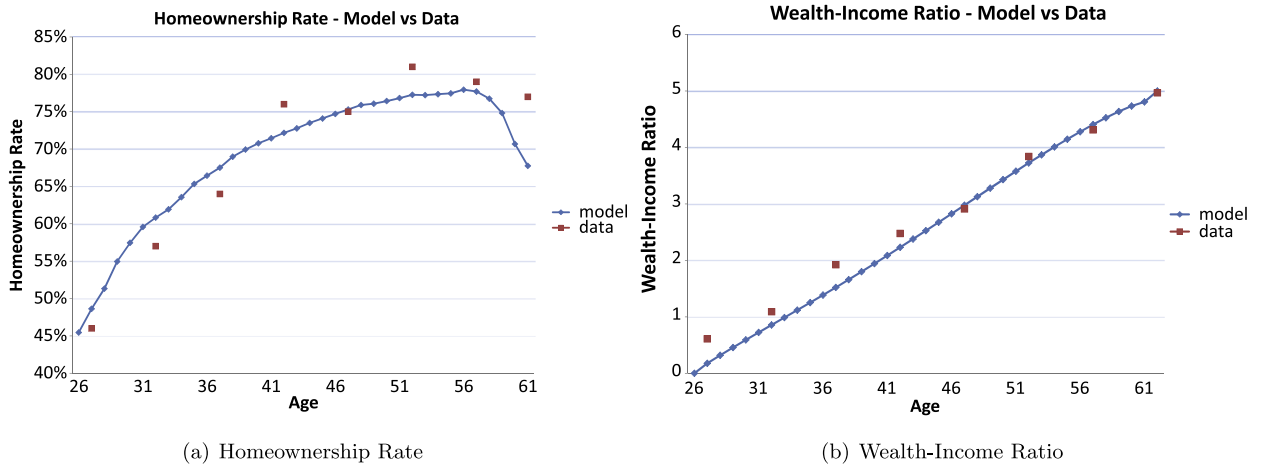


Fig. 1. Homeownership rate and wealth–income ratio: the data is from 2004 SCF. In the data homeownership rate is calculated using 5-year age bins. For the wealth–income ratio, I exclude the top 1% of the wealth distribution and individuals over age 65. The ratio is calculated as the ratio of net wealth to average income in the remaining population.

outstanding mortgage debt to the house value, is 53.9% in the model. The same ratio is 58.4% in the data. The average mortgage premium in the model is 0.67%, less than half of its data counterpart. Since the model misses some important sources of mortgage premium, such as aggregate house price uncertainty, liquidity and collateral premium for lenders, it is not surprising that the model cannot generate a sizable mortgage premium.

3.2.1. Who buys a house?

The richness of the model makes it possible to contrast the predictions of the model to the data at the micro level. [Fig. 1\(b\)](#) plots the wealth–income ratio for the model and data. The model not only matches the average wealth–income ratio in the economy, but also matches quite well the life-cycle path of this ratio. The main reasons behind the success of the model are the hump-shaped labor income profile that the households have over the life-cycle, and the uninsurable idiosyncratic labor income risk. Increase in the wealth–income ratio over the life-cycle produced by the model, together with the large financing costs associated with the purchase of a house, generates a hump-shaped pattern for the homeownership rate over the life-cycle in the model as shown in [Fig. 1\(a\)](#), which is similar to what I observe in the data. Early in the life-cycle households have little wealth, and it takes time for them to accumulate sufficient wealth to buy a house. Some households with good income prospects accumulate wealth faster and become homeowners very early in the life-cycle. For some households, especially those with poor income prospects, this process takes a longer time and they become homeowners later in the life-cycle. The reason for the decrease in the homeownership rate late in the life-cycle is related to consumption smoothing. Since there is a drop in the income after retirement, some households sell their houses before retirement in order to smooth their non-housing consumption. Moreover, since I do not allow any house tenure choices after retirement, the drop in homeownership around retirement is higher than in the data counterpart.

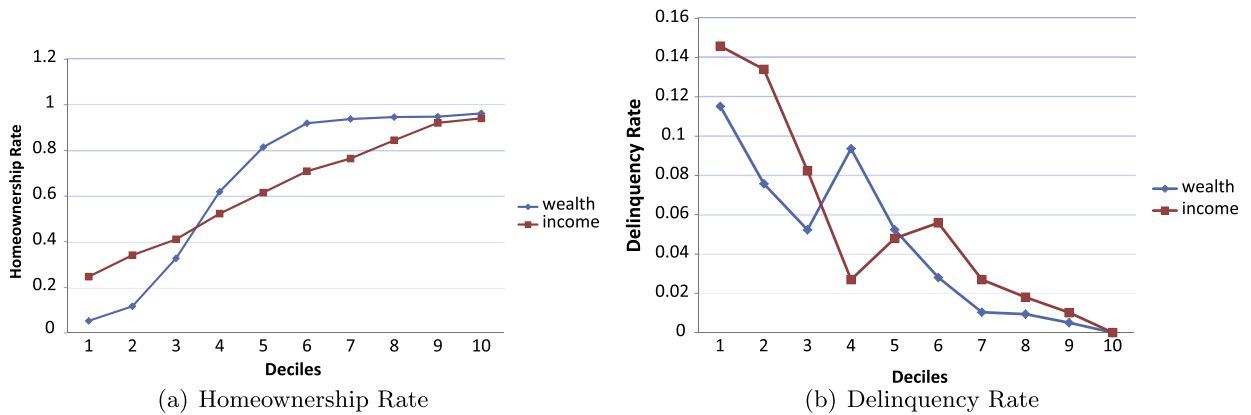


Fig. 2. Homeownership and delinquency rate over income and wealth: the data is from 2004 SCF. Excluding the top 1% in the wealth distribution, this figure shows homeownership and delinquency rate as a function of income and net wealth. Mortgage delinquency is defined as households who are behind their regular mortgage payments.

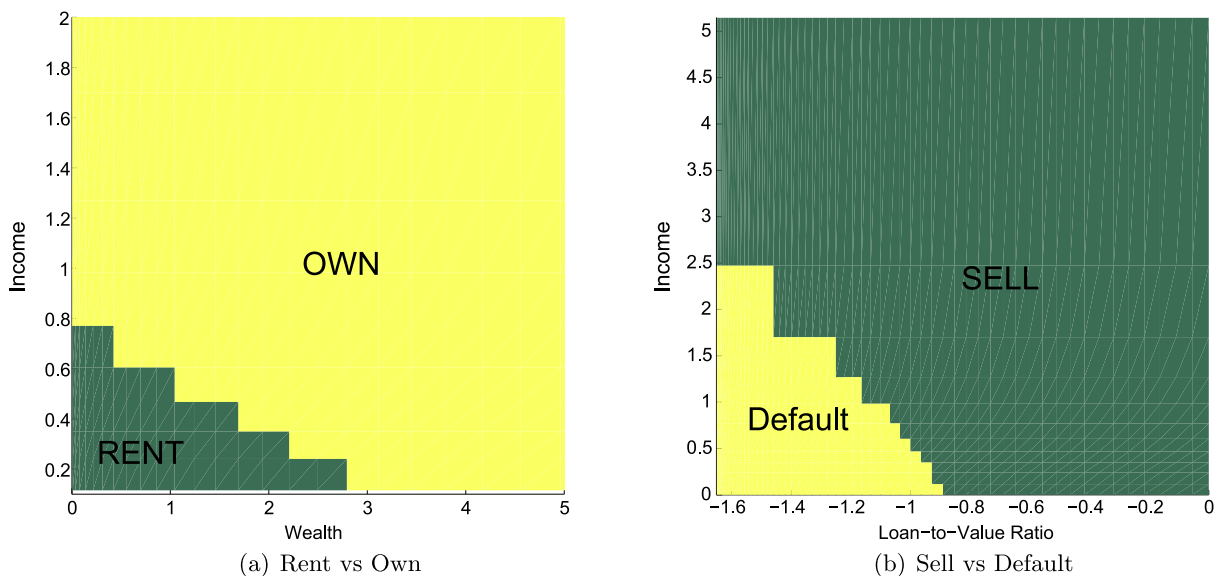


Fig. 3. Tenure decisions as a function of income and wealth: the figure shows the choice of tenure for a renter and a mover as a function of income and asset. The choices are depicted for an low-risk individual subject to mortgages with 30-years maturity.

Fig. 2(a) shows the homeownership rate for different percentiles of the income and wealth distribution from the 2004 SCF data. As income and wealth increase, so does the likelihood of being a homeowner. Fig. 3(a) plots the renting versus owning choice of an individual as a function of income and wealth in the model. Similar to the data, as income, and wealth increase the household prefers owning over renting. This observation is also apparent from Table 4, which shows the share, income and wealth of the households along different housing choices. Among the renters, the average income of the households who choose to rent in the next period is 0.35. The same statistic is 1.24 for those who choose to purchase a house with a mortgage and 3.55 for those who choose to purchase a house without a mortgage. The same comparison is valid for the wealth dimension. Outright home buyers have 14 times greater wealth than home buyers with a mortgage, who have 7 times greater wealth than renters. Another important number from Table 4 is the fraction of buyers with mortgages out of all of the buyers. In the benchmark model, 80% of the buyers use mortgages to purchase a house. Therefore, households rely significantly on mortgages to purchase a house.

3.2.2. Who defaults?

A necessary condition for default in the model is negative equity. However, it is not sufficient to have negative equity for default. Table 4 shows that, in the model, 10.7% (=6.1%–56.8%) of the mortgage holders are in negative equity, but only 4% of them choose to default if they do not receive moving shocks. The rest choose to either stay with the current mortgage or refinance. Homeowners, first, have to decide whether to exit ownership in order to consider defaulting. As Table 4 shows that among homeowners with mortgages who do not receive moving shocks, only 5.1% (4.6% + 0.5%) choose

Table 4
Tenure choices.

Tenure ^a	Tenure choice	Share	Income	Wealth	House price
Defaulter		2.1%	0.90	0.46	
		29.3%	0.65	0.68	
Renter	Rent	77.8%	0.35	0.11	
	Buy-mortgage	17.8%	1.24	0.74	
	Buy-outright	4.4%	3.55	10.66	
		68.6%	2.16	5.71	3.76
Owner w/mortgage		56.8%	1.32	1.63	3.81
	No moving shock				
	Stay	72.2%	1.57	1.51	3.74
	Refinance	22.7%	0.72	1.98	3.88
	Sell	4.5%	0.49	2.14	4.64
	Default	0.6%	0.35	−0.56	3.10
	Moving shock				
	Sell	91.7%	1.37	1.82	3.89
	Default	8.3%	0.70	−0.50	3.00
w/Neg. equity		6.1%	0.99	−0.48	2.96
	No moving shock				
	Stay	87.0%	0.97	−0.49	2.92
	Refinance	9.0%	1.50	−0.20	3.38
	Sell	0%	–	–	–
	Default	4.0%	0.36	−0.82	2.84
	Moving shock				
	Sell	33.7%	1.48	−0.23	3.08
	Default	66.3%	0.74	−0.60	2.89
No mortgage		43.2%	3.26	11.07	
	Stay	98.3%	3.30	11.17	3.69
	Refinance	1.1%	0.70	4.05	3.93
	Sell	0.6%	0.99	7.99	5.25

^a This table shows the share, income and wealth of households for different house tenure choices. The average income in the economy is 1.67, and average wealth is 4.17.

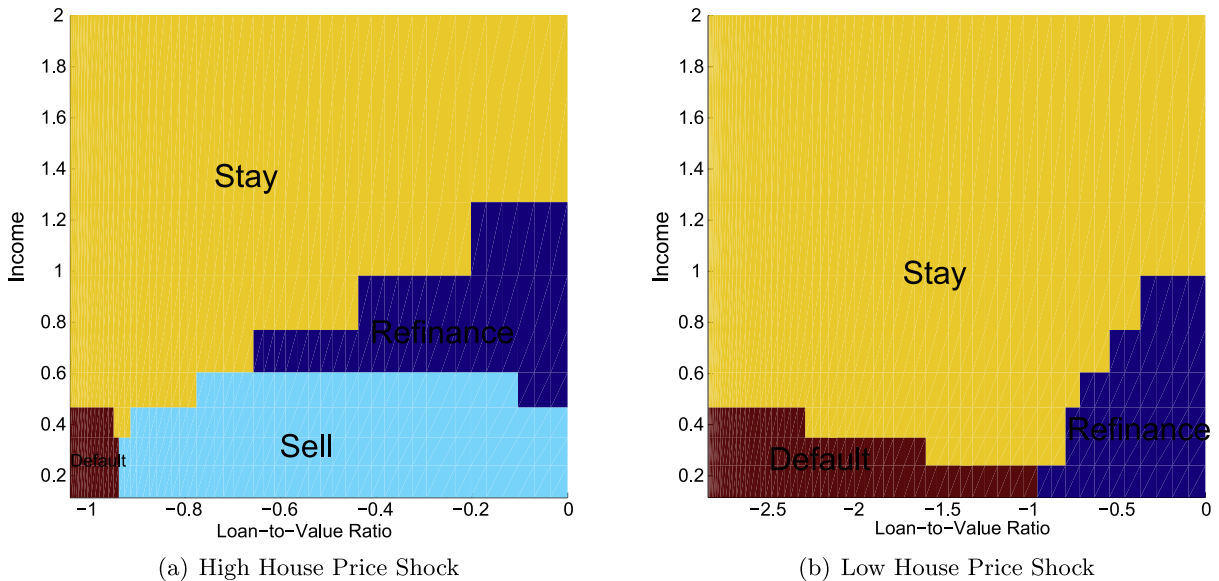


Fig. 4. Tenure decisions of a homeowner as a function of income and wealth: the figure shows the choice of tenure for a mortgage holder who is not subject to moving shock as a function of income and debt conditional on different house price shocks. The choices are depicted for a low-risk homeowner with a 30-years maturity mortgage.

to exit homeownership. The rest choose to stay with the current mortgage or refinance. Then, what triggers the choice of exiting homeownership? In the model, thanks to the high utility advantage of homeownership, households, in general, prefer homeownership. However, three kinds of events will force them to exit homeownership. One is exogenous moving shocks that force homeowners to exit ownership. In the benchmark model, the exogenous moving probability is 5%. Therefore, 5% of the homeowners are exogenously forced to exit ownership. However, the moving rate of the owners is 8%, which means that the other 3% (40% of the total moves) choose to exit ownership endogenously. Second, adverse income shocks can

result in homeowners choosing to become renters. Income shocks, together with low current wealth, can result in making the mortgage payments unaffordable, rendering the homeowner liquidity constrained, and forcing the homeowner to exit homeownership. Finally, house price shocks can force homeowners to choose to exit ownership. As shown in Fig. 4(a), high house price shocks together with low income shocks, which make the homeowner liquidity constrained, force her to sell the house to capitalize on the gain from its sale, and smooth consumption. In the case of a low house price shock, if it is accompanied by a low income shock, then the homeowner will have an incentive to exit homeownership by defaulting (see Fig. 4(b)).

A homeowner has two options when she decides to exit homeownership. She can either sell the house or default on the mortgage, if she has one. As explained in Section 2.2.1, default is preferable over selling only if the net home equity is negative. As shown in Table 4, only 8.3% of mortgage holders who receive moving shocks choose to default. The remaining 91.7% sell their house. When I compare the characteristics of sellers and defaulters, I see that defaulters have significantly lower incomes (0.7 vs. 1.37), lower net wealth (-0.5 vs. 1.82), and lower house price realizations (3.00 vs. 3.89) compared to sellers. This observation further justifies the view that negative equity is an important determinant of default. Mortgage holders can end up with negative equity for two reasons. First, if their initial mortgage balance is higher than $(1 - \varphi_h)$ of the purchase price, then the net home equity of the homeowner is negative. Secondly, idiosyncratic low house price shocks can cause the homeowner to have negative equity. Table 4 reveals that all defaulters in the model have negative equity. However, not all of these homeowners with negative equity choose to default over selling. Among the homeowners with negative equity who receive moving shocks, 33.7% choose to sell their houses instead of defaulting, which happens because default is costly due to the utility disadvantage of defaulting and stochastic exclusion from the market. If I compare the sellers and defaulters among this group, I observe that those who have a higher income (1.48 vs. 0.74), higher net wealth (-0.23 vs. -0.60), and higher house price realization (3.08 vs. 2.89) choose to sell. These are the very households that have less to lose (by paying back the debt) and more to gain (by obtaining access to the mortgage market) by choosing to sell.

In sum, negative equity that originates with adverse house price shocks is a necessary condition for default, but it is not sufficient. Idiosyncratic moving shocks and adverse income shocks are the triggering factors for default. Fig. 5 shows the cumulative default probability of a mortgage along the loan-to-value ratio dimension for different household characteristics. The probabilities represent the lifetime probability of default of a mortgage with the corresponding loan-to-value ratio. As expected, an increase in the loan-to-value ratio and a decrease in the current income increase the cumulative default probability of a mortgage. Fig. 2(b) plots the delinquency rate of the mortgages over the income and wealth percentiles in the data. The overall pattern in the data is also consistent with the findings of the model (i.e., as income and wealth increase, the mortgage delinquency rate decreases).

Fig. 5 also implies that loans that are offered to high-risk types for high-priced houses and that carry higher mortgage interest rates have a higher default probability. The effect of the type in this case is obvious. Since high-risk types are more likely to default, they have a higher default probability. As the value of the house increases, the cumulative default probability dramatically increases for two reasons.²¹ First, the higher house price means a higher amount of debt, which increases the default probability. Second, the house price process is mean-reverting. Therefore, high prices in the current period imply a higher chance of a price drop in the future, which increases the likelihood of having negative home equity upon the impact of an adverse income or moving shock, which, in turn, increases the probability of default.

The effect of the mortgage interest rate on default is more involved. The direct effect of a higher mortgage interest rate is higher mortgage payments, which increase the likelihood of being liquidity constrained upon impact of an adverse shock, which increases the default probability. However, a higher mortgage interest rate also increases the likelihood of refinancing for a lower interest rate. Refinancing is particularly beneficial for low loan-to-value ratio loans. These loans carry a low risk of default, so they have a lower mortgage premium. As a result, for loans with a low loan-to-value ratio, households can avoid defaulting in consequence of adverse income shocks through refinancing, which is more likely to happen for loans with higher mortgage interest rates. Hence, for high loan-to-value ratio loans, a higher mortgage interest rate is associated with a higher risk of default, but, for low loan-to-value ratio loans, a higher mortgage interest rate increases the refinancing probability and decreases the likelihood of default.

3.2.3. Mortgage interest rates

The novel part of this paper is the endogenous determination of the mortgage contracts. Most of the papers in the literature assume a constant mortgage interest rate and down payment for mortgages. However, these assumptions can dramatically distort the results of these papers. The households in the margin of owning versus renting are the low-income and low-wealth households. They can only afford to purchase a house with a high loan-to-value mortgage. However, in my model, the mortgage interest rate for such loans is higher and, as a result, home buyers face endogenous borrowing terms through collateralized mortgages.

Figs. 6 and 7 show how mortgage interest rates are affected by loan-to-value ratio, income, type, and house prices. Since, the default probability is the main determinant of the mortgage interest rates, these figures are reflections of Fig. 5. That

²¹ These are refinancing mortgages. The purchase price in the model is constant across the home buyers. However, as a result of idiosyncratic house price shocks, homeowners have different house prices over time, and this heterogeneity in house prices plays a crucial role in the determination of the mortgage interest rate if these homeowners choose to refinance.

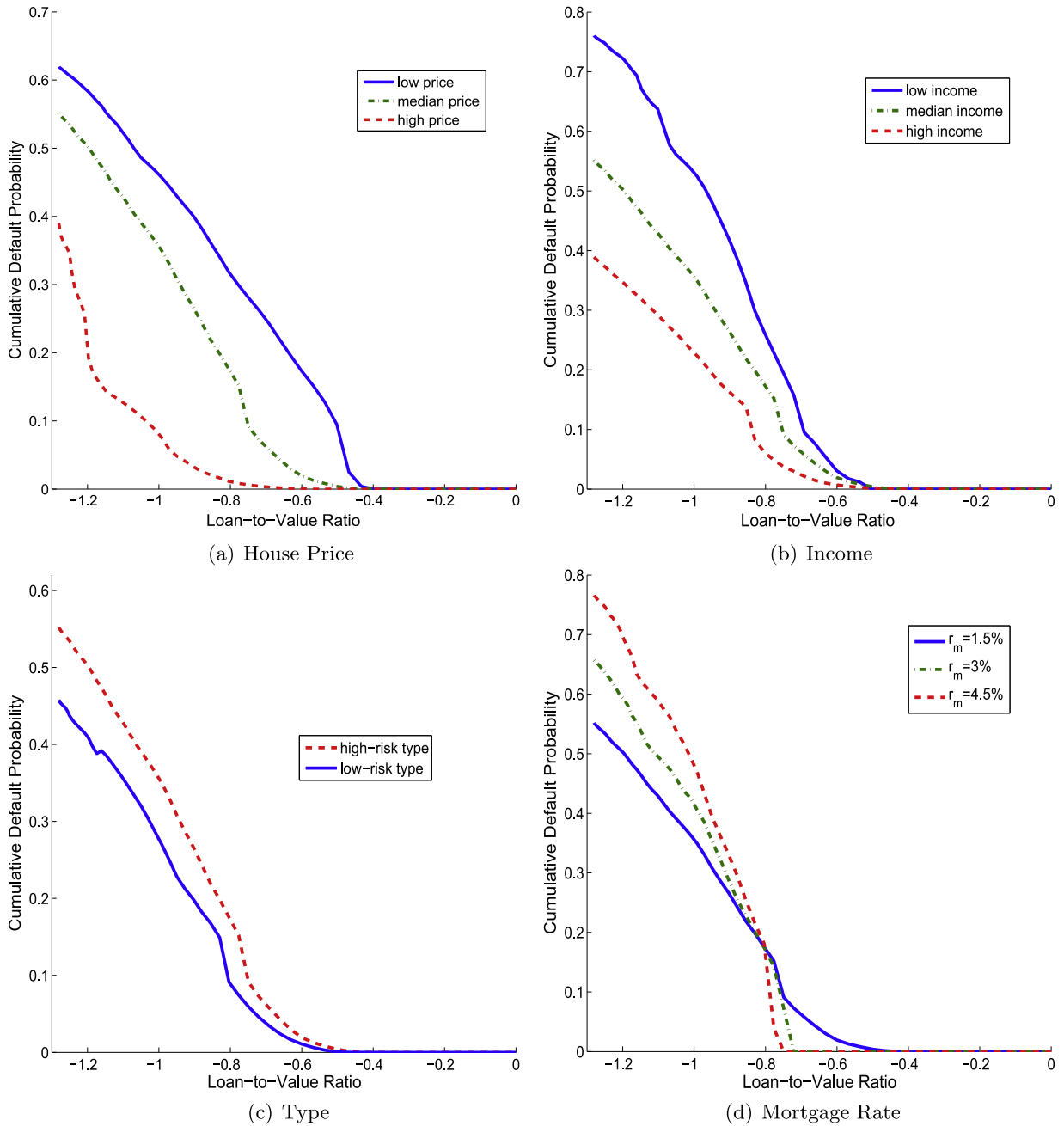


Fig. 5. Cumulative default probabilities: the figures show the lifetime default probability of a mortgage with the corresponding debt-price ratio. The benchmark mortgage is the one with 30-year maturity and risk-free mortgage interest rate issued to a low-risk household with median income level and median house price level.

is, the mortgage interest rate increases as the loan-to-value ratio increases, income decreases, and house price increases. Similarly, high-risk types face a higher mortgage premium compared to low-risk types. One important observation from these figures is the significant sensitivity of the mortgage interest rate to all of these characteristics.

3.2.4. Who refinances?

Refinancing serves two purposes in the model. First, it allows households to decrease the mortgage interest rate on a loan. Secondly, it allows households to insure against adverse incomes shocks. These shocks can render the homeowner liquidity constrained. Without refinancing, they might choose to either sell the house or default on the mortgage. However, with refinancing, they can borrow using their houses as collateral, and smooth consumption. The presence of a proportional

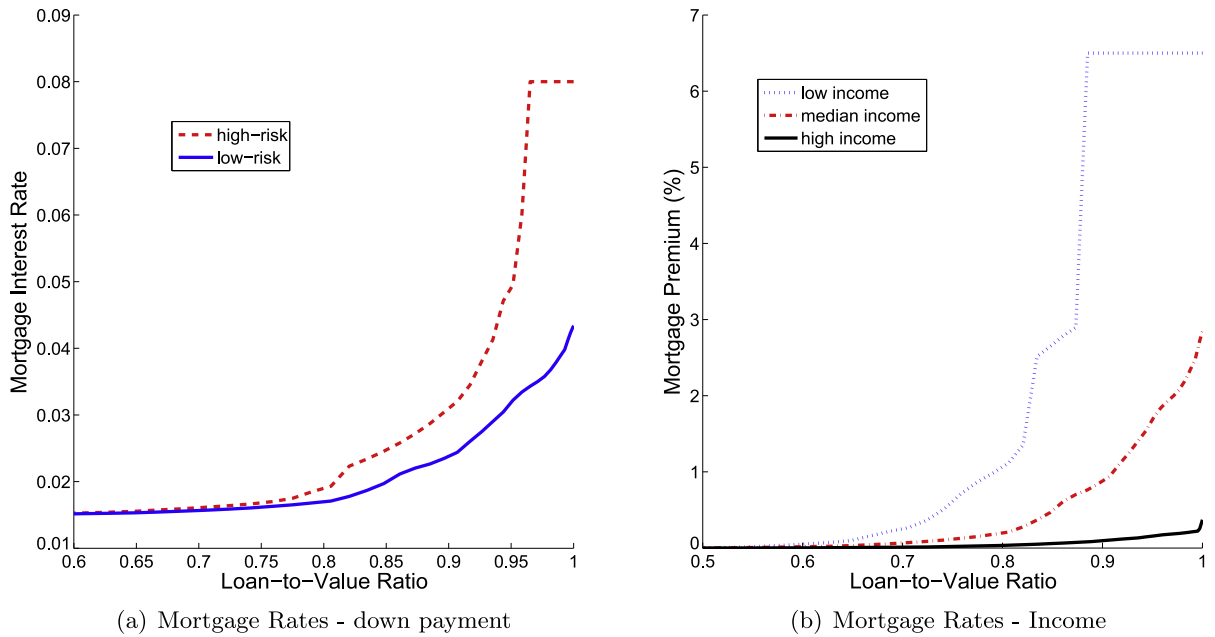


Fig. 6. Mortgage interest rate in SI economy: in these figures, the benchmark mortgage is with a maturity of 30 years offered to a low-risk household with median income level.

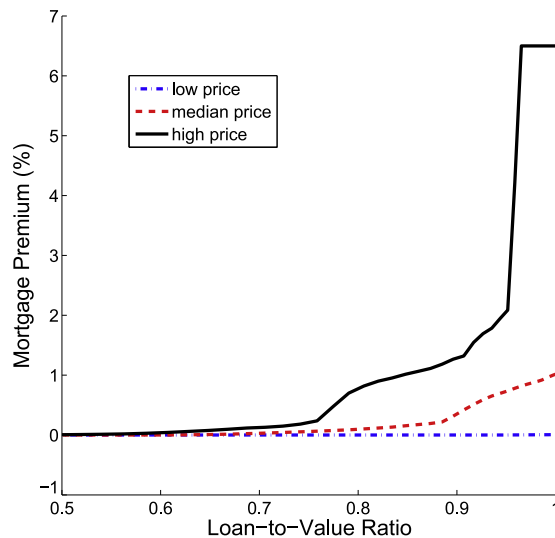


Fig. 7. Mortgage interest rate in SI economy: the benchmark mortgage drawn in this figure is with a maturity of 30 years offered to a low-risk household with a median income level.

refinancing cost decreases the benefit of this channel. In the benchmark economy, 60% of the mortgage originations are for refinancing, and the rest is for house purchases.

Analyzing Table 4 shows that refinancing is extensively used by the homeowners. Among the mortgage holders, 22.7% refinance their mortgages. These households are income poor. Their average income is 0.72, which is almost half of the average income of mortgage holders. However, they have higher net wealth (1.98) and higher house price realization (3.88). The comparison of house prices in Table 4 shows that it is actually the homeowners with a high house price realization who refinance. The average house price of a refiner among mortgage holders with no moving shock is 3.88. The same number is 3.74 for those who choose to stay and 3.10 for those who choose to default. More significantly, among the mortgage holders with negative equity, the average house price of a refiner is much higher compared to a stayer (3.38 vs. 2.92).

Table 5
Steady-state comparison.

Economy ^a	Data		Model		
	92–96	02–06	AI r^{AI}, p^{AI}	SI r^{SI}, p^{SI}	SI-2 r^{AI}, p^{AI}
Statistic					
Homeownership rate	64.2%	68.6%	64.2%	68.6%	64.8%
Foreclosure rate	0.7%	0.9%	0.69%	0.98%	0.93%
Average down payment	25%	20%	30.6%	22.9%	26.7%
Mortgage premium	1.3%	1.7%	0.31%	0.67%	0.54%
Refinancing share	36%	60%	48%	60%	50%
Debt–service ratio	14.7%	17.2%	16.6%	17.1%	17.4%

^a This table compares the steady-states of the three economies. AI represents the economy with asymmetric information, risk-free interest set to 3.6%, and mean of house price process set to 1.1. SI represents the symmetric information economy with risk-free interest rate set to 1.5%, and mean of house price process is set to 1.16. Lastly, SI-2 represents the symmetric information economy with the risk-free interest rate and house price mean set to the ones in AI economy.

3.3. Steady-state comparisons

I want to understand whether the improvements in information technology—specifically, the emergence of the AUS—can explain the recent changes in the mortgage market, particularly the decrease in the down payment and the increase in the mortgage premium, the foreclosure rate, and the homeownership rate. In order to pursue this goal, given the above set of parameters, I first solve the SI economy, which is my benchmark economy, and then compare the results to the AI economy. The AI economy represents the period before the introduction of the AUS, and the SI economy represents the period after its introduction. These two periods differ from each other not only in terms of information structure, but also in terms of the risk-free interest rate and house price. Therefore, I solve the AI economy with the corresponding value for the risk-free interest rate in the period 1992–1996 and set the mean of the house price process, μ_p^{AI} , by keeping the persistency and standard deviation of the house price process as in the SI economy, in order to match the homeownership rate in the period 1992–1996, representing the AI economy. The risk-free interest rate in this period is 3.6%. Using this interest rate, I solve the AI economy to match the homeownership rate of 64.2%, which is the average homeownership rate in the period between 1992 and 1996. This calibration results the mean of the house price process in the AI economy as $\mu_p^{AI} = 3.05$. Such a house price process, together with the zero-profit condition for the real estate agents, implies the house purchase price in the AI economy as $p^{AI} = 3.90$.

Table 5 presents the steady-state comparison of these two economies. The transition from the AI economy to the SI economy involves three changes. First, the risk-free interest rate decreases. Such a decrease in the risk-free interest rate makes mortgages more affordable and increases the homeownership rate. As the homeownership rate increases, the mean income of the homeowners decreases since the new home buyers are lower income, lower wealth households. As these new home buyers can only afford smaller down payments, the average down payment in the economy decreases.²² Further, as the down payment decreases, the default risk of the household increases, which pushes up the foreclosure rate. However, a lower risk-free interest rate also implies a lower mortgage interest rate, which decreases the likelihood of foreclosure. Thus, the net effect of the risk-free interest rate on foreclosure depends upon the magnitude of these two effects. The second change along the transition is a slight increase in the house price, which makes the houses less affordable, and causes the homeownership rate to decrease. The decrease in the homeownership rate is mainly due to low-income, low-wealth households. The average down payment of the remaining home buyers should be higher. Higher down payments mean higher home equity, which decreases the foreclosure rate. Finally, the lenders' information about the characteristics of home buyers advances. I leave the discussion of this change to Section 4.1, but this change increases the homeownership rate, foreclosure rate and mortgage premium, whereas it decreases the down payment. With the current calibration, the first and third effects dominate over the second effect and the transition from the AI economy to the SI economy increases the homeownership rate (from 64.2% to 68.6%), foreclosure rate (from 0.69% to 0.98%), and mortgage premium (from 0.31% to 0.67%), while also decreasing the down payment (from 30.6% to 22.9%).

4. Counterfactual: the effect of the information structure

In order to quantify the contribution of information technology to the mortgage market, I run a counterfactual experiment. In this experiment, I focus on the effect of the information structure. I assume that during the transition from the AI economy to the SI economy, the risk-free interest rate and house price do not change, but the information structure does. That is, I solve the SI economy with the same set of parameters used for the AI economy. I call this economy the SI-2 economy. The only difference between the AI economy and the SI-2 economy is that in the AI economy lenders have partial information about the households whereas in the SI-2 economy they have full information. The last column of Table 5

²² Lower risk-free interest rate also result lower accumulation of wealth. This also contributes to the decrease in the down payment.

Table 6
Decomposition of the change across types.

Economy ^a	AI		SI-2		SI	
Type	High risk	Low risk	High risk	Low risk	High risk	Low risk
Statistic						
Homeownership	63.4%	64.4%	63.4%	65.2%	67.1%	69.0%
Foreclosure rate	1.36%	0.50%	1.36%	0.82%	1.34%	0.88%
Down payment	27.0%	31.2%	27.0%	26.6%	23.3%	22.8%
Mortgage premium	0.85%	0.16%	0.85%	0.46%	0.92%	0.60%
Refinancing share	52%	47%	52%	50%	61%	60%
Welfare gain	–	–	0%	0.3%	1.9%	1.6%

^a This table presents the decomposition of the effect of an advance of information, and the decrease in the risk-free interest rate together with an increase in the house price.

presents the results of this counterfactual experiment. I define the difference between the results of the AI economy and this counterfactual as the contribution of the change in the information structure.²³

Most of the results presented in the benchmark calibration hold qualitatively. Homeownership rate, foreclosure rate, average down payment, and mortgage premium all have the same patterns as in the benchmark calibration but the quantitative effects are different. Better information results in an increase in the homeownership rate from 64.2% to 64.8%, an increase in the foreclosure rate from 0.69% to 0.93%, an increase in the mortgage premium from 0.31% to 0.54%, and a decrease in the average down payment from 30.6% to 26.7%. According to the model, better information can explain 87% of the increase in the foreclosure rate, 51% of the decrease in the down payment fraction, and 64% of the increase in the mortgage premium. The other changes in the variables come from the combination of a decrease in the risk-free interest rate and an increase in the house price. However, better information can only explain 14% of the increase in the homeownership rate.

Table 6 shows the breakdown of the change across the economies for each type. Better information affects only the low-risk type households. Thanks to the construction of separating contracts in the AI economy, high-risk types receive exactly the same contracts in the AI and SI-2 economies. However, in the SI-2 economy, low-risk types get better mortgage contract terms since they are perfectly separated from the high-risk types. Better mortgage terms result in a decrease in the average down payment from 31.2% to 27.0% and an increase in the refinancing share from 47% to 50%. However, such a decrease in the down payment comes at the cost of an increase in the mortgage premium from 0.16% to 0.46%, and an increase in the foreclosure rate from 0.50% to 0.82%.

Such an increase in the foreclosure rate does not necessarily mean lower welfare for a household. In fact, access to better mortgage contract terms makes the low-risk types better off in the SI-2 economy. Their welfare increases by 0.3% in consumption-equivalent terms. However, the main welfare gain comes through the transition from the SI-2 economy to the AI economy. Relative to the AI economy, the welfare of the low-risk types, in consumption equivalent terms, increases by 1.9% in the SI economy. The same number is 1.6% for the high-risk types. Such a large increase in the welfare comes from a higher homeownership rate in the SI-2 economy.

However, there are some further costs of a transition from the AI economy to the SI-2 economy. There are some unmodeled costs in the economy, such as the selling cost of a house and refinancing cost. In the AI economy, the total selling cost (incurred either by the household or the lender) is 1.22% of the aggregate income. This cost increases to 1.28% in the SI-2 economy due to higher amount of foreclosures. Moreover, along the transition from the AI economy to the SI-2 economy, the total refinancing cost increases from 0.64% to 0.80% of the aggregate income due to the higher volume of refinancing and higher amount of mortgage debt.

4.1. Inspection of the mechanism

The main mechanism for these results is the change in the mortgage terms. As lenders acquire better information about households, the pricing of the mortgages changes. Better information allows lenders to differentiate between low and high-risk types. As a result, the terms of the mortgages offered to both of these types may change. In the AI economy, lenders cannot observe the types and so face an adverse selection problem. More specifically, if contracts designed in the SI-2 economy are offered, the high-risk types also demand the contracts designed for the low-risk types, causing these contracts to carry a higher risk of default and yield negative profits. As a result, lenders design separating contracts. As explained in Section 2.3, these contracts result in the same type of contracts for the high-risk types. However, the low-risk types cannot receive the contracts, which are offered to them in the SI-2 economy. More specifically, any contract which also attracts a high-risk type is not offered to the low-risk household in the AI economy. Therefore, the low-risk types suffer in the AI economy due to the presence of high-risk types. Fig. 8 displays this fact. In this figure, I show the equilibrium mortgage

²³ Since I treat the house price as exogenous, it is not exactly the right definition. In a world with endogenous house prices, this counterfactual should result in a higher house price than the house price in the AI economy. Therefore, the actual contribution should be lower than as defined here. However, when I solve the SI-2 economy with endogenous prices, the price difference is very small, mainly because the effect of a change in the information does not produce a significant change in the homeownership rate.

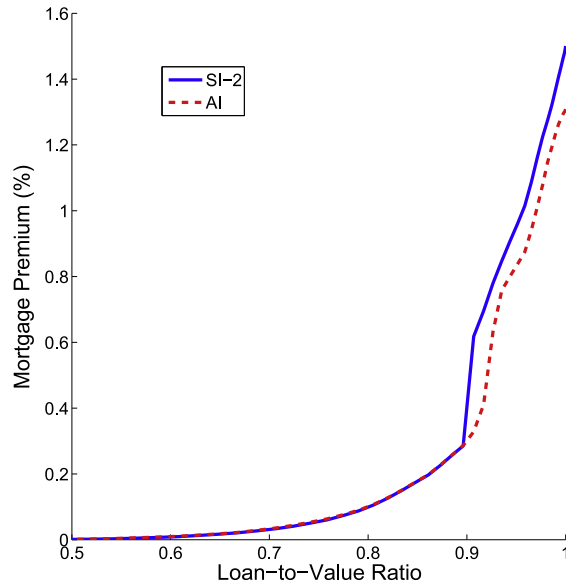


Fig. 8. Mortgage interest rate in SI-2 and AI economies: the benchmark mortgage is with a maturity of 30 years offered to a low-risk household with a median income level.

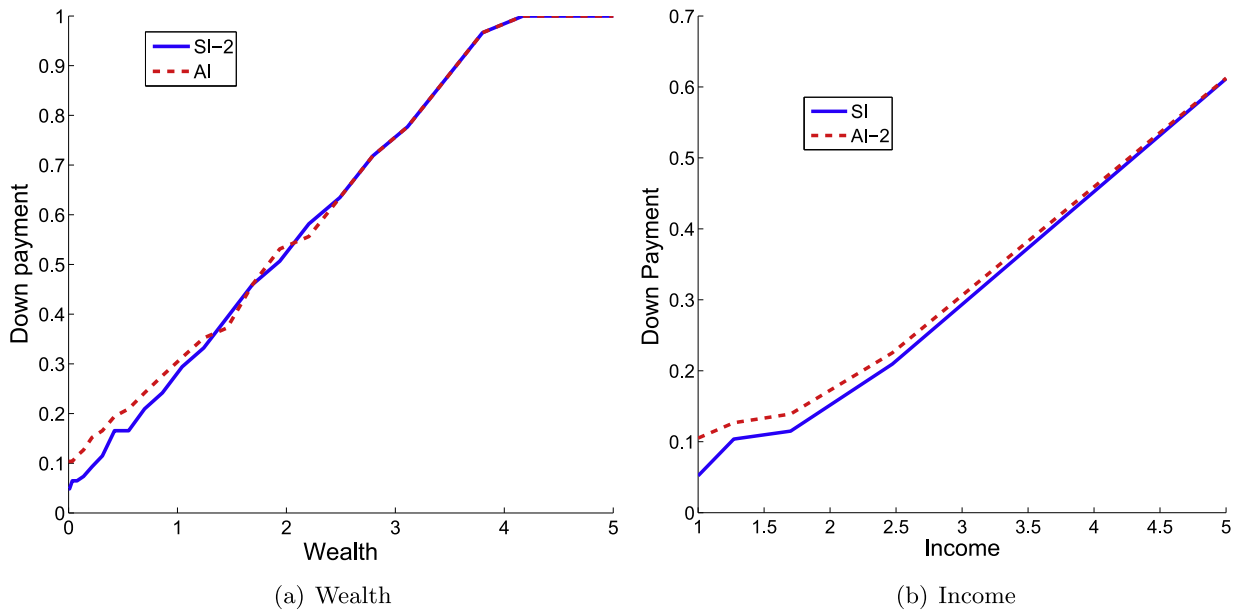


Fig. 9. Optimal down payment choice across both economies: both figures are drawn for a mortgage with maturity of 30 years originated to a low-risk household. The figure on the left assumes a median income household, and the figure on the right assumes a household with very low wealth.

interest rate as a function of the loan-to-value ratio in both the AI and SI-2 economies for the same type of loans offered to a low-risk type. The dashed line shows the mortgage interest rate in the AI economy, while the solid line is for the SI-2 economy. The main difference is that, in the AI economy, loans with a higher loan-to-value ratio have higher mortgage premiums. Given this difference in the pricing of the mortgages, the mortgage choice of the low-risk households can differ between the AI and SI-2 economies.

Fig. 9(a) compares 30-year mortgage loan choices for a low-risk household with a median income level across both economies and along the wealth dimension. Although for high-wealth households, the optimal down payment fraction is the same across both economies, low-wealth households use a larger down payment in the AI economy compared to the SI-2 economy. The main reason for this result is the higher mortgage interest rate associated with high loan-to-value mortgages in the AI economy due to the adverse selection problem. Fig. 9(b) plots the same graph over income. Again, I observe the same pattern. For high-income households, the choices are the same, whereas for low-income households, the

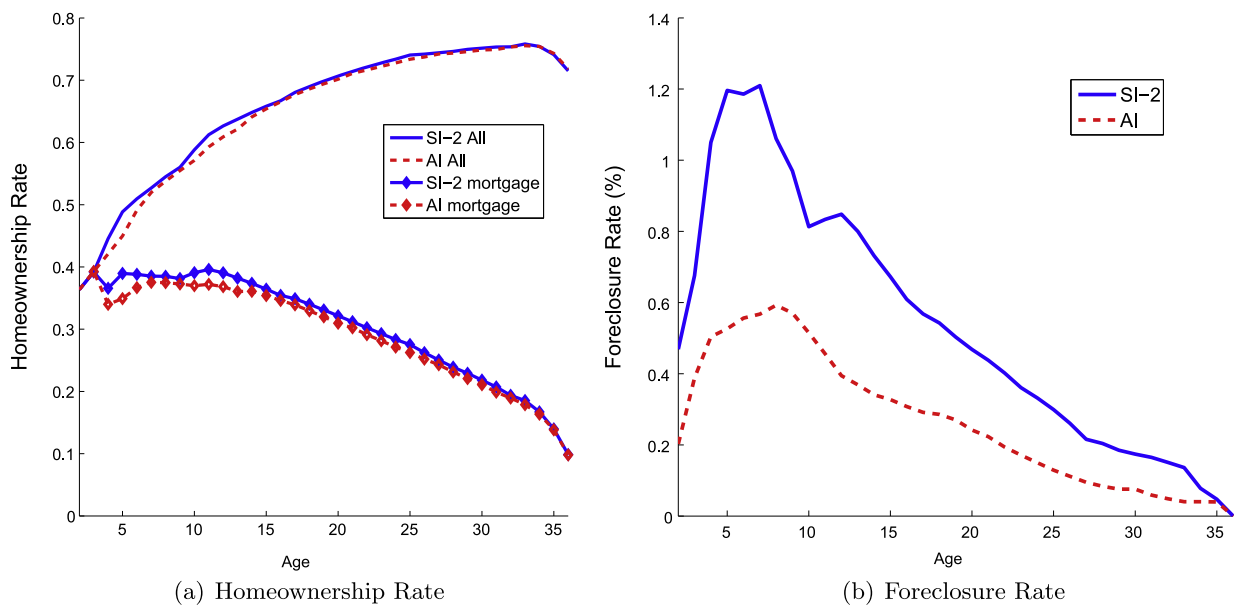


Fig. 10. Life-cycle comparisons: the left figure shows the comparison of the AI and SI-2 economies for the homeownership rate over the life-cycle. The right figure compares both economies along the foreclosure rate.

AI economy results in a higher down payment fraction, which is the main reason that a lower average down payment is observed in the SI-2 economy. Better information endogenously causes a relaxation of the financing terms of the mortgages. More importantly, the decrease in the down payment happens for low-income and low-wealth households.

4.1.1. Life-cycle comparisons

4.1.1.1. Homeownership rate I also look at the differences between these two economies over the life-cycle. Fig. 10(a) shows how the homeownership rate of low-risk households change over the life-cycle in both economies. The lines without marks plot the homeownership rates in both economies, the solid line representing the SI-2 economy and the dashed line representing the AI economy. The lines with diamonds plot the fraction of homeowners with mortgages out of all the populations in both economies. Remember that most of the house purchases are made through mortgages (80% in the benchmark model, as shown in Table 4) and, early in their lives, the households are both income- and wealth-poor. Thus, the change in the mortgage interest rates especially affects young households. As a result, the homeownership rate in the AI economy is slightly lower than that in the SI-2 economy early in the life-cycle, which is especially more pronounced for the homeowners with mortgages.

4.1.1.2. Down payment and mortgage premium Fig. 11(a) compares the average down payment of the low-risk types at the time of house purchase over the life-cycle and across the two economies. The average down payment is lower in the SI-2 economy than in the AI economy over the life-cycle. The adverse selection that lenders face in the AI economy forces them to separate low from high-risk types. As explained in Section 4.1, this separation results in higher down payments or lower loan-to-value ratios for the low-risk households in the AI economy. Therefore, the average down payment observed in the AI economy is higher than that observed in the SI economy. Notice that this difference is more striking early in the life-cycle because that is precisely when households are wealth- and income-poor and tend to demand high loan-to-value mortgages. As explained earlier, these mortgages are the ones that are subject to the most significant changes during the transition from the AI economy to the SI-2 economy.

Fig. 11(b) is the comparison of the average mortgage premium that low-risk home buyers are charged over the life-cycle across the two economies. As a direct implication of the increasing down payment over the life-cycle, the mortgage premium decreases over the life-cycle. Similarly, as the down payment decreases, the transition from the AI economy to the SI-2 economy results in an increase in the average mortgage premium.

4.1.1.3. Foreclosure rate Fig. 10(b) shows the foreclosure rate over the life-cycle of the low-risk types in both economies. The foreclosure rate has a hump over the life-cycle. Early home buyers in the model are income- and wealth-rich households. These households carry a lower risk of default. However, as the low-income and low-wealth households accumulate wealth, they choose to buy houses. These households carry a higher risk of default, and they increase the foreclosure rate early in the life-cycle. Moreover, as households age, the maturity of the mortgages decreases, which increases the mortgage payments. Larger mortgage payments make homeowners more vulnerable to adverse income shocks and, thus, increase the foreclosure rate early in the life-cycle. However, over the life-cycle, new home buyers put down higher payments as shown

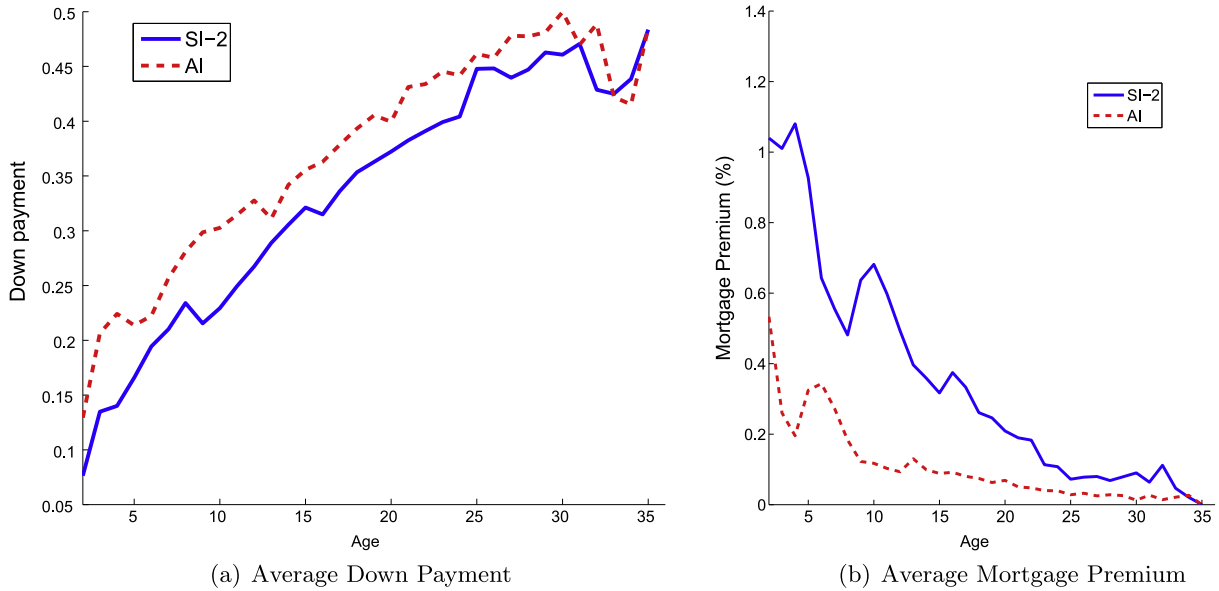


Fig. 11. Life-cycle comparisons: the left figure shows the comparison of the ai and SI-2 economies along the average down payment home buyers put over the life-cycle. The right figure compares both economies along the average mortgage premium home buyers are charged.

in Fig. 11(a). The increase in the down payment decreases the default probability and, hence, decreases the foreclosure rate late in the life-cycle.

The foreclosure rate in the SI-2 economy is higher than that in the AI economy over the life-cycle. The reason for this difference lies in the difference of the down payment and mortgage premium between the two economies. Since in the SI-2 economy households contribute lower down payments at the origination and face higher mortgage premiums, their risk of default is higher and they experience a higher foreclosure rate. The difference is especially sizable early in the life-cycle when households choose lower down payments.

4.2. Comparison of responses to an unexpected aggregate house price shock²⁴

Although better information improves the welfare of the individuals in the economy, a higher amount of borrowing and a higher foreclosure rate in the SI-2 economy motivate the question of how sensitive both economies are to an unexpected aggregate house price shock. To pursue this goal, I shock AI and SI-2 economies with a 20% unexpected house price drop.²⁵ Using the decision rules computed for the steady-state economies, I compute the counterfactual foreclosure rate in both economies on impact.²⁶ In response to a 20% decrease in the house price, the aggregate foreclosure rate increases from 0.69% to 1.57% in the AI economy. This corresponds to a 0.88% point increase in the foreclosure rate. However, the same shock results in an increase in the foreclosure rate from 0.93% to 2.03%, which is a 1.1% point increase, in the SI-2 economy. So, better information results in 25% ($= 1.1/0.88 - 1$) more foreclosure in response to a 20% unexpected decrease in the house price. Overall, this counterfactual shows that although better information improves the welfare of a household, it comes at the cost of a higher sensitivity of the foreclosure rate to the changes in the house price.

5. Conclusion

In this paper, I have explored the effects of improvements in information technology on the mortgage market. I show that as lenders' information about the credit risk of households increases, the housing market experiences a decrease in the down payment fraction and, consequently, an increase in the mortgage premium, foreclosure rate, and homeownership rate, which are all consistent with the trends observed in the data. The model allows me to understand the mechanism behind the relaxation of the mortgage terms. I show that improvements in information technology can explain half of the decrease in the down payment fraction that the mortgage market experienced in the mid-2000s. The model can also

²⁴ I would thank to one of the referees and the Editor for suggesting this experiment.

²⁵ More precisely, I decrease the idiosyncratic house price level for each household one grid level. I use 5 grid points for house price shock. The lowest house price level essentially receives no shock. Households at the second and the fifth house price grids experience 27% decrease in the house level. Finally, households at the third and the fourth house price grids experience 18% decrease in the house price level.

²⁶ Notice that this calculation ignores the response of the households to the unexpected shock. To compute the actual foreclosure rate, one needs to solve for the transitional dynamics of both economies as in Arslan et al. (2013).

generate two-thirds of the increase in the mortgage premium and almost all of the increase in the foreclosure rate between the mid-1990s and the mid-2000s. Moreover, through a counterfactual experiment I show that better information improves the welfare of the households, but it makes the foreclosure rate more sensitive to the changes in the house price.

My quantitative work sheds some light on how the supply of the mortgage market responds to changes in the information structure and market fundamentals. It also has the potential to answer the implications of different policies directed to the mortgage market. The model emphasizes the role of the fluctuations in the house prices on the mortgage contract terms and the foreclosure dynamics. However, these fluctuations are assumed to be exogenous in the model. Understanding the sources of these fluctuations seems to be important for fully capturing the real effects of different policies. The extension of the current framework with endogenous house price fluctuations is an ambitious but necessary step forward.

Moreover, the recent financial crisis that stemmed from the subprime mortgage market has brought a lot of attention to the question of how the mortgage market operates. Although my framework is useful with regard to understanding the interaction between lenders and households, it does not illuminate the interaction between lenders and investors, which is an important cause of the latest financial crisis. So, as a next step, it is important to model the interaction between lenders and investors, regarding which there is significant informational asymmetry.

Appendix A

A.1. Theoretical appendix

A.1.1. A simplified model

To better address the issues involved with the existence of the equilibrium, I modify the model to a simpler version. Assume that there are only two periods, there is no saving, and households are risk-neutral. Households are hand-to-mouth agents. I abstract from the first period housing tenure choice problem, because the issues involved with the existence of equilibrium are relevant for the households who are offered contracts. So, in the first period, I assume that households are all purchasers. I fix the house price to 1 and assume that households are sufficiently impatient so that they finance all the funds necessary to purchase the house through a mortgage from a lender. Lending market is perfectly competitive, and lenders only offer interest-only mortgages, i.e., mortgage payments in both periods are equal to the interest payments on the loan, and households pay the original loan amount at the end of the second period.

In the second period households can default on the mortgages. I assume that there are two types of households. Type I households are risky and type II households are safer. Let q_i denotes the default probability of household i in the second period. So, I have $q_1 > q_2$. In case of default, a household does not have any obligation to the lender, and the lender can only recover an exogenous amount, κ , by selling the house, and this amount is assumed to be significantly lower than the loan amount. As a result, lenders face a default risk, and set the mortgage interest rate to recover their expected loss due to default risk. If households do not default, they continue to stay in the house by making the necessary mortgage payments.

I first solve for the symmetric information equilibrium, i.e., lenders observe the default probability of each household. In this case, thanks to the assumption of impatience, households will request a mortgage loan of $d = 1$.

Since mortgages are interest-only mortgages, given a loan amount d , mortgage payments at the end of both periods become

$$m = dr_m \quad (16)$$

when the mortgage interest rate is r_m . Moreover, the household has to pay the original loan amount, d , at the end of the second period. Thanks to the risk-neutrality assumption, the problem of the household becomes a minimization problem for the cost of the housing purchase. Notice that in case of default in the second period, the household makes no mortgage payment. However, if the household does not default, I assume that she continues to stay in the house, which can be justified by a sufficiently large ownership premium for households. Given these assumptions, the expected utility cost of purchasing a house with a mortgage loan amount of d in the first period for type- i household is the following:

$$u_i(d, r_m) = -1 + d - \frac{dr_m}{1+r} - \beta(1-q_i)\frac{1+r_m}{1+r}d, \quad (17)$$

where $1-d$ is the down payment the household puts in the first period, $\frac{dr_m}{1+r}$ is the first period mortgage payment, and $\beta(1-q_i)\frac{1+r_m}{1+r}d$ is the discounted expected value of the second period mortgage payments. Notice that in the second period, the household only makes mortgage payments if she does not default, which happens with probability $1-q_i$, and at the end of the second period, the household pays the original loan amount back with a balloon payment.

Similarly, the expected value of a mortgage contract (d, r_m) offered to type- i household in the first period becomes:

$$v(d, r_m; i) = \frac{dr_m}{1+r} + \frac{1}{1+r} \left[q_i \min\{\kappa, d\} + (1-q_i) \frac{1+r_m}{1+r} d \right].$$

This corresponds to the present value of the expected payments the lender receives for a mortgage with a loan amount d originated to a type- i individual at the mortgage interest rate r_m . Then no-arbitrage condition simply implies that the profit to the lender is equal to zero:

$$\pi(d, r_m; i) = \frac{dr_m}{1+r} + \frac{1}{1+r} \left[q_i \min\{\kappa, d\} + (1 - q_i) \frac{1+r_m}{1+r} d \right] - d = 0.$$

Solving this equation for r_m results in the equilibrium mortgage interest rate for a loan amount d originated to type- i household:

$$1 + r_m = (1 + r) \frac{2 + r - \frac{\min\{\kappa, d\}}{d} q_i}{2 + r - q_i}. \quad (18)$$

First of all, notice that if $d \leq \kappa$, then $r_m = r$, and essentially the loan becomes risk free. However, for $d > \kappa$, there is default risk, and I have $r_m > r$. Moreover, since $\kappa < d$, it should be straightforward to show that $\frac{dr_m}{dq_i} > 0$, i.e., households with higher default probability receive mortgages with higher interest rates for the same amount of mortgage. Using implicit function theorem, I can show that

$$\frac{dr_m}{dd} = \frac{(1+r)q_i \frac{\kappa}{d^2}}{2+r-q_i} > 0,$$

which means the iso-profit curve for the lenders in the (d, r_m) space is upward sloping. Similarly, I can show that $\frac{\partial \frac{dr_m}{dd}}{\partial d} < 0$,

which means the iso-profit curve is a concave function in the (d, r_m) space. Lastly, I can show that $\frac{\partial \frac{dr_m}{dd}}{\partial q_i} > 0$, which means as the default probability increases, the iso-profit curve becomes steeper.

I can also draw the indifference curves of the households in the (d, r_m) space. The slope of the indifference curve is characterized by $\frac{dr_m}{dd}$, which can be computed by taking the total derivative of Eq. (18):

$$\frac{dr_m}{dd} = \frac{1 - \frac{r_m}{1+r} - \beta(1 - q_i) \frac{1+r_m}{1+r}}{d \left(\frac{1+\beta(1-q_i)}{1+r} \right)}.$$

Since I assume households are sufficiently impatient, I have $1 - \frac{r_m}{1+r} - \beta(1 - q_i) \frac{1+r_m}{1+r} > 0$, which means $\frac{dr_m}{dd} > 0$. Moreover, I can also characterize the slope of the indifference curve further: $\frac{\partial \frac{dr_m}{dd}}{\partial d} < 0$ and $\frac{\partial \frac{dr_m}{dd}}{\partial q_i} > 0$.

Given these characterizations, I can now illustrate the equilibrium to the above economy in a phase-diagram of contract space: (d, r_m) . First of all, notice that in a symmetric information equilibrium, households set $d = 1$ due to their high impatience level. Using Eqs. (17), (18), and the characterization of the $\frac{dr_m}{dd}$ both for the indifference and the iso-profit curves, I can construct the indifference curve for the household and the iso-profit curves for the lender. Fig. 12(a) shows typical indifference curves. For a low-risk type, it is denoted by u_l , and for a high-risk type, it is denoted by u_h . The iso-profit curve, for a low-risk type, is denoted by π_l , for a high-risk type it is denoted by π_h , and for the pool it is denoted by π_p . The indifference curves yield higher utility as they shift to the right, so the equilibrium to the symmetric information economy is the point where the households receive the highest possible loan amount, which is the house price. So, (d_l, r_l) and (d_h, r_h) are the equilibrium to the SI economy. In the SI economy, high-risk households face a higher mortgage interest rate compared to the low-risk households.

A.1.2. Problem of existence of Nash equilibrium

In the asymmetric information economy, the types are not observable. So, both contracts are available for the households. Clearly, the contract designed for the low-risk type gives a higher utility for the bad type. If both contracts are offered, both types choose the contract (d_h, r_h) and the lender makes negative profit. So, the equilibrium in the SI economy is not sustainable in the AI economy. In the literature two types of contracts are suggested as a potential equilibrium to the AI economy facing the adverse selection problem: *pooling contracts* and *separating contracts*. A pooling contract pools both types into a single contract, while a separating contract is able to separate the types. As it is analyzed in Rothschild and Stiglitz (1976), a pooling contract cannot be a Nash equilibrium to the AI economy. The intuition is simple. As is seen in Fig. 12(b), point E_p is a candidate pooling equilibrium. It is on the iso-profit curve for the pool. However, a point like point \tilde{E} cream-skims only the low-risk types and since it is on the left of the iso-profit curve for the low-risk type, it yields a positive profit to the lender. So, such a deviation is profitable for the lender which results in a pooling contract not to be an equilibrium contract. Although it is not guaranteed, a separating equilibrium may exist. Fig. 12(c) shows a candidate separating equilibrium. Such a separating contract is called a *least-cost separating contract*. Contracts E_h and E_l separate both types. Either type finds it not optimal to choose the contract designed for the other type and both contracts make zero-profit. Since the iso-profit curve for the pool denoted by π_p is to the left of the indifference curve for the low-risk type, low-risk types never prefer a pooling contract. So, pooling contracts cannot break the separating equilibrium. However, if the proportion of the low-risk types is sufficiently high, then it is possible to break the candidate separating equilibrium by either a pooling contract or another separating contract which relies on cross-subsidization. Fig. 12(d) shows how a pooling contract breaks the separating equilibrium. Point \tilde{E} is a profitable deviation for the lender. It attracts both types and yields a positive profit. In such an environment no Nash equilibrium exists. Note that the least-cost separating contract can only be broken by contracts which rely on cross-subsidization. However, such contracts can always be broken with a separating contract which cream-skims only the low-risk types.

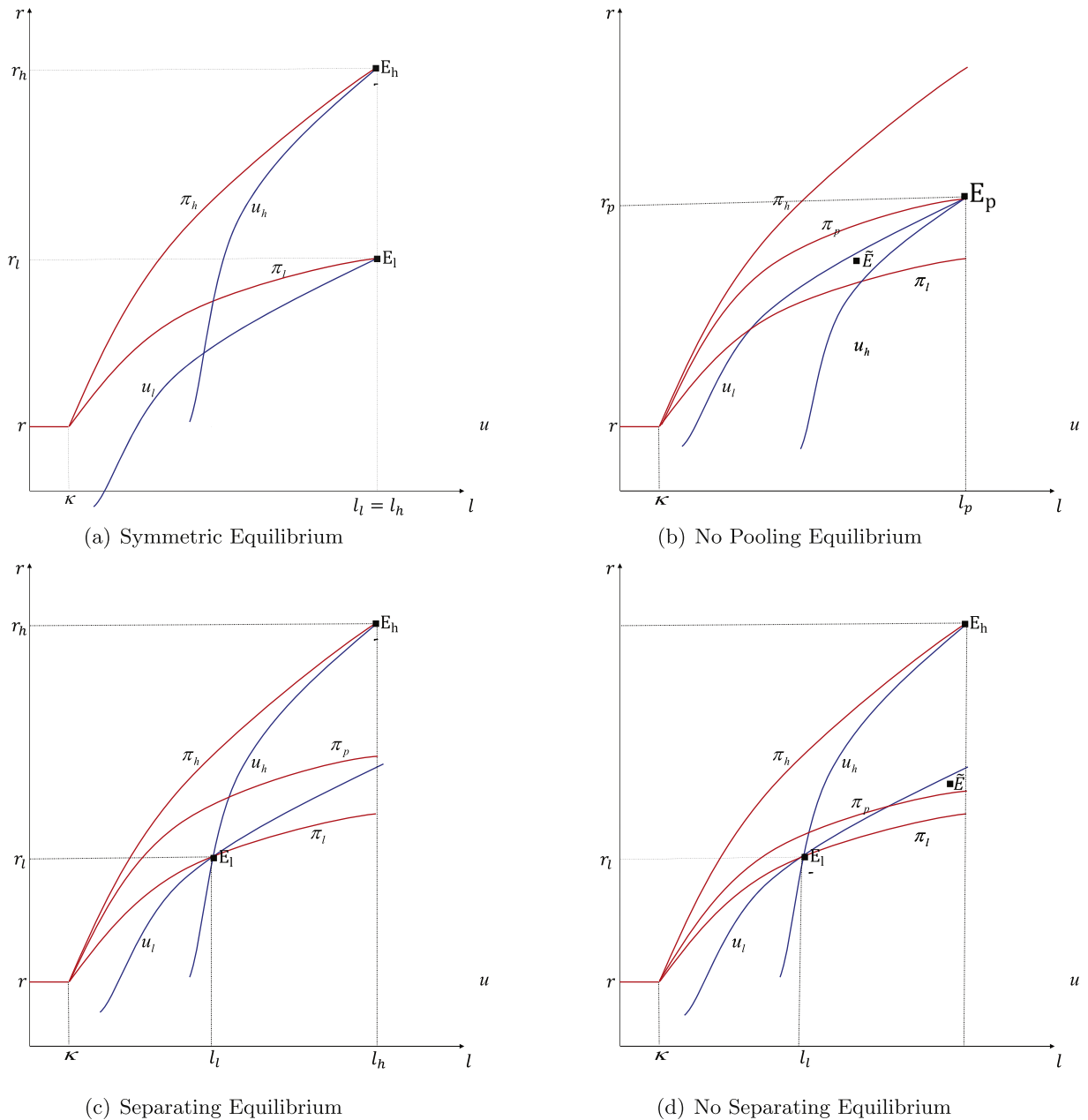


Fig. 12. Illustration of equilibrium.

A.1.3. Reactive equilibrium

It is possible to support a pooling contract by modifying the equilibrium concept as in [Riley \(1979\)](#). He offers another equilibrium concept, *Reactive Equilibrium*, so that the least-cost separating contract survives as an equilibrium. The only difference of the Reactive equilibrium from the Nash equilibrium is that it does not allow any deviations that would become unprofitable if they led the other lenders to react by adding new contracts. Note that the least-cost separating contract can only be broken by a contract which depends on cross-subsidization. Any contract with cross-subsidization can be broken with another separating contract by cream-skimming the low-risk types and yields the lender offering such a contract to only the high-risk types and consequently a negative profit.

Here, it is useful to mention that it is also possible to model the above economy as a signaling game rather than a screening game. In signaling games, the uninformed player moves first. In my economy, it corresponds to the following game. In stage one, households move and choose a loan amount. After observing the loan amount and other characteristics of the household, in the next and last stage, lenders compete by offering a mortgage interest rate. The last stage of the game, due to perfect competition, is simple. Basically, lenders set the zero-profit mortgage interest rate corresponding to

the observable and loan amount. In the signaling games, I have to deal with the beliefs. In my environment, the households can signal their types by choosing the loan amount. Then the lenders have to form their beliefs on the types of households based on this signal. The common equilibrium concept used in the literature is the perfect Bayesian equilibrium. Wherever possible, the beliefs are formed using the household's strategies in a Bayesian fashion. However, the lenders also have to assign beliefs for off-the-equilibrium strategies. This feature of the model gives potential multiplicity of the equilibria. It is possible to have a continuum of pooling and separating equilibria. Nevertheless, using the equilibrium refinements, specifically intuitive criterion, introduced in [Cho and Kreps \(1987\)](#), and universal divinity, introduced in [Banks and Sobel \(1987\)](#), the unique outcome of the game becomes the least-cost separating equilibrium.

A.2. Computational appendix

I first discretize the state space of a household. The state space includes the beginning period asset level, $a \in A$, income level, $y \in Y$, mortgage interest rate, $r_m \in R$, current house price, $p_h \in P$, and the age of the household, $j \in \mathfrak{J} \equiv \{1, 2, \dots, J\}$. I solve the problem using backward induction since households have finite lifetime. The problem after retirement is simple and can be solved analytically since there is no uncertainty and housing choice after retirement. So, denote V_{J_r} as the value of a household at the time of retirement. In any other period before retirement, the household can be in one of the three different housing statuses: inactive renter, active renter, and homeowner. For a homeowner, the state space is $\theta \in \Theta_h \equiv A \times Y \times R \times P \times \mathfrak{J}$, and for an active and inactive renter the state space is $\theta \in \Theta_r \equiv A \times Y \times \mathfrak{J}$. Then starting from the period right before retirement, I solve the problem for each household, and I solve the continuation value of a mortgage held by a homeowner. That is, given the value functions at age j , I do the following:

1. Solve the problem of an inactive renter given by Eq. (1). This involves solving for optimal consumption and saving choices for a household who will stay as an active renter with probability δ , and as an inactive renter with probability $1 - \delta$.
2. Solve the problem of an active renter given by Eq. (4). This involves solving the problem of a renter given by Eq. (2) and a purchaser given by Eq. (3). For a renter, the problem is the same as an inactive renter except a renter in the next period stays as an active renter for sure. For a purchaser, the problem is more involved. I do the following:
 - (a) For each possible down payment fraction, solve the lender's problem to pin down the mortgage interest rate which gives zero profit to the lender. This is a fixed point problem given the continuation value of the contract. This gives me the menu of contracts offered to a particular individual. In a symmetric information economy, this problem is trivial as the lender can condition the continuation of the contract to the characteristics of the household. So, in the symmetric information economy, I use Eq. (14) to solve for the menu of the contracts. I explain the solution method for the asymmetric information economy later. This problem involves the calculation of the continuation value of the contract which is given by Eq. (13). I explain how to solve for this value function below.
 - (b) Given the menu of the contracts, I solve the household's choice of the contract which maximizes the welfare of the household.
 - (c) Then I compare the value of a purchaser and a renter to determine the housing tenure choice of an active renter, i.e., solve for Eq. (4).
3. Solve the problem of a homeowner given by Eq. (10). This involves solving the problem of stayer given by Eq. (5), seller given by Eq. (7), refinancer given by Eq. (6), and defaulter given by Eq. (8). I solve the household's problem for each choice. Notice that the solution to this problem also involves the solution of the continuation value of the contract. Each choice of the homeowner implies a mortgage payment to the lender. Then using Eq. (13), I can solve for the continuation value of the contract in each period.
4. After updating all value functions for the household and the continuation value of the mortgage contracts at age j , I set $j = j - 1$, and repeat the above steps.
5. The only difference for the solution in the asymmetric information economy is in the calculation of menu of contracts. Since the lender cannot condition the continuation value of the contract on the household, I proceed as follows:
 - (a) For the purchaser's problem, first I solve the purchaser's problem for the high-risk type given by Eq. (3). This will also result in a menu of mortgage contracts offered to the high-risk type, which are computed using Eq. (14).
 - (b) Then solve the problem of a low-risk purchaser. But now use Eq. (15) in the computation of the menu of the contracts. That is, discard all the mortgage contracts which give strictly higher utility to the high-risk household. The remaining mortgage contracts will specify the feasible contracts offered in the asymmetric information economy to the low-risk household.
6. After solving for the value functions and the corresponding policy functions, I simulate the economy starting from an initial distribution of wealth and income (I assume households start with zero wealth and median income) and compute the statistics of interest.

A.3. Innovations in information technology

There are three basic components of single-family mortgage underwriting: the value of the collateral, the ability of the borrower to make monthly mortgage payments, and the willingness of the borrower to pay back outstanding mortgage debt.

They are summarized as the traditional “three C’s” of Credit: Collateral, Capacity and Credit Reputation. The loan-to-value ratio is the measure of the collateral, which is basically measured by the down payment fraction and the real value of the house. Capacity is useful to understand the ability of the borrower to make the monthly mortgage payments and is measured through several economic variables regarding the home buyer such as debt-to-income ratio, debt-service ratio, employment status, and savings. Lastly, credit reputation shows both the ability and willingness of the borrower to pay back the debt and is assessed through a credit report summarizing the historical performance of the home buyer in the credit market.

Until the mid-1990s, credit reputation was the missing piece of the three C’s. Insufficient available credit data for individuals was the main reason for the absence of credit reports in mortgage underwriting. Unlike unsecured credit, mortgages are long-term contracts and larger amounts of loans are at-risk or fraudulent. Knowing the ability and willingness of the home buyer to make the periodic mortgage payments is the most important information for the lenders. The home buyer’s loyalty to the payments strongly depends on her credit history, which captures the historical performance of the individual in the credit market. Borrowers with poor credit records go into mortgage default at much higher rates than borrowers with good credit records. Since insufficient credit report data may be misleading, lenders hesitated to use the credit reports for a long time. [Straka \(2000\)](#) shows the relationship between credit scores and default rates using a 1995 assessment of a large sample of Freddie Mac loans which were originated between 1990 and 1991. The result shows that in a weak regional housing market, a mortgage holder with a credit score, measured as a FICO score, smaller than 620 is 17 times more likely to default than a mortgage holder with a credit score higher than 760. He also shows that even in a strong regional housing market, credit scores have a great predictability of mortgage default.²⁷

As the IT revolution has made computers part of our daily life, enabled data storage to become more efficient and less expensive, and allowed computer networking through local area networks and the internet, there has been an explosion in the growth of credit reports in the late 1980s and early 1990s.²⁸ As a result long-time dominant manual and decentralized underwriting and origination systems requiring labor and paper intensive loan processing and risk assessment have been rapidly replaced by automated and centralized underwriting systems based on credit scores, statistical model loan processing, and risk evaluations. Before 1995, negligible amount of mortgage lenders had been using automated underwriting systems. In 1995, Freddie Mac and Fannie Mae published industry letters that endorsed the use of credit scores to assess credit quality. In subsequent years, the mortgage industry experienced a growing adoption of automated underwriting systems which rely on credit scores and statistical models.²⁹

This transition has brought two innovations to the mortgage industry: usage of credit scoring and automation of the underwriting process. These innovations have increased the ability of the lenders to assess the credit risk of the home buyers. [Straka \(2000\)](#) documents the result of an experiment which compares the performance of manual –without credit scores– and automated –with credit scores– underwriting. A pool of one thousand mortgages were originated between 1993 and 1994, and they were evaluated both by manual and automated underwriting systems.³⁰ Although both underwriting systems chose half of the loans as investment-quality loans, the overlap was quite few. After three years, the performance of the loans was compared in four categories (share of the 30 days, 60 days, 90 days delinquent loans and foreclosed loans) and the results were striking. While the investment quality loans determined by the automated underwriting system performed quite better than the non-investment quality loans, there was essentially no difference between the investment and the non-investment quality loans determined by the manual underwriting in terms of delinquency rates. The results were quite remarkable especially in terms of the foreclosure rates. Non-investment quality loans ended up in foreclosure eight times more than the investment quality loans according to the automated underwriting system selection. However, according to the manual underwriting selection, the investment quality loans ended up in foreclosure seventeen times more than the non-investment quality loans.³¹

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²⁷ See also [Pennington-Cross \(2003\)](#), [Cutts and Green \(2004\)](#) and [Barakova et al. \(2003\)](#) for further evidence of predictive power of credit scores in mortgage repayment and default.

²⁸ See [Hunt \(2005\)](#) on the evolution of consumer credit reports and [LaCour-Little \(2000\)](#) and [Pafenberg \(2004\)](#) for the adoption of credit reporting in the mortgage industry.

²⁹ According to [Pafenberg \(2004\)](#), among the loans Freddie Mac and Fannie Mae purchased from enterprises, the percentage of mortgages evaluated using automated underwriting systems by the enterprises prior to the purchase increased from 10% to 60% between 1997 and 2002.

³⁰ [Straka \(2000\)](#) notes that the assessment of all mortgages through manual underwriting lasted six months while through automated underwriting it lasted only a couple of hours.

³¹ [Gates et al. \(2002\)](#) also provide a comparison of manual and automated underwriting systems. They also show how automated underwriting outperforms manual underwriting in terms of predicting delinquency and foreclosure.

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