Time Preferences and Mortgage Default

Yongheng Deng
Institute of Real Estate Studies
NUS Business School,
and School of Design and Environment
National University of Singapore
ydeng@nus.edu.sg

Jia He
Institute of Real Estate Studies
Department of Real Estate
National University of Singapore
hejia@nus.edu.sg

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Abstract

Recent financial crisis calls for a better understanding of the increasing mortgage defaults and corresponding foreclosures. Previous studies using option-based mortgage default models predict that borrowers should exercise the default option immediately whenever the market value of the mortgage exceeds the value of the underlying property. However, empirical evidence shows that a substantial number of borrowers are less likely to default as 'ruthlessly' as the option theory predicts. Why some borrowers do not terminate their mortgages even when their option is deeply in the money? There are copious empirical works try to illustrate and explain this phenomenon. The underlying stories emphasize that transaction costs resulting from default are pervasive and significant.

This paper presents an alternative theoretical model to analyze this irrational default behaviour and support these existing empirical works theoretically. It has been documented that implicit or explicit transaction costs have played important role in borrowers' default decision. We hypothesize that borrowers' time preferences for the contingent costs are heterogeneous. As a result, borrowers with present-biased preference can overweigh the immediate costs coupled with their default decision, and they may procrastinate in their decision of default. Under extreme circumstances, some present-biased borrowers may never default during the life of their mortgage contract. The empirical results strongly support the importance of time preference in explaining heterogeneous mortgage default behaviour. Borrowers' heterogeneous time preferences for the contingent costs of default may help to better understand mortgage default behaviour, and will assist in the creation of better policies to deal with the issue of foreclosure crisis, such as mortgage modification and mortgage contract design.

Key words: Mortgage default, heterogeneity, present-biased preference, borrower's behaviour, transaction costs
JEL Codes: D1, D9, G1, R2

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1. Introduction

The financial crisis of 2008 triggered by the stunning rise of subprime mortgage delinquencies forces people to reconsider mortgage defaults and foreclosures. In the past five years, millions of homeowners in the United States were "walking away" and letting their homes to be foreclosed. Moreover, according to the negative equity report from CoreLogic, there were 11.1 million residential properties with a mortgage in negative equity situation and at the risk of foreclosure by the end of the fourth quarter of 2011.[1] This negative home equity situation is known as the mortgage value exceeds the underlying property value, and mortgages are "underwater". Table 1 shows the negative equity and near negative equity distributions of the top ten states in United States. Nevada had the highest percentage with 56.9% mortgage borrowers were in negative equity position and 5.3% borrowers were in the position of near negative equity.[2] Followed by Florida, there were 42.1% borrowers in negative equity position. Other states, such as Arizona, Georgia, Michigan and California also appeared as the high negative equity share states.

Insert Table 1 about here

Unlike simply "walking away" and default concerned by most people during this financial crisis, vast of underwater homeowners still continue to make their mortgage payments. This leads us to wonder why some homeowners choose to default on their mortgages while others do not when facing the negative equity condition.

Insert Figure 1 about here

Pioneered by Asay (1978), there was a quick expansion of studies on mortgage valuation and borrower behaviour based on the contingent claims models, mainly developed by Black and Scholes (1973), Merton (1973a), Cox, Ingersoll and Ross (1985). The contingent claims model provides a useful framework for analysing

[1] http://www.corelogic.com/about-us/news/corelogic-reports-negative-equity-increase-in-q4-2011.aspx Accessed on March 15, 2012.

[2] Negative equity is often used to refer to as "underwater" or "upside down," which means the borrower owes more on their mortgage than the home is worth. In other word, the borrowers' mortgage value exceeds the property value. Near negative equity is when mortgages are within five percent of being in a negative equity position, which is defined by CoreLogic. Negative equity can occur because of a decline in property value, an increase in mortgage debt or a combination of both.

borrowers' behaviour, in which prepayment is treated as an American call option and default as a compound put option. The "pure" option-theoretic mortgage pricing models assume that well-informed borrower will default immediately when the mortgage value exceeds the property value at any time during the loan term (see Titman and Torous (1989) and Kau, Keenan, and Kim (1994)). These models build on perfectly competitive market without any transaction cost or reputation cost, and with no exogenous reason for residential mobility. Nevertheless, frictionless market is just an ideal assumption, negative equity may be a necessary condition to trigger default, but not a sufficient one (see Vandell (1995), Deng, et al. (2000), and Bajari et al. (2008)). Evidence shows that a substantial number of borrowers are less likely to default as 'ruthlessly' as the option theory predicts. White (2010b) argued that not all the homeowners who were underwater on their mortgage walking away from their home immediately during this financial crisis, including those who lived in "nonrecourse states", such as California and Arizona.[3] Although such behaviour may appear irrational on its face, these homeowners all struggle with the same decision: to continue paying their mortgage or not.

Virtually, in the option-based framework, there are substantial empirical works try to illustrate and explain this irrational phenomenon. The underlying stories emphasize that transaction costs resulting from default are pervasive and significant (e.g., see Stanton (1995), Harding (1997), Archer, Ling, and McGill (1996)).[4] They assume that transaction costs are sufficiently high to force homeowner to leave home, including moving costs, reputational issues, or default penalties, and so on. In addition to the economic consideration of transaction costs, recent attention has been paid on the emotional constraints to strategic default. Guiso, Sapienza, and Zingales (2009) using survey data documented that social and moral considerations may partially play a role to explain the willingness of homeowners continue to pay their underwater mortgages. White (2010b) also argued that shame or guilt associated with foreclosure and fear over the perceived consequences of foreclosure led those underwater homeowners choose not to default.

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[3]In these non-recourse states, lenders cannot pursue defaulting homeowners for a deficiency judgment. The lender may compensate some of its loss through foreclosure. However, the lender may not sue the borrower for additional funds. If the foreclosure sale does not generate enough money to satisfy the loan, the lender must accept the loss.

[4]For an explicit discussion about the transaction costs, see Kau, Keenan, and Kim (1993).

The role of transaction costs is important in determining the exercise of both default and prepayment options. What cause those default borrowers accept the economic and emotional transaction costs accompanied with their default decision? The empirical heterogeneity of mortgage borrowers is discussed extensively in the literature. Deng et al. (2000) assumed that there were discrete groups of heterogeneous agents. Hall (2000) assumed that distributions of agents with different underlying hazards were mixed. In addition, Stanton (1995, 1996) and others specified heterogeneity among mortgage pools. But theoretically, the unobserved heterogeneity is still a black box attracting much attention. There is no uniform theoretical framework to explain how the transaction costs and unobserved heterogeneity affect borrowers' default decision.

This paper presents an alternative theoretical model to analyse the irrational default behaviour. The model is built upon behavioural economics, and being applied to study borrower's heterogeneous default behaviour after modifying. In this model, borrowers' time preferences for the contingent costs are hypothesized as heterogeneous across individuals. There are two kinds of time preferences with corresponding discounting factors for borrowers: present-biased preference (quasi-hyperbolic discounting) and time-consistence preference (standard exponential discounting). The key distinction between these two is the presence and absence of a "present bias". Facing potential significant transaction costs coupled with default decision immediately, borrowers with present-biased preference may overweigh the immediate costs, such as moving costs, moral and social costs etc. Therefore, they tend to be postposed on their default decision because of their present-biased preference. For borrowers with time-consistence preference, they choose to default on their mortgage earlier than those with present-biased preference.

Based up individual loan-level mortgage data principally collected by BlackBox Logic (BBL) and survey data of 'Behavioural Risk Factor Surveillance System (BRFSS)' developed by the Centers for Disease Control and Prevention, the empirical analysis employs Cox proportional hazard model to examine borrower's heterogeneity default decision. The results indicate that option theory is still significant and important in explaining borrowers' mortgage default decisions, but it is inadequate by itself. Borrowers may not default when their option is 'in the money', and which should be extended. Secondly, the behavioural correlates of the unobserved heterogeneity of individual borrowers which can be observed in the data are quite important in accounting for borrower heterogeneity default behaviour. In Deng and Quigley (2002), these correlates are named as 'woodheads' factors. Consistent with them, the woodheads factor offers advantage in precision in comparison with conventional variables. Thirdly, after adding proxies of time preference, regression results indicate that borrowers' different time preferences play important role in explaining heterogeneous default decisions. Borrowers with present-biased preference tend to delay their default decision and have a lower default probability.

The rest of this paper is organized as follows: in section 2, following the original work of Phelps and Pollak (1968) (later employed by Laibson (1994, 1996, 1997) and other papers), a typical form of present-biased preference (i.e., quasi-hyperbolic) is simply presented; The conceptual theoretical framework is shown in section 3; section 4 outlines and describes the data used for this paper, and also the empirical methodology; based upon the theoretical framework have developed in section 3, section 5 empirically discusses default behaviour using Cox proportional hazard model; section 6 concludes this paper; appendixes of this paper present proof of the theoretical framework and introduction of the survey data of Behavioural Risk Factor Surveillance System (BRFSS).

2. Present-Biased Preferences

The traditional economic inter-temporal preference models have been able to capture the fact that agents are impatient by using exponential discounting. This approach explicitly assumes that preferences are inter-temporally consistent. Different with the standard economic assumption, considering trade-offs between two future moments, people with present-biased preference tend to give stronger relative weight to the earlier future moment as it gets closer, and their inter-temporal preference are time inconsistent (O' Donoghue and Rabin (1999a)). One method to model Present-Biased preferences called "quasi-hyperbolic discounting" or "(β, δ)-preferences" which is originally developed by Phelps and Pollak (1968), later employed by Laibson (1994, 1996, 1997) to capture self-control problems within an individual, and O' Donoghue and Rabin (1999a, 1999b, 1999c, 2001), Fischer (1999), Carrillo (1999), and others. This method has been widely utilized in literature and also being employed throughout this paper.

Let u_t be the instantaneous utility the borrower gets in period t, and $U(u_t, u_{t+1}, u_{t+2}, \dots, u_T)$ be the borrowers' inter-temporal preference function from the perspective of period t. Borrowers are assumed has quasi-hyperbolic preference. Time is divided into two periods: the present period (t) and all future period (begins from t+1 to T). Borrowers with present-biased preference, their inter-temporal preference function can be expressed as:

$$(1) U(u_t, u_{t+1}, u_{t+2}, \dots, u_T) = \delta^t u_t + \beta \sum_{\tau=t+1}^{T} \delta^\tau u_\tau \quad \text{for } t \in [1, T];\ 0 < \delta \le 1;\ 0 < \beta \le 1$$

As in the standard exponential discounting model, the parameter δ represents the "time-consistent" long-run discounting factor. In this inter-temporal preference model, an additional parameter β is added into the standard time-consistent model for the future period to capture an individual's "bias for the present" – how the agent favours now over all future periods. There are two types β: $\beta = 1$ and $0 < \beta < 1$. For $\beta = 1$,

$$(2) \qquad U(u_t, u_{t+1}, u_{t+2}, \dots, u_T) = \sum_{\tau=t}^{T} \delta^\tau u_\tau,$$

The inter-temporal preference function reduces to standard exponential discounting utility function with time-consistent inter-temporal preference (the discrete version). Under this time preference, borrowers treat the present period and all future period as the same. For $0 < \beta < 1$,

$$(3) \qquad U(u_t, u_{t+1}, u_{t+2}, \dots, u_T) = \delta^t u_t + \beta \sum_{\tau=t+1}^{T} \delta^\tau u_\tau$$

This function parsimoniously captures the present-biased preference, and greater weight is assigned to the present relative to the future. The β-parameter in this model thus fully captures the dynamic-inconsistency suggested by present-biased preference (O' Dognohue and Rabin (1999)). For simplicity, without loss of generality, δ is assumed equals to 1 in this paper, eliminating the long-term discounting.

3. Theoretical Framework

3.1 Model Set Up

Building upon the model of 401(k) enrollment of Carroll et al. (2009), this paper modifies and models the decision of default as the result of a dynamic optimization problem in which individual borrower decides whether to incur the cost of default today or at some future date. Borrowers has quasi-hyperbolic preferences, so they have the discount function 1, β, β, … where $0 < \beta \leq 1$.

Assumption is made that there is no adverse transitory income events have happened for the borrowers and they have the ability to pay the mortgage.[5] Consider a homeowner whose property value drop below the mortgage value at the beginning of period t. From the period t and after, homeowner indexed by i has opportunity to default on his mortgage. Should he act, he incurs a stochastic transaction cost C_τ^i which is drawn from a uniform distribution on the interval $[\underline{C}, \bar{C}]$, where $\underline{C} < \bar{C}$ and $\tau \geq t$.[6] This transaction cost of default is determined at the beginning of the period and this is known to the homeowner at the time of his decision (it assumes that costs are independent across period, then C_τ^i at each period is i.i.d.). After each period in which homeowner choose to continue to pay the mortgage, however, he faces a flow loss L, which equals to the monthly payment to stay at this negative equity situation at the next period.[7] It assumes that homeowner incurs this cost at the beginning of the next period without loss of generality. The decision process and related cost correspond to this decision at the period τ are presented in Figure 2.

Insert Figure 2 about here

At period τ-1, borrower chooses not to default, and continue to pay his underwater mortgage. This decision leads he should pay a flow loss L at the beginning of period τ to stay at this negative equity situation, where L equals to the monthly payment. At period τ, he faces the embarrassing situation similar with in period τ-1: default or not.

[5]Exclude the exogenous reason to default.

[6] This assumption tries to capture some characteristics of mortgage default: firstly, transaction costs of default are various across time. For example, one important part of the moving cost after default is that borrower should find a new house (rent or buy). The time costs spending on searching a new house depend on the rental market or housing market, which is stochastic. Moreover, the opportunity cost of time spending on searching new house is also stochastic. Take another instance, after default, as well as find a new house, borrower may need to live in the hotel. Daily price of the hotel are not the same but stochastic. The same is with moving kids from schools, etc. Secondly, the cost of default in the future is less certain than the cost of cashing in the present.

[7] If borrowers do not choose to default on their mortgages, they should continue to make their monthly mortgage payment to mortgage lenders. For FRM, the monthly payment is fixed from the perspective of a single borrower. For ARM, the difference between monthly payments is very small. Therefore, we simplify notation by temporarily defining L is fixed.

Should he act, he incurs a stochastic transaction cost C_τ^i accompanied with default, should not act, the same process of period τ is repeated in the next period τ+1.

The borrower's decision of default takes the form of a "cut-off rule". Borrowers default if and only if the stochastic cost C_τ^i below some optimal cost C^*. Otherwise, he will continue to pay the "underwater" mortgage, and pay the flow cost L. The strategy in each period is to determine a cut-off point C^* whereby the borrowers is indifferent between default and not default. Next, strategies for time-consistence borrowers and present-biased borrowers are presented.

3.2 Model Overview

Denote the borrower's current discounted loss function as W, and borrower attempts to minimize it. Thus,

$$\text{(4)} \qquad W\,(L, C) = \begin{cases} C_\tau^i & \text{if default at } \tau \\ \beta\left[L + E\left[\omega\left(L, C_{\tau+1}^i\right)\right]\right] & \text{if not default at } \tau \end{cases}$$

where L is the monthly payment. At period τ, borrower decide whether or not to default according to the "cut-off rule". If choose to default, he will pay the cost C_τ^i. If not default at period τ, he will make the decision in the next period, and the discounted loss is the flow cost and expected discounted loss in the future. The function $\omega(.)$ represents the borrower's current perception of future loss when, having not default at the end of this period, he faces the same decision in next period. Then,

$$\text{(5)} \qquad \omega\left(L, C_{\tau+1}^i\right) = \begin{cases} C_{\tau+1}^i & \text{if default at } \tau+1 \\ L + E\left[\omega\left(L, C_{\tau+2}^i\right)\right] & \text{if not default at } \tau+1 \end{cases}$$

At each period, borrower views trade-off between the current period and future period differently, and the future periods is viewed as a result of the quasi-hyperbolic discounting. At the cut-off point, he should be indifferent in the current period (but not in perceived future period) between default or not. [8] Thus,

[8] A crucial insight under the present-biased preference is the distinction between naïve and sophisticated individuals. Sophisticated are fully aware of their future self-control problems, and exactly know what her future selves' preference even though her future preferences differ from those of the current self. By contrast, not anticipating her future procrastination, naifs

(6) $$C_p^* = \beta\left[L + E\left[\omega\left(C_p^*, L, C_{\tau+1}^i\right)\right]\right]$$

Where

(7) $$\omega\left(C_p^*, L, C_{\tau+1}^i\right) = \begin{cases} C_{\tau+1}^i & \text{if } C_{\tau+1}^i < C^* \\ L + E_{+1}\left[\omega\left(C_p^*, L, C_{\tau+2}^i\right)\right] & \text{if } C_{\tau+1}^i > C^* \end{cases}$$

If the cost of default at each period is less or equal to the optimal cost C_p^*, then borrower chooses to default. Otherwise, borrower chooses to stay at the "underwater" situation and continue to make mortgage payment. The optimal point C_p^* can be solved, and the optimal cutoff point for present-biased borrowers can be expressed as:

(8) $$C_p^* = \frac{\underline{C} + \sqrt{\underline{C}^2(1 - (2 - \beta)\beta) + 4\beta\left(1 - \frac{\beta}{2}\right)\left(\overline{C} - \underline{C}\right)L}}{2 - \beta}$$

Although the expression of this function is complex mathematically, it is quite intuitive. Firstly, C_p^* is increasing in L, the flow cost for not default. The positive relationship indicates that the more flow cost needed to pay in next period (monthly payment of the mortgage), the more willing borrower to incur the cost of default. Furthermore, C_p^* is increasing in β, the hyperbolic discounting factor. As borrower becomes less patient (β near to 0), he is less willing to incur the transaction costs to reduce all the future flow cost. If β infinitely approaches to 0, thenthe criterion C_p^* becomes very small. It is nearly impossible to find a C_τ^i smaller than C_p^* under the "cut-off rule". Then borrowers are less likely to choose default decision.

For time-consistence borrowers (TCs), they view the current period and future period as the same. Let β equals to 1 for the present-biased borrowers' optimal cut-off level, then the optimal default cut-off point for TCs are:

(9) $$C^* = \underline{C} + \sqrt{2\left(\overline{C} - \underline{C}\right)L}$$

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are fully unaware of their future self-control problems, and believe their future preferences will be identical to their current preferences. This false belief induces them to act at the later date, even when their current cost of acting is very low. Under the same preference, the sophisticated people do the activity sooner than do a naïve people (O'Donoghue and Rabin (1999a)). In this model, all borrowers are assumed as sophisticated, and there is no distinction between sophisticate and naïfs.

$C^*$is also increasing in L. As same with the present-biased borrowers, the more flow cost needed to pay in next period (monthly payment of the mortgage), the more willing of time-consistence borrower to incur the cost of default

Using the optimal cut-off point of time-consistence and present-biased borrowers, their expected delay time on default decision can be calculated. After comparing these two kinds of borrowers, we have:

$$\mathrm{E_P}(\mathrm{delay}) > E(\mathrm{delay}) \tag{10}$$

where $\mathrm{E_P}(\mathrm{delay})$ is the delay time of present-biased borrowers, and $\mathrm{E}(\mathrm{delay})$ is the delay time of time-consistence borrowers.

Proof. See Appendix.

Figure 3 shows the timing of default for borrowers with different time preferences which are derived from the theoretical model. The 'Negative equity point' is the time point that borrowers' house value firstly drop below the mortgage amount they owned. After this point, mortgage with negative equity situation is "underwater" and borrowers face the decision to default or not at each period. The 'Ruthless default point' is the defaul point predicted by pure option theoretical model that the well-informed borrower will default immediately when the mortgage value exceeds the property value at any time during the loan term. The 'TCs default point' is the default time point for borrowers with time-consitance preference. It is a littler later than 'Ruthless default point' becasue of existance of transaction costs. The 'Present-Biased borrower's default and procrastination' is the default time for borrower with present-biased preference. It follows 'TCs default point'.

Insert Figure 3 about here

Compared the default sequence under both time-consistence preference and present-biased preference derived from the theoretical model, it can be seen that default decision under present-biased preference is later than the decision under time-consistence preference. The later action of borrowers with present-biased preference can be referred as default procrastination of present-biased preference. For borrowers with present-biased preference, the default costs of current period are greater than the future in their view since they put more weight to current period. These borrowers tend to delay the default decision till next period. But in the next period, they may do the same decision as current period and delay the default decision again. Under extreme situation, some present-biased borrowers may never default on their mortgage during the mortgage term, even their mortgage is deeply ‘underwater’.

4. Empirical Methodology

4.1 Empirical Model

The default probability estimated in this paper is a Cox proportional hazard model by incorporating the proxies of time preference into the default hazard function:

$$(11) \qquad h_i(T;\, X_i) = h_0(T)exp(O_i'\delta + X_i'\beta + W_i{}'\mu + TP_i'\gamma)$$

Here $h_0(T)$ is the baseline hazard function, which only depends on the loan age (duration), T, of the mortgage and is an arbitrary function that allows for a flexible default pattern over time[9]; O_i' is time varying option-based vector that include both default and prepayment option premium; X_{it} is a vector of non-option related variables that include FICO score, combine loan to value ratio, original loan balance and unemployment rate. W_i' is the woodheads factor defined following Deng and Quigly (2002), which are some correlates of unobserved heterogeneity of individual borrowers that can be observed in the data. TP_i' is the proxy of time preference. The hazard model is estimated with Maximum Likelihood Estimation (MLE) method using the event-history data[10].

4.2 Data Sources

There are two main sources of data used in this paper: individual loan-level mortgage data furnished by BlackBox Logic (BBL) and selected metropolitan areas survey data of Behavioural Risk Factor Surveillance System (BRFSS) developed by the Centers for Disease Control and Prevention.[11]

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[9] Notice that the loan live duration time T is different from the natural time t, which allows identification of the model.

[10] See Kalbfleisch and Prentice (2002) for details about the MLE estimation of the hazard model.

[11] For more information about BRFSS, go to http://apps.nccd.cdc.gov/brfss-smart/index.asp

BlackBox Logic (BBL) is a private company that provides a comprehensive, dynamic dataset with information about twenty-one million privately securitized subprime, Alt-A, and Prime loans of United States. These loans account for about ninety percent of all privately securitized mortgages from that period. The BlackBox data, which are obtained from mortgage services and securitization trustees include static information taken at the time of mortgage origination, such as mortgage contract date, original loan amount, the initial loan-to-value ratio, borrowers' FICO credit score, mortgage service name, mortgage contract interest rate, mortgage term, interest rate type, the state, the region, and the major metropolitan area in which the property is located. In addition, the BlackBox data also include dynamic data on monthly payments, mortgage balances, current loan to value ratio, and delinquency status.

The analysis in this paper is confined to mortgage loans issued between 2002 and 2011 for owner occupancy, and includes those loans that were either closed or still active at the fourth quarter of 2011. The analysis is confined to fix-rate loans issued in 65 major metropolitan areas (MSAs). From the quarter of origination through the quarter of termination, maturation, or censor time 2011 quarter 4, loans are observed at each quarter. After removing mortgages with incomplete information on LTV ratio and other key information, the final sample includes 461,282 individual mortgages with 7,500,019 quarterly payment events.

The second database used in this paper is the 'Behavioral Risk Factor Surveillance System' developed by the Centers for Disease Control and Prevention. There is one specific project named 'The Selected Metropolitan/Micropolitan Area Risk Trends (SMART)', which uses the Behavioral Risk Factor Surveillance System (BRFSS) survey data to analyze the data of selected metropolitan and micropolitan statistical areas (MMSAs) with 500 or more respondents. In this project, several factors related behavioural risk and health risk have been listed out for selected Metropolitan/Micropolitan Areas from 2002 to 2011. In this paper, two popular variables related with people's time preference which have been studied extensively in the literature in the database are selected as the proxies of time preference, and section 4.4 gives a detailed introduction of these proxies. Finally, a panel data is created for 65 metropolitan areas from 2002 to 2011.

4.3 Data Description: Loan Level

Table 2 shows the basic descriptive statistics of the individual loan-level sample used in this analysis.

Insert Table 2 about here

As shown in Panel A of Table 2, the mean value of LTV ratio at origination is slightly greater than 81%, and the corresponding interest rate is 7.0576%. The average loan age in the sample is greater than 4 years (age=16 quarters). In Panel B, sample is described by termination status with 32.19% terminate with default and 35.28% terminate with prepayment. When stratified by property type in Panel C, single-family is shown to dominate the sample, constituting nearly 75% of the sample. Default rate of PUD and Single Family are similar. For Condo loans, the default rate is obviously lower than other two property types.

Figure 4 shows the origination rate and default rate by origination year. In terms of loans origination, the most loans are issued in 2006 with 29.55% of total sample. After the burst of financial crisis, there were very fewer loans have been issued. For the default rate, it can be seen that there is a sharp growth of default rate for loan originated between 2003 and 2007. At 2007, the default rate of loans originated in this year reach the peak value with nearly 44% of total sample. Mortgage originated between 2007 and 2009, the breaking point of financial crisis, their default rate began to decrease. For loans originated between 2010 and 2011, the default rate is nearly 0. This maybe because that underwriting standards to issue loans have been improved after the financial crisis and fewer loans are issued during this period.

Insert Figure 4 about here

Following Deng, Quigley and Van Order (2000), the "put option" and "call option" related variables are included as the key variables into the estimation. The "call option" reflects borrowers' prepayment risk on mortgage, which is calculated as the ratio of the present discounted value of the unpaid mortgage balance at the contract interest rate relative to the value discounted at the current market mortgage rate.[12] Option theory indicates that, if the "put option" is "in the money", borrowers default ruthlessly. Then the put option can be defined as the probability of negative equity.[13] The squared terms of option variables are also be calculated and added into the model. Unemployment rate by state is included as a proxy for "trigger event".[14] Table 3 presents the descriptive statistics of mean and standard deviations of some explanatory variables measured at both origination and termination with default of the all individual loans in the sample.

Insert Table 3 about here

The mean value of the prepayment option, "Call Option", is "out of money" when mortgage is originated, but is "in the money" when terminated for both all loans and default loans. The mean value of put option for all loans is lower than defaulted loans both at origination and termination. Moreover, both the mean value of put option for all loans and defaulted loans growth nearly two times from origination to termination (from 0.1162 to 0.2270 and from 0.1427 to 0.2633). The original LTV ratio of defaulted loans is higher than the whole sample, which supports that higher LTV ratio is related with higher probability of default. Borrower's Fico Score of default loans are lower than the whole sample, which supports that borrowers with lower Fico

[12] The "call option" can be defined as: $\mathrm{CALL\_OPTION} = \frac{V_{i,mj,\tau_{i+k_i}} - V^*_{i,r_i}}{V_{i,mj,\tau_{i+k_i}}}$, and $V_{i,mj,\tau_{i+k_i}} = \sum_{t=1}^{TM_i - k_i} \frac{1}{\left(1+m_{j,\tau_{i+k_i}}\right)^t}$, $V^*_{i,r_i} = \sum_{t=1}^{TM_i - k_i} \frac{1}{(1+r_i)^t}$, where TM_i is the term of the mortgage, r_i is the mortgage note rate, j indicates the local region, $m_{j,\tau_{i+k_i}}$ is the market interest rate and k is the quarter after origination.

[13] Following Deng, Quigley and Van Order (2000), "put option" is defined as: $\mathrm{PUT\_OPTION} = \Phi\left(\frac{\log\left(V^*_{i,r_i}\right) - \log(M_{i,k_i})}{\sqrt{\omega^2}}\right)$, where $\Phi(.)$ is the standard normal cumulative distribution function, V^*_{i,r_i} is the current outstanding loan balance and M_{i,k_i} is the current market value of property i. Current outstanding loan balance is calculated using the current interest rate and monthly payment which are obtained from the database. The current market value is calculated as: $M_{i,k_i} = \frac{ORIBAL}{LTV} \times \frac{H_t}{H_0}$ with LTV is the original loan-to-value ratio which is indicated in the database, H_t is the FHFA housing index and ω^2 is the variance of the FHFA housing index.

[14] Deng, Quigley and Van Order (2000) using both unemployment and divorce rate as proxies of trigger events. For California, there is no divorce rate data in the National Bureau of Statistics of US, so this paper just includes unemployment rate as the proxy of trigger events.

Score are easier to default. Finally, at termination the unemployment rate is lower than at origination.

Table 4 presents the means and standard deviations of the explanatory variables measured at the termination of the mortgage loans, separate by Combined LTV (CLTV) ratio groups. The differences in the value of put option across CLTV groups are significant, which means higher CLTV ratio is associated with higher probability of negative equity at the termination. The put option value of the highest CLTV group is nearly ten times greater than the lowest CLTV group (0.0570 for CLTV=<70 and 0.4954 for CLTV>97). However, differences of the values of call option across CLTV categories are insignificant. For the unemployment rate and Fico Score, there are no obvious trends across different CLTV groups.

Insert Table 4 about here

In the mortgage market, some correlates of borrowers' unobserved heterogeneity of individual borrowers are observed from the data (see Deng and Quigly (2002)). In this paper, this information of unobserved heterogeneity among mortgage borrowers is also calculated. The correlate of unobserved heterogeneity (i.e., M) is calculated as: at each quarter, whether the put option is in the money is examined, then the frequency of in the money put option (this indicates that the house value is lower than the mortgage amount owned by borrower) was not exercised of each borrower since origination is computed. In Deng and Quigley (2002), M is named as 'woodheads factor', which being used to describe that borrowers systemically pass up profitable prepayment opportunities. In this paper, this correlate is also called as 'woodheads factor'. By adding the correlate M, the hazard model used in this essay does not depend upon information obtained only after the borrowers make a terminate decision, but also the information revealed by the earlier behaviour of borrowers holding mortgage contract. In this step, calculating M treats borrowers' transaction costs as observationally equivalent.

Table 5 summarized information of M of the sample separately for mortgage loans and mortgage payment events. Panel A shows distribution of M by mortgage loans, separately for the full sample and for different seasoned mortgage pools.[15] It can be seen that, nearly 28% mortgage loans in the sample have missed at least one time opportunity to exercise their in the money put option. About 30% of borrowers in the five years seasoned pools have missed at least one opportunity. About 3.13% of borrowers in the two years seasoned pools have missed more than twelve opportunities, and for five years seasoned pools, this percentage is larger, 3.24% The results for the payment events listed in the Panel B are calculated similarly with Panel A. Nearly 30% payment events in the sample missed at least one time opportunity to exercise their in the money put option.

Insert Table 5 about here

Figure 5 presents the cumulative frequency of M among mortgage loans of full sample and different pools. It indicates that more seasoned mortgages are associated with more numbers of missed opportunities to exercise the in the money put options. This is consistence with Deng and Quigley (2002), where they have indicated that borrowers with more seasoned mortgages are more likely to miss a profitable opportunity to exercise prepayment options, and larger missed numbers are likely associated with more seasoned mortgage pools.

Insert Figure 5 about here

4.4 Data Description: Proxies of Time Preference

Time preference is frequently referred as “the preference for immediate utility over delayed utility” (Frederick et al. (2002)). Thus, time preference affects individuals’ time-allocation decisions over a lifetime such as investments in education and training (Mincer (1974) and Becker (1975)). Time preference also affects individuals’ investments in health because health-enhancing activities involve incurring current costs for the sake of future benefits, and individuals differ in their time preference that will induce them to undertake such investments (Fuchs (1979)). Except the health, there are many researchers have investigated that the consumption of harmful

[15] The two year seasoned pool is a sub-sample of mortgage loans whose durations are greater than two years. The three and five years seasoned pools also have the similar intuition, meaning the sub-sample of mortgage loans with durations greater than three years or five years. As indicated in Deng and Quigley (2002), full sample may be interpreted as a pool containing newly issued mortgage loans, like duration year bigger than 0 but smaller than 2.

addictive products, such as cigarettes also related with people's time preference (see Becker and Murphy (1988) and Donoghue and Rabin (2002)). In this paper, two popular and different proxies of time preference which have been documented extensively in the literature are selected: exercise rate and smoking rate.

a) Exercise Rate

The relationship between time preference and exercise has been studies extensively in both the economics and psychology literature (see Grossman (1972), Fuchs (1986, 1991), Ehrlich and Chuma (1990) etc.). Exercise requires the expenditure of time (with its associated opportunity costs) and effort today for the sake of potential future health benefits. Exercise may also require monetary investment (e.g. joining a health club). Taken together, for people discounting future utility heavily[16] (more present-biased) will, *ceteris paribus*, have less investment in exercise.

Based on this, the null hypothesis between exercise rate and mortgage default is that, small exercise rate corresponds to less or delayed default. For those exercise more, they do not discount future utility very much, and will choose to default earlier when facing the negative equity situation.

b) Smoking Rate

Similarly with exercise, losts of researchs have been done for studying the relationship between smoking and time preference (see Mitchell (1999), Odum, Madden, and Bickel (2002), Khwaja, Silverman, and Sloan (2006)). In both the economics and psychology literature on time preference and smoking suggests that measures of smoking behavior are not a simple proxy for the constant discount rate, but still, based on the multiple-motive to intertemporal choice, a strong indicator of individuals' time preference (Becker et al. (1994), Chesson and Viscusi (2000), Baker et al. (2003)). Current smokers have stronger preference for immediate utility over delayed utility than never smokers, and they have present-biased preference.[17] Therefore, the null hypothesis between smoking rate and mortgage default is that:

[16] For people discounting future utility heavily, they have a lower β:
$U(u_t, u_{t+1}, u_{t+2}, \dots, u_T) = \delta^t u_t + \beta \sum_{\tau=t+1}^{T} \delta^\tau u_\tau$, then they are more presented-biased.
[17] For smoking people, they have a lower β:
$U(u_t, u_{t+1}, u_{t+2}, \dots, u_T) = \delta^t u_t + \beta \sum_{\tau=t+1}^{T} \delta^\tau u_\tau$, then they are more presented-biased.

current higher smoking rate (with present-biased preference or more present-biased) corresponds to less or delayed default.

In the BRFSS database, data of ‘exercise rate’ and ‘current smoking rate’ in 65 selected metropolitan areas are available from 2002 to 2011.[18] A panel dataset is created for ‘exercise rate’ and ‘current smoking rate’ of these 65 metropolitan areas from 2002 to 2011. Table 6 shows the descriptive statistics of mean and standard deviations of exercise rate and smoking rate measured at both origination and termination with defaulted and all individual loans in the sample. At origination, the exercise rate for all loans is a little higher than exercise rate for default loans. However, the exercise rate for all loans is lower than default loans at termination. Smoking rate of default loans is lower than smoking rate for all loans at both origination and termination.

Insert Table 6 about here

Figure 6 compares the trends between average exercise rate, average smoking rate and default rate by year. The expected relationship between exercise rate and default rate should be positive. From Panel A, it can be seen that there is no clear relationship between average exercise rate and default rate before 2008. However, starting from 2008, the average exercise rate has a similar trend to default rate. The expected relationship between smoking rate and default rate should be negative. Remarkably, the trend between average smoking rate and default rate are the exact opposite which can been seen from Panel B.

Insert Figure 6 about here

5 Empirical Results

5.1 Time Preferences and Mortgage Default

To conduct empirical analysis, information for each loans in the sample are restructured to include one observation for each quarter from origination to the period of termination or censor.

[18] The detailed introduction about these two variables in the BRFSS database is shown in appendix 2.

Table 7 presents the maximum likelihood estimates of the parameters. Except the measures of financial value of the prepayment and default option, their squared terms are also included into the model. In addition, the combined LTV category and borrower FICO score category are also included. The unemployment rate is included as trigger event.

Insert Table 7 about here

Model 1 in Table 7 extends the "ruthless" default model predicted by option theory by adding LTV ratio categories, logarithm original loan amount, borrower FICO score categories and unemployment rate. The results show that financial motivations are still important in generating borrower's default decision with the parameter of put option is positive and significant. In addition, the default decision may be driven by other events. For example, the parameters of LTV ratio categories are positive for all LTV categories in the sample, suggesting that borrowers with higher LTV ratios are more likely to exercise their put option. This is consistence with the asymmetric information argued by some research, that risky borrowers tend to choose higher LTV loans (see Yezer, Philips, and Trost (1994) and Deng, Quigley, and Van Order (2000)). In addition, results also indicate that borrowers with higher FICO score are less likely to default on their mortgages. The impact of unemployment rate on default hazard is positive and significant, which suggests that trigger events are important in governing borrowers to exercise options.

Model 2 adds the number of missed opportunities M (woodheads factor) into the model, which is similar with the prepayment model empirically developed by Deng and Quigley (2002).[19] From the results of Model 2, it can be seen that the put option is still positive and significant to support the importance of option theory in predicting borrowers' default decision. For asymmetric information of LTV ratio categories, borrower FICO score and trigger events, same results are presented as in Model 1. The covariate variable M is very significant accounting for heterogeneity in this way, and increases the magnitude of the option-related variables and improves the model fit very much

[19] In some models employed by financial analysts, a variable measuring the spread between contract and current interest rates is employed, as a measure of the "burnout" of prepayment in pools of mortgages (Richard and Roll (1989) and Hall (2000)).

Model 3 uses ‘exercise rate’ as the proxy of time preference. For people discounting future utility heavily (with present-biased preference or more present-biased) will, *ceteris paribus,* have less investment in exercise. Derived from the theoretical model, borrowers with present-biased preference tend to delay their default decisions. Therefore, the expected relationship between exercise rate and default probability is positive. In other words, for these with higher exercise rate at current stage, they discount future utility not as heavily as these with lower exercise rate, and they default earlier. The result of ‘exercise rate’ in Model 3 is consistence with expected results.

Model 4 in Table 7 uses current ‘smoking rate’ as the proxy of time preference. For current smokers, they have stronger preference for immediate utility over delayed utility, and tend to discount future utility heavily (with present-biased preference or more present-biased). Following the results derived from the theoretical model, borrowers with present-biased preference tend to delay their default decisions. Therefore, the expected relationship between smoking rate and default probability is negative. The result of ‘smoking rate’ in Model 4 is consistence with expected results.

Overall, financial motivations are still important in generating borrower’s default decision with the parameter of put option is positive and significant. However, it is inadequate by itself. From Model 1 to Model 4, by adding trigger events (unemployment rate), woodheads factor and proxies of time preference, the marginal effect of the put option increase substantially – by about 40 percent from Model 1 to Model 4. This suggests that estimating the default risk without accounting the time preference effect leads to a substantial underestimate of option-driven default behaviour.

5.2 Robustness Check 1: Four States

The data used in last section is focusing on 65 Metropolitan Statistical Areas (MSAs). The selection of these 65 MSAs is based on the availability of exercise rate and smoking rate data in the BFFSS database. In order to avoid sample selection bias, this part run the same estimation for four states: California (CA), Florida (FL), Nevada (NV) and Arizona (AZ). Nevada (NV) and Arizona (AZ) and Florida (FL) are top three states with highest negative shares during this financial crisis. The economy of

California (CA) is strong and growing throughout the whole sample period, but it also appears on the top ten high negative equity shares states lists.

Table 8 shows the maximum likelihood estimation for mortgage default with proxies of time preference for four states. The coefficients of woodheads factor of these four states are negative and statistically significant, which are consistence with previous part. In these fours Panels, smoking rate are negatively correlated with default probability, which are consistence with section 5.1. For California (CA), Florida (FL) and Nevada (NV), exercising rate are positively and significantly related with default probability. However, in Arizona (AZ), exercising rate is insignificant in explaining default probability. Taken altogether, in these four states, present-biased preference is negatively related with default probability, which support the results from theoretical model that borrowers with present-biased preference tend to have a lower default probability and delay their default decisions.

Insert Table 8 about here

5.3 Robustness Check 2: Mortgages Originated between 2002 and 2006

The subprime mortgage market experienced explosive growth between 2001 and 2006. Angell and Rowley (2006) and Kiff and Mills (2007), among others, argue that this was facilitated by the development of private-label mortgage backed securities, which do not carry any kind of credit risk protection by the Government Sponsored Enterprises. Demyanyk and Hemert (2011) employed loans originated between 2001 and 2006, indicated that during the dramatic growth of the subprime (securitized) mortgage market, the quality of the market deteriorated dramatically. In this part, a sub-sample is selected with mortgages originated between 2002 and 2006 to run the same regressions as Table 7.

Table 9 shows the maximum likelihood estimation for mortgage default with proxies of time preference for mortgages originated between 2002 and 2006. Consistence with previous results, option variables are significant and important for default decisions. Higher unemployment rate is positively related with higher default rate. The coefficients of woodheads factor are negative and statistically significant, which are consistence with the main results. For mortgages loans originated during this period, the exercising rate are positively and significantly related with default probability, which support the argument that borrowers with present-biased preference tend to delay their default decisions and take a lower default probability. Negative and significant relationship between smoking rate and default probability also strongly validate our findings about the delay effect of present-biased preference on mortgage default.

Insert Table 9 about here

5.4 Robustness Check 3: Expectation about home prices

Borrower's expectations about home price can affect the value of keeping a mortgage alive, and therefor influence the default decision (Bajari et al (2008)). Borrower can delay their default option exercise because they are waiting for a recovery of housing market in the future. In this part, we re-examine the empirical results by controlling expectation about home price. Following Bajari et al (2008), we assume that expectations about home price are adaptive and equal to the previous period's home appreciation. More specifically, the expectation about home price is calculated as home price growth rate over the previous twelve months.

Table 10 shows the regression results by controlling the expectations about home price. The results indicate that higher house price growth over the previous twelve months reduces the financial incentive to default, where the house price growth rate is negatively related with default probability. After controlling the house price growth rate over the previous twelve months, the coefficients of exercise rate and smoking rate are consistence with previous parts.

Insert Table 10 about here

6 Conclusion

The financial crisis triggered by subprime crisis causes economic to exacerbate into depression from US to global. This leads us to reconsider residential mortgage defaults and foreclosures. Mortgage default behaviour is complex. Correctly identify borrowers' different default behaviour is not only important for the mortgage lenders and investor of mortgage backed securities, but also crucial to the policy makers.

Contingent claims model provides a useful framework for analysing borrowers' behaviour. Nevertheless, substantial empirical works show that borrowers do not behave as ruthlessly as the option theory predicts. Based upon behavioural economics, this paper develops an alternative model to analyse this irrational default behaviour with hypothesis that borrowers have different time preferences among transaction costs of default. As a result, borrowers with present-biased preference can face additional significant costs coupled with default decision, and they may procrastinate in their default decision.

The empirical results in this paper support the importance of option theory in explaining mortgage default behaviour: the probability that put option in the money is significantly and positively related with mortgage default. In addition, risky borrowers tend to choose higher LTV ratio. Borrower with higher FICO score tend to default less. Moreover, the trigger events represented by unemployment rate are also important to predict borrowers' default decision. After adding the woodheads factor into the model, the explanation power of option variables has improved. Moreover, the model fit also improved very much. Finally, the different proxies of time preference are significant in explain default decision. For borrowers with present-biased preference, they tend to be postponed on their default decision.

Overall, borrowers' heterogeneous time preferences for the contingent costs of default may help to better understand mortgage default behaviour, and will assist in the creation of better policies to deal with the issue of foreclosure crisis, such as mortgage modification and mortgage contract design.

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Appendix

Appendix 1: Model Proof

The optimal cut-off for present-biased borrowers can be expressed as:

$$\mathrm{C}_{\mathrm{p}}^{*}=\frac{\underline{\mathrm{C}}+\sqrt{\underline{\mathrm{C}}^{2}(1-(2-\beta)\beta)+4\beta\left(1-\frac{\beta}{2}\right)(\overline{\mathrm{C}}-\underline{\mathrm{C}})\mathrm{L}}}{2-\beta}$$

Proof:

For the present-biased borrower, at the cut-off point, he should be indifferent between acting now and not acting in the present, then

$$\mathrm{C}_{\mathrm{p}}^{*}=\beta\left[\mathrm{L}+\mathrm{E}\left[\omega\left(\mathrm{C}_{\mathrm{p}}^{*},\mathrm{L},\mathrm{C}_{\tau+1}^{\mathrm{i}}\right)\right]\right] \qquad (\mathrm{A}.1)$$

we can write $\mathrm{E}\left[\omega\left(\mathrm{C}_{\mathrm{p}}^{*},\mathrm{L},\mathrm{C}_{\tau+1}^{\mathrm{i}}\right)\right]$ as:

$$E\left[\omega\left(C_{p}^{*},L,C_{\tau+1}^{i}\right)\right]=E\left(C_{\tau+1}^{i}\middle|C_{\tau+1}^{i}<C_{p}^{*}\right)\times P\left(C_{\tau+1}^{i}<C_{p}^{*}\right)$$
$$+\left(L+E\left[\omega\left(C_{p}^{*},L,C_{\tau+2}^{i}\right)\right]\right)\times P\left(C_{\tau+1}^{i}>C_{p}^{*}\right) \qquad (\mathrm{A}.2)$$

$C_{\tau+1}^{i}$ is the costs draw from current period, and $C_{\tau+2}^{i}$ is the costs draw from the next period. let $\phi=\mathrm{E}\left[\omega\left(\mathrm{C}_{\mathrm{p}}^{*},\mathrm{L},\mathrm{C}_{\tau+1}^{\mathrm{i}}\right)\right]$, at $\mathrm{C}_{\mathrm{p}}^{*}$ the function$\omega(.)$ must be a fixed point for the future value function. We can solve for $\mathrm{C}_{\mathrm{p}}^{*}$by first noting that[20]:

$$\phi=\frac{E\left(C_{\tau+1}^{i}\middle|C_{\tau+1}^{i}<C_{p}^{*}\right)\times P\left(C_{\tau+1}^{i}<C_{p}^{*}\right)+L\times P\left(C_{\tau+1}^{i}>C_{p}^{*}\right)}{1-P\left(C_{\tau+1}^{i}>C_{p}^{*}\right)} \qquad (\mathrm{A}.3)$$

Generalizing over periods and dropping the notation on $\mathrm{C}_{\tau}^{\mathrm{i}}$, implies that:

$$\phi=\frac{\int_{\underline{C}}^{C_{p}^{*}}C\,dc+\int_{C_{p}^{*}}^{\overline{C}}L\,dc}{\int_{\underline{C}}^{C_{p}^{*}}dc}=\frac{C_{p}^{*2}-2LC_{p}^{*}+2L\overline{C}-\underline{C}^{2}}{2(C_{p}^{*}-\underline{C})} \qquad (\mathrm{A}.4)$$

Combine equation A.1 and equation A.4, we can get a quadratic equation in $\mathrm{C}_{\mathrm{p}}^{*}$. Using the quadratic formula, and choosing the upper root so that $\mathrm{C}_{\mathrm{p}}^{*}>\underline{\mathrm{C}}$, and so we find that:

$$C_{p}^{*}=\frac{\underline{C}+\sqrt{\underline{C}^{2}(1-(2-\beta)\beta)+2\beta(2-\beta)(\overline{C}-\underline{C})L}}{2-\beta} \qquad (\mathrm{A}.5)$$

[20]Since $\mathrm{C}_{\tau}^{\mathrm{i}}$, $\mathrm{C}_{\tau+1}^{\mathrm{i}}$, $\mathrm{C}_{\tau+2}^{\mathrm{i}}$ is i.i.d., then $\mathrm{E}\left[\omega\left(\mathrm{C}^{*},\mathrm{L},\mathrm{C}_{\tau+1}^{\mathrm{i}}\right)\right]$= $\mathrm{E}\left[\omega\left(\mathrm{C}^{*},\mathrm{L},\mathrm{C}_{\tau+2}^{\mathrm{i}}\right)\right]$. we then solve for $\mathrm{E}\left[\omega\left(\mathrm{C}^{*},\mathrm{L},\mathrm{C}_{\tau+1}^{\mathrm{i}}\right)\right]$

Furthermore, in order to see the relationship between C_p^* and β, we calculate first order derivative:

$$\frac{\partial C_p^*}{\partial \beta} = \frac{(2-\beta)\left(\frac{2(1-\beta)\left((\overline{C}-\underline{C})L-\underline{C}^2\right)}{\sqrt{\underline{C}^2(1-(2-\beta)\beta)+2\beta(2-\beta)(\overline{C}-\underline{C})L}}\right)}{(2-\beta)^2} + \frac{\left(\underline{C}+\sqrt{\underline{C}^2(1-(2-\beta)\beta)+2\beta(2-\beta)(\overline{C}-\underline{C})L}\right)}{(2-\beta)^2}$$

$$= \frac{\underline{C}\left(\sqrt{\underline{C}^2(1-(2-\beta)\beta)+2\beta(2-\beta)(\overline{C}-\underline{C})L}-\underline{C}(1-\beta)\right)+2(2-\beta)(\overline{C}-\underline{C})L}{(2-\beta)^2\sqrt{\underline{C}^2(1-(2-\beta)\beta)+2\beta(2-\beta)(\overline{C}-\underline{C})L}} > 0 \qquad (A.6)$$

Since both parts are positive, this means that C_p^* is increasing in β.

The optimal cut-off point of each kind of borrowers is different. In order to make the comparison more clearly, we will calculate the expected delay. The expected delay will be:

$$E_P(delay) = 1 \times P\left(C_{\tau+1}^i < C_p^*\right) + 2 \times P\left(C_{\tau+1}^i > C_p^*\right) \times P\left(C_{\tau+2}^i < C_p^*\right)$$
$$+3 \times P\left(C_{\tau+1}^i > C_p^*\right) \times P\left(C_{\tau+2}^i > C_p^*\right) \times P\left(C_{\tau+3}^i < C_p^*\right) + \cdots$$
$$= 1 \times \left(C_p^* - \underline{C}\right) + 2 \times \left(\overline{C} - C_p^*\right)\left(C_p^* - \underline{C}\right) + 3 \times \left(\overline{C} - C_p^*\right)^2\left(C_p^* - \underline{C}\right) + \cdots \qquad (A.7)$$

For the present-biased borrowers, their expected delay will be:

$$E_P(delay) == \left(C_p^* - \underline{C}\right) \times \frac{1}{1-\left(\overline{C}-C_p^*\right)} \times \frac{1}{1-\left(\overline{C}-C_p^*\right)} = \frac{\left(C_p^* - \underline{C}\right)}{\left[1-\left(\overline{C}-C_p^*\right)\right]^2}$$

$$= \frac{\frac{\underline{C}+\sqrt{\underline{C}^2(1-(2-\beta)\beta)+2\beta(2-\beta)(\overline{C}-\underline{C})L}}{2-\beta} - \underline{C}}{\left[1-\left(\overline{C}-\frac{\underline{C}+\sqrt{\underline{C}^2(1-(2-\beta)\beta)+2\beta(2-\beta)(\overline{C}-\underline{C})L}}{2-\beta}\right)\right]^2} \qquad (A.8)$$

For TCs, let β equals to 1 for the present-biased borrowers' optimal cutoff level, then the optimal default cutoff point will be:

$$\mathrm{C}^* = \underline{\mathrm{C}} + \sqrt{2(\overline{\mathrm{C}} - \underline{\mathrm{C}})\mathrm{L}} \quad (\mathrm{A}.9)$$

$\mathrm{C}^*$is also increasing in L.

Let β=1 for the expected delay time of present-biased borrowers, the expected delay of time-consistence borrowers is:

$$E \quad (delay) = \frac{\sqrt{2(\overline{C} - \underline{C})L}}{\left[1 - (\overline{C} - \underline{C}) + \sqrt{2(\overline{C} - \underline{C})L}\right]^2} \quad (\mathrm{A}.10)$$

For comparing:

$$\frac{E_P(delay)}{E \quad (delay)} > 1 \quad (\mathrm{A}.11)$$

where $E_P(delay)$ is expected delay time of present-biased borrowers and $E \quad (delay)$ is expected delay time of time-consistence borrowers.

Appendix 2: Survey Questions about Exercise and Smoking in BRFSS

In the Behavioural Risk Factor Surveillance System (BRFSS) dataset, many variables related with behavioural risk and health risk are listed out for selected metropolitan and micropolitan statistical areas (MMSAs). Based on the literature of time preference in behavioural economics, two most popular proxies of time preference are employed in this paper: exercise rate and smoking rate. The survey questions about exercise rate and smoking rate in BRFSS are:

a) Survey question of exercise rate in BRFSS

The survey question about exercise set in the BRFSS is:

During the past month, did you participate in any physical activities?

Answer Choice: Yes or No

b) Survey question of smoking in BRFSS

The survey data about smoking set in the BRFSS is:

Tobacco Use: Adults who are current smokers.

Figure 1 Underwater Rate, Payment and Default Rates of Underwater Mortgages

This figure shows the underwater rate, default rate and payment rate of underwater mortgages by year. In Panel A, the underwater mortgage rates began to increase from 2007, the breaking point of financial crisis. Even the underwater rates of mortgages have increased sharply from 2007, in panel B, payment rates of these underwater mortgages remained at a very high level (exceeding 75%). From panel C, it can be seen that the default rate also increased from 2007 and peaked at 2009. During the period of 2007 and 2011, the default rate remained at a high level compared with the historical data. However, compared with the default rate, the majority underwater borrowers still continue to make their monthly payments. Derived from BlackBox data.

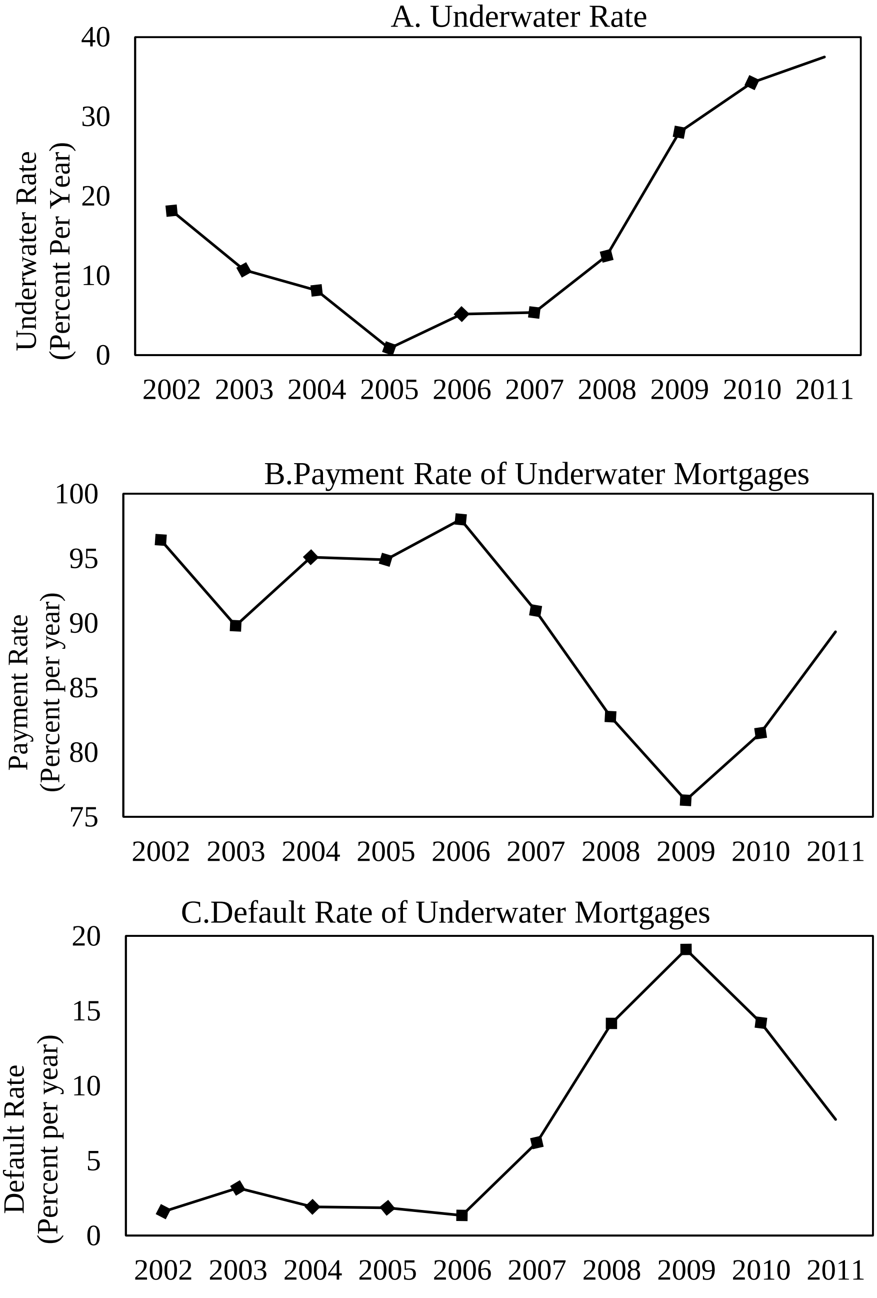


Figure 2 Timing of Game

The decision process after borrowers' equity become negative is shown in this figure. At period τ-1, borrower chooses not to default, and continue to pay his underwater mortgage. This decision leads he should pay a flow loss L at the beginning of period τ to stay at this negative equity situation, where L equals to monthly payment. At period τ, he face the embarrassing situation similar with period τ-1: default or not. Should he act, he incurs a stochastic transaction cost C_{τ}^{i} accompanied with default, should not act, the same process of period τ is repeated in the next period τ+1.

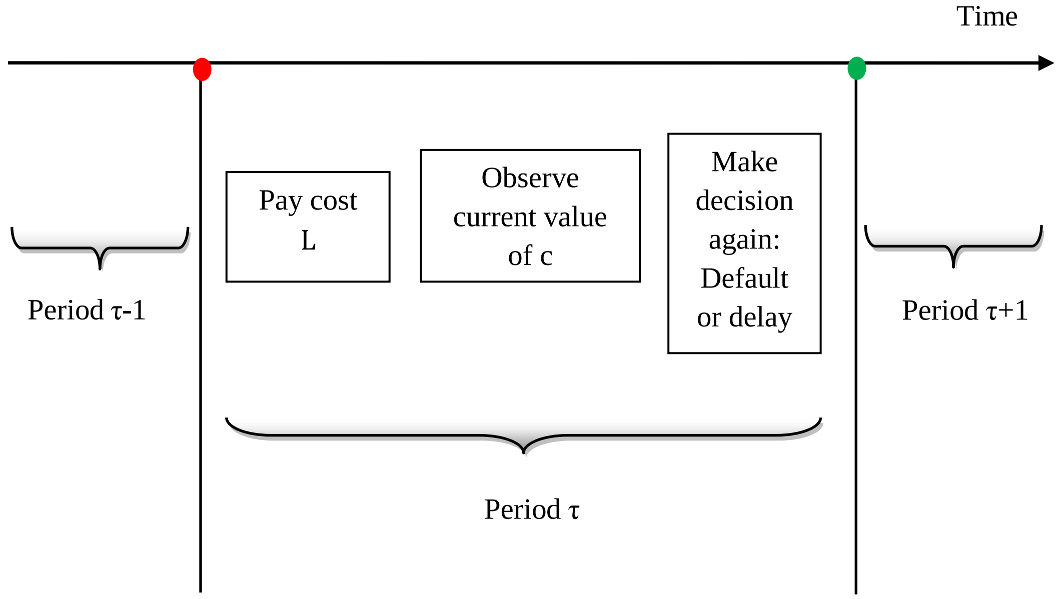


Figure 3 Timing of Default

This figure shows the default time for each kind of borrower. The 'Negative equity point' is the time that borrowers' house value firstly lower than mortgage amount they owned. After this point, we call this mortgage is "underwater" and borrowers face the decision of default or not. The 'Ruthless default point' is the result predicted by pure option theoretical model that the well-informed borrower will default immediately when the mortgage value exceeds the property value at any time during the loan term. The 'TCs default point' is the default time for borrowers with time-consitance preference. It is a littler later than 'Ruthless default point'. The 'Sophisticated default point' is the default time for sophisticated borrower with present-biased preference. It follows 'TCs default point', becauese borrower with presnet-biased preference may overweigh their transaction costs when they make decision. The 'Naïve procrastination' try to illustrate that the default time of naïve borrowers with present-biased preference is the latest, and under some extreme circumstances, they may never default during the life of the mortgage contract. Both sophisticated and naïve borrowers take preference as present-biased, but difference between these two is whether they can fully aware of their future self-control problems. Sophisticated are fully aware of their future self-control problems, and exactly know what her future selves' preference even though her future preferences differ from those of the current self. By contrast, not anticipating her future procrastination, naifs are fully unaware of their future self-control problems.

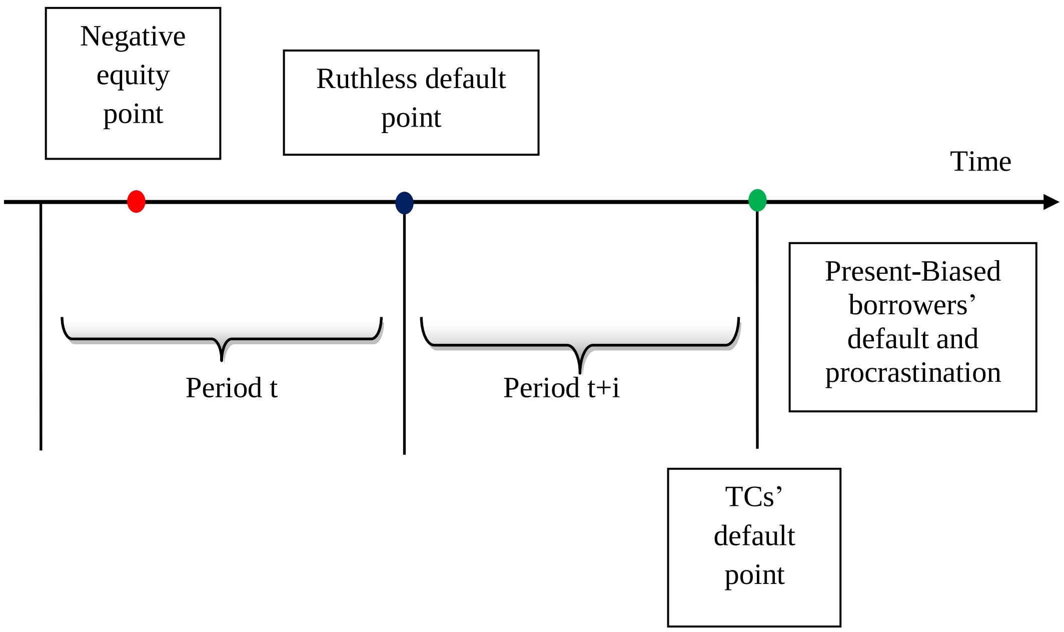


Figure 4 Origination Rates and Default Rates at Origination Year

This figure shows the default and prepayment rates separated by origination year. From 2003 to 2007, the default rates of mortgage originated during this period increase sharply. Numerous papers try to explain this unexpected phenomenon from different angles, like irrational expectation regarding future house price growth, mortgage securitization, lax underwriting, and so on (Bajari et al (2008), Keys et al (2010) among others). The default rate is the higheset of those originated in 2007, which is consistant with the recent financial crisis began from the end of 2007. Mortgage originated between 2007 and 2009, the breaking point of financial crisis, their default rate begain to decrease. This maybe induced by the improvement of underwriting standards.

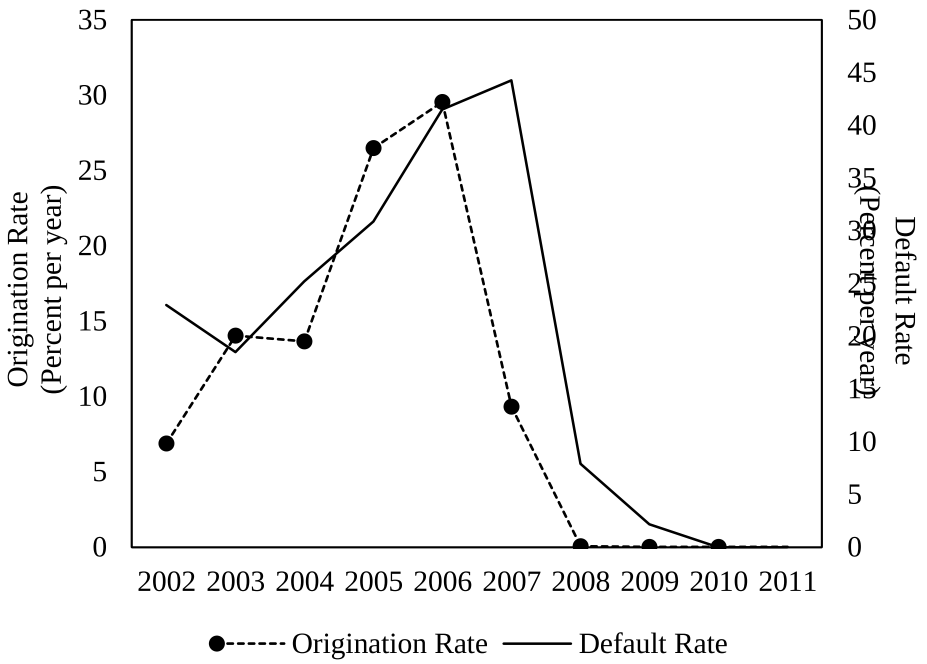


Figure 5 Cumulative Frequency of Missed Put Opportunity

This figure presents the cumulative frequency of missed put opportunities (measured in quarters), separtely for the full sample and for mortgage pools with different seasoning.

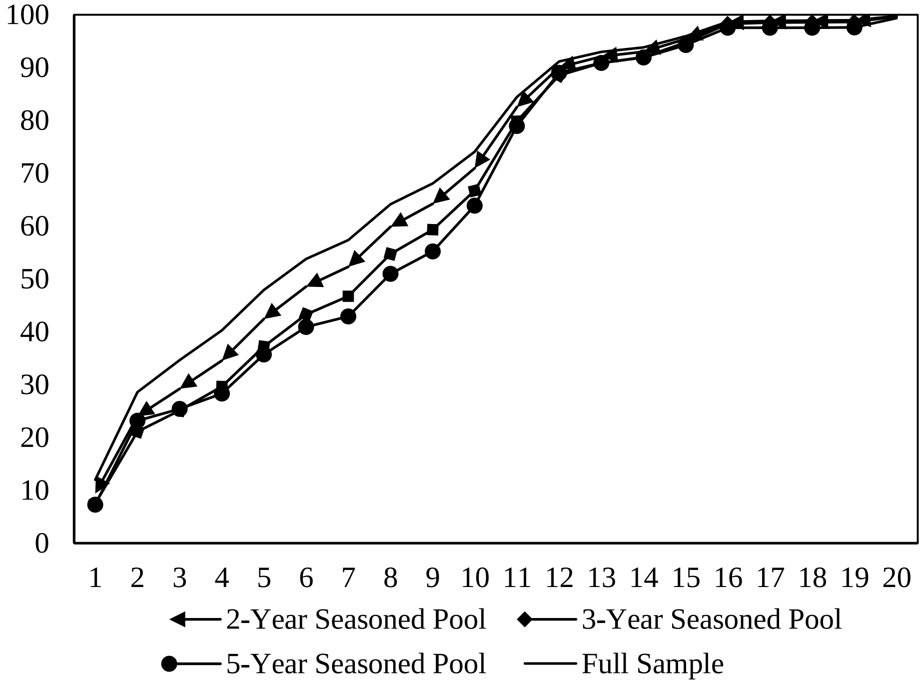
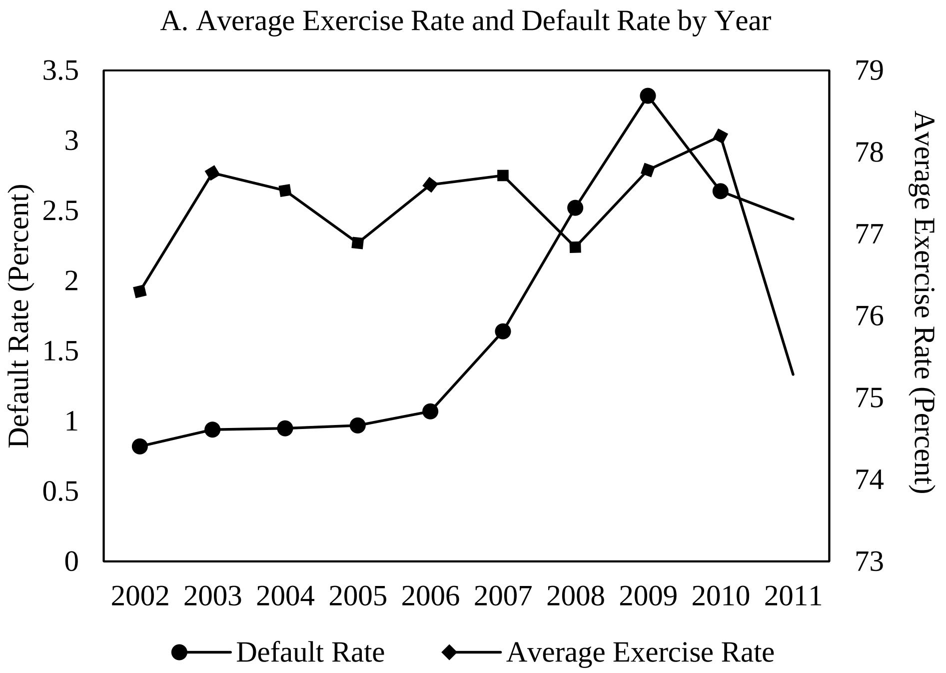


Figure 6 Average Smoking Rate, Average Exercise Rate and Default Rate by Year



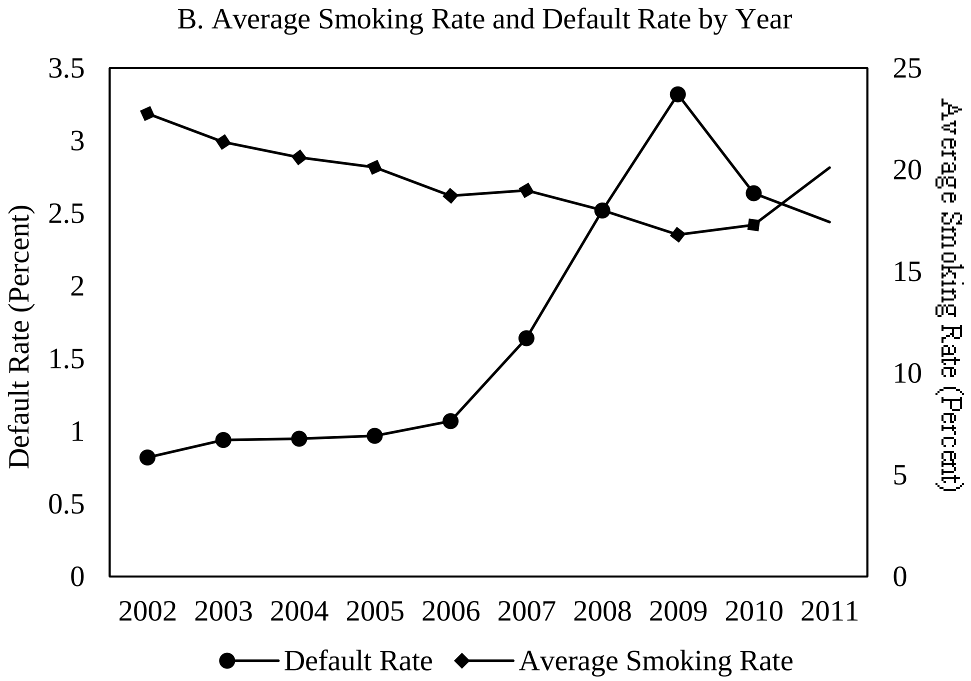


Table 1 Negative Equity in Selected States of US

This table presents the top ten states with higher negative equity distribution. From Negative Equity Summary Report of CoreLogic, Jan-2013.

State	Negative Equity Share	Near Negative Equity Share
Nevada	56.9%	5.3%
Florida	42.1%	4.1%
Arizona	38.6%	5.1%
Georgia	35.6%	6.3%
Michigan	32%	4.8%
California	28.3%	4.5%
Illinois	25.4%	4.6%
Ohio	23.8%	5.7%
Maryland	22.9%	4.8%
Idaho	22.3%	5.3%

Table 2 Descriptive Statistics of Sample

Panel A: Means and Standard Deviations

	Mean	Std. Dev
Origination Year	2004.8600	1.4079
Loan Age	16.2591	9.1139
Original Interest Rate (%)	7.0576	1.2191
Combine LTV (%)	81.4541	15.8320
Original Loan Size	203212.4200	172688.8100

Panel B: Distribution by Termination Status

Total	Number of Default	Percent of Default	Number of Prepaid	Percent of Prepaid
461,282	148,482	32.19	162,726	35.28

Panel C: Distribution by Property Type

Property Type	Number of Loans	Percent of the Total	Number of Default	Percent of Default	Number of Prepaid	Percent of Prepaid
Condo	22503	4.88	6201	27.56	7927	8375
PUD	94,333	20.45	30,717	32.56	32,553	34.51
SF	344,446	74.67	111,564	32.39	122,246	35.49

Note: Mean and standard deviation in Panel A are calculated based on 461,282 loans.

Table 3 Descriptive Statistics on Mortgages Loans
Mean Value at Origination and Termination

Variables	At Origination		At Termination		All
	All loans	Defaulted	All loans	Defaulted	
Put Option (probability of negative equity)	0.1162 (0.1928)	0.1427 (0.2054)	0.2270 (0.3380)	0.2633 (0.3462)	0.1358 (0.2723)
Call Option (fraction of contract value)	-0.0018 (0.0271)	-0.0019 (0.0263)	0.0667 (0.0688)	0.0479 (0.0657)	0.0237 (0.0682)
Square Term of Put Option	0.0507 (0.1138)	0.0626 (0.1236)	0.1658 (0.3112)	0.1892 (0.3224)	0.0926 (0.2402)
Square Term of Call Option	0.0007 (0.0009)	0.0007 (0.0008)	0.0092 (0.0087)	0.0066 (0.0072)	0.0052 (0.0071)
Unemployment Rate (percent)	5.0816 (0.5957)	4.9115 (0.4877)	7.5214 (1.9978)	6.9665 (2.0726)	6.4009 (2.0472)
Combined Loan-to-Value Ratio(CLTV)	81.4541 (15.8320)	85.0845 (13.3973)	--	--	80.7108 (15.9922)
Fico Score	687.4762 (71.5082)	650.7312 (71.9334)	--	--	696.7516 (67.3608)
Observations	461,282	148,482	461,282	148,482	7,500,019

Note: standard deviations are in parentheses.

Table 4 Descriptive Statistics on Mortgages Loans
Mean Value at Termination by LTV Category

Variables	All loans	CLTV≤70	70< CLTV ≤80	80< CLTV ≤90	90< CLTV ≤97	CLTV >97
Put Option (probability of negative equity)	0.2270 (0.3380)	0.0570 (0.1980)	0.1329 (0.2755)	0.1892 (0.3081)	0.3076 (0.3513)	0.4954 (0.3642)
Call Option (fraction of contract value)	0.0667 (0.0688)	0.0690 (0.0710)	0.0691 (0.0706)	0.0658 (0.0694)	0.0620 (0.0668)	0.0678 (0.0647)
Square Term of Put Option	0.1658 (0.3112)	0.0424 (0.1778)	0.0936 (0.2485)	0.1307 (0.2799)	0.2181 (0.3356)	0.3781 (0.3795)
Square Term of Call Option	0.0092 (0.0087)	0.0098 (0.0097)	0.0098 (0.0091)	0.0092 (0.0086)	0.0083 (0.0078)	0.0088 (0.0076)
Unemployment Rate (percent)	7.5214 (1.9978)	7.7051 (1.9810)	7.6332 (1.9821)	7.4865 (2.0039)	7.3177 (2.0039)	7.4195 (1.9866)
Fico Score	687.48 (71.51)	696.10 (77.10)	689.40 (72.18)	677.42 (72.41)	679.34 (68.08)	695.81 (62.61)
Observations	461,282	93,952	164,429	163,445	86,748	90,139

Note: standard deviations are in parentheses.

Table 5 Number of Loans and Payable Events by Number of Missed Put Options

This table summarizes the distribution of missed default opportunities M, which is calculated at each quarter for each mortgage in the sample. There are a total of 461282 loans with 7500019 payable events in the sample. Panel A shows the distribution of M among loans, separately for the full sample and mortgage pools with different seasons (2 year seasoned, 3 year seasoned, and 5 year seasoned). Panel B shows the distribution of M among payable events similar with Panel A, separately for the full sample and mortgage pools with different seasons. For more seasoned pools, the missed opportunities are less for both mortgage loans and payment events.

	Full sample	2-Year Seasoned Pool	3-Year Seasoned Pool	5-Year Seasoned Pool
	PANEL A- NUMBER OF LOANS			
M=0	335,858	243,909	198,601	129,292
	(72.81)	(68.52)	(67.14)	(70.57)
M=1-2	35,830	26,910	20,527	12,492
	(7.77)	(7.56)	(6.94)	(6.82)
M=3-4	14,669	11,847	8,316	2,786
	(3.18)	(3.33)	(2.81)	(1.52)
M=5-8	29,928	28,330	24,339	12,222
	(6.49)	(7.96)	(8.23)	(6.67)
M=9-12	33,862	33,862	32,896	20,479
	(7.34)	(9.51)	(11.12)	(11.18)
M≥13	11,135	11,135	11,135	5,938
	(2,41)	(3.13)	(3.76)	(3.24)
Total	461,282	355,993	295,814	183,209
	PANEL B- NUMBER OF PAYABLE EVENTS			
M=0	5,302,329	4,901,197	4,476,733	3,405,357
	(70.70)	(69.69)	(69.23)	(72.54)
M=1-2	549,585	508,111	447,877	322,810
	(7.33)	(7.22)	(6.93)	(6.88)
M=3-4	203,774	189,126	155,257	74,926
	(2.72)	(2.69)	(2.40)	(1.60)
M=5-8	539,766	529,943	491,601	299,410
	(7.20)	(7.54)	(7.60)	(6.38)
M=9-12	686,995	686,995	677,133	465,260
	(9.16)	(9.77)	(10.47)	(9.91)
M≥13	217,570	217,570	217,570	126,996
	(2.90)	(3.09)	(3.36)	(2.71)
Total	7,500,019	7,032,942	6,466,171	4,694,759

Note: Column percentages in parentheses.

Table 6 Descriptive Statistics on Exercise Rate, Smoking Rate Mean Value at Origination and Termination

Variables	At Origination		At Termination		All
	All loans	Defaulted	All loans	Defaulted	
Exercise Rate	77.4546	77.1457	76.7195	77.1934	77.3524
	(4.1477)	(4.1217)	(4.1394)	(4.0402)	(4.0194)
Smoking Rate	19.8128	19.6534	18.9784	18.2661	18.6828
	(3.3207)	(3.2708)	(3.4177)	(3.3269)	(3.3010)
Observations	460,652	148,482	461,282	148,482	7,500,019

Note: standard deviations are in parentheses.

Table 7 Maximum Likelihood Estimates for Mortgage Default with Proxies of Time Preference

	Model 1	Model 2	Model 3	Model 4
Option Variables				
Put Option	0.4173 ***	0.5734 ***	0.5758***	0.5828***
	(0.0099)	(0.0104)	(0.0104)	(0.0104)
Call Option	0.1535 ***	0.1919 ***	0.1973***	0.1983***
(fraction of contract value)	(0.0063)	(0.0064)	(0.0064)	(0.0064)
Square Term of Put Option	-0.1066 ***	0.7278 ***	0.7172***	0.7071***
	(0.0085)	(0.0097)	(0.0097)	(0.0097)
Square Term of Call Option	-0.1688 ***	-0.1267 ***	-0.1258***	-0.1239***
	(0.0043)	(0.0042)	(0.0042)	(0.0042)
Mortgage Loan Characteristics				
Original Loan Amount	-0.0078 **	0.0105 ***	0.0018***	0.0010
	(0.0031)	(0.0031)	(0.0032)	(0.0031)
70<CLTV≤80	0.1621 ***	0.1728 ***	0.1762***	0.1741***
	(0.0042)	(0.0042)	(0.0042)	(0.0042)
80<CLTV≤90	0.1620 ***	0.2128 ***	0.2172***	0.2170***
	(0.0035)	(0.0035)	(0.0035)	(0.0035)
90<CLTV≤97	0.1280 ***	0.1923 ***	0.1970***	0.1950***
	(0.0032)	(0.0032)	(0.0032)	(0.0032)
CLTV>97	0.1207 ***	0.3298 ***	0.3378***	0.3339***
	(0.0042)	(0.0042)	(0.0042)	(0.0042)
Borrower Characteristics				
580<ficoscore<=620	-0.1395***	-0.1330 ***	-0.1332***	-0.1330***
	(0.0025)	(0.0024)	(0.0024)	(0.0024)
620<ficoscore<=660	-0.3040 ***	-0.2877 ***	-0.2894***	-0.2881***
	(0.0031)	(0.0030)	(0.0030)	(0.0030)
660<ficoscore<=720	-0.6118 ***	-0.5625 ***	-0.5660***	-0.5642***
	(0.0039)	(0.0038)	(0.0038)	(0.0038)
ficoscore>720	-1.0227 ***	-0.9463 ***	-0.9506***	-0.9470***
	(0.0046)	(0.0046)	(0.0046)	(0.0046)
Trigger Event				
Unemployment Rate	0.2688 ***	0.2137 ***	0.2091***	0.1981***
(percent)	(0.0058)	(0.0059)	(0.0059)	(0.0059)
		-1.8946 ***	-1.8933***	-1.8891***
Woodheads Factor		(0.0071)	(0.0071)	(0.0071)
Proxies of Time Preference				
Exercise Rate			0.0430***	
			(0.0028)	
Smoking Rate				-0.0657***
				(0.0027)
-2 LOG L	3611021.5	3502281.0	3502039.9	3501694.6
AIC	3611049.5	3502311.0	3502071.9	3501726.6
SBC	3611188.2	3502459.6	3502230.4	3501885.1
Likelihood Ratio	108352.2	217092.7	217333.8	217679.1
Score	121991.0	218596.9	219737.8	220583.5
Wald	104749.2	245303.9	245917.6	246349.1

*Note: * p<0.1, **p<0.05, ***p<0.01.*

1. *The data used to estimate is panel dataset with one observation at each quarter for each loan during the payment period.*
2. *Standard deviations are in parentheses. In all models, there is no competing risk between prepay and default.*

Table 8 Maximum Likelihood Estimates for Mortgage Default with Proxies of Time Preference: Four States

This table consists of four panels (Panel A, Panel B, Panel C and Panel D), showing the results of maximum likelihood estimates for mortgage default with proxies of time preference for the four states, i.e., California, Florida, Nevada and Arizona. All the regressions for these four states used the same regression variables as stated in table 7. For simplify, only selected variables are presented. Those variables not indicated in this table, their coefficients are consistence with table 7.

Panel A State of California (CA)		
Variables	**(1)**	**(2)**
Woodheads Factor	-2.4722 ***	-2.3688 ***
	(0.0086)	(0.0083)
Exercise Rate	0.4750 ***	
	(0.0074)	
		-0.3184 ***
Smoking Rate		(0.0080)
-2 LOG L	1664201.9	1666613.3
AIC	1664233.9	1666645.3
SBC	1664382.3	1666793.7
Likelihood Ratio	230150.010	227738.620
Score	264523.784	274714.182
Wald	227347.547	226905.191
Panel B State of Florida (FL)		
Variables	**(1)**	**(2)**
Woodheads Factor	-2.8700 ***	-2.8274 ***
	(0.0131)	(0.0130)
Exercise Rate	0.0429 ***	
	(0.0049)	
Smoking Rate		-0.4813 ***
		(0.0077)
-2 LOG L	1167875.6	1163549.0
AIC	1167907.6	1163581.0
SBC	1168050.9	1163724.3
Likelihood Ratio	127217.964	131544.580
Score	113519.599	124840.408
Wald	127678.497	129556.712
Panel C State of Nevada (NV)		
Variables	**(1)**	**(2)**
Woodheads Factor	-2.0589 ***	-2.0801 ***
	(0.0222)	(0.0223)
Exercise Rate	0.0348 **	
	(0.0148)	
Smoking Rate		-0.2411 ***
		(0.0117)
-2 LOG L	283532.37	283080.04
AIC	283564.37	283112.04
SBC	283687.01	283234.69
Likelihood Ratio	27474.9751	27927.3025
Score	27477.9006	28085.0501
Wald	29389.5170	29796.5449

Panel D State of Arizona (AZ)		
Variables	**(1)**	**(2)**
Woodheads Factor	-2.8376 ***	-2.8429***
	(0.0173)	(0.0170)
Exercise Rate	-0.0029	
	(0.0096)	
Smoking Rate		-0.2377 ***
		(0.0100)
-2 LOG L	452064.15	451484.59
AIC	452096.15	451516.59
SBC	452225.96	451646.39
Likelihood Ratio	70540.3478	71119.9135
Score	72711.8282	70901.5892
Wald	64643.5417	64607.5395

*Note: * p<0.1, **p<0.05, ***p<0.01.*

1. *The data used to estimate is panel dataset with one observation at each quarter for each loan during the payment period.*
2. *Standard deviations are in parentheses. In all models, there is no competing risk between prepay and default.*

Table 9 Maximum Likelihood Estimates for Mortgage Default with Proxies of Time Preference: Mortgages Originated between 2002 and 2006

This table shows regressions similar with Table 7 using mortgages originated between 2002 and 2006. For simplify, only selected variables are presented. Those variables not indicated in this table, their coefficients are consistence with table 7.

	Model 1	Model 2	Model 3	Model 4
Option Variables				
Put Option	0.4078 ***	0.5510 ***	0.5533***	0.5602***
	(0.0102)	(0.0108)	(0.0108)	(0.0108)
Call Option	0.1356 ***	0.1752 ***	0.1800***	0.1814***
(fraction of contract value)	(0.0064)	(0.0065)	(0.0065)	(0.0065)
Square Term of Put Option	-0.1117 ***	0.6681 ***	0.6587***	0.6494***
	(0.0087)	(0.0100)	(0.0100)	(0.0100)
Square Term of Call Option	-0.1363 ***	-0.1023 ***	-0.1017***	-0.1006***
	(0.0043)	(0.0042)	(0.0034)	(0.0042)
Trigger Event				
Unemployment Rate	0.2668 ***	0.2063 ***	0.2020***	0.1918***
(percent)	(0.0064)	(0.0059)	(0.0064)	(0.0064)
		-1.7926 ***	-1.7917***	-1.7880***
Woodheads Factor		(0.0071)	(0.0076)	(0.0076)
Proxies of Time Preference				
Exercise Rate			0.0408***	
			(0.0030)	
Smoking Rate				-0.0649***
				(0.0029)
-2 LOG L	3121107.9	3035326.3	3035137.1	3034823.4
AIC	3121135.9	3035356.3	3035169.1	3034855.4
SBC	3121272.7	3035502.9	3035325.4	3035011.7
Likelihood Ratio	96010.5426	181792.099	181981.355	182295.059
Score	109074.866	185068.915	185877.538	186537.376
Wald	92845.1747	203688.822	204167.126	204549.530

*Note: * p<0.1, **p<0.05, ***p<0.01.*

1. *The data used to estimate is panel dataset with one observation at each quarter for each loan during the payment period.*
2. *Standard deviations are in parentheses. In all models, there is no competing risk between prepay and default.*

Table 10 Maximum Likelihood Estimates for Mortgage Default with Proxies of Time Preference by controlling expectation about home price

For simplify, only selected variables are presented. Those variables not indicated in this table, their coefficients are consistence with table 7.

	Model 1	Model 2
Option Variables		
Put Option	0.4416***	0.4464***
	(0.0104)	(0.0104)
Call Option	0.1984***	0.1981***
(fraction of contract value)	(0.0064)	(0.0064)
Square Term of Put Option	0.6674***	0.6633***
	(0.0095)	(0.0095)
Square Term of Call Option	-0.0411***	-0.0404***
	(0.0043)	(0.0043)
Trigger Event		
Unemployment Rate	0.1215***	0.1173***
(percent)	(0.0060)	(0.0061)
	-1.8257***	-1.8245***
Woodheads Factor	(0.0070)	(0.0070)
Expectation about home price		
Home price growth rate over the previous	-0.3473***	-0.3421***
twelve months	(0.0044)	(0.0044)
Proxies of Time Preference		
Exercise Rate	0.0198***	
	(0.0028)	
Smoking Rate		-0.0328***
		(0.0028)
-2 LOG L	3495555.1	3495464.0
AIC	3495589.1	3495498.0
SBC	3495757.5	3495666.5
Likelihood Ratio	223818.635	223909.687
Score	233031.522	233368.091
Wald	252664.826	252922.480

*Note: * p<0.1, **p<0.05, ***p<0.01.*

1. *The data used to estimate is panel dataset with one observation at each quarter for each loan during the payment period.*
2. *Standard deviations are in parentheses. In all models, there is no competing risk between prepay and default.*