Mortgage Market Institutions and Housing Market Outcomes*

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Abstract

I develop an equilibrium model of housing and mortgage markets where house prices, mortgage interest rates, and leverage ratios are all determined endogenously. Agents are forward looking and have rational expectations. House prices adjust so that demand from new buyers clears with supply created by existing sellers. Housing demand is affected by the price and availability of contracts in the mortgage market. Mortgage interest rates are set so that the expected return on mortgages is equal to the opportunity cost of funds. Counterfactuals related to mortgage credit availability and mortgage contract design are explored. General equilibrium effects are shown to be important.

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1 Introduction

The housing market and mortgage market are incredibly large sectors of the U.S. economy. Residential property accounted for 60 percent of U.S. households' non-financial wealth in 2007, and residential mortgage debt accounted for 85 percent of debt.[1] The two markets are also inextricably linked. Most households are unable to purchase homes without obtaining mortgage financing, creating a direct linkage from the mortgage market to housing market outcomes. On the other hand, housing serves as collateral for mortgage borrowing, and so the price and availability of mortgage credit directly depends on what is happening in housing markets.

The great insight of models of collateralized borrowing, as exemplified in Kiyotaki and Moore (1997), is that there are important dynamic interactions between collateral prices and borrowing limits. The market for collateral and the market for debt therefore cannot be studied in isolation. Housing and mortgages are a prime example of this kind of interlinked market. In order to understand how changes to mortgage market institutions—such as decreased credit availability or new contract designs—affect housing market outcomes, one needs to consider these complex interactions. The goal of this paper, then, is to construct a model of the housing and mortgage markets, in which house prices, mortgage interest rates, and leverage ratios are all determined simultaneously in equilibrium.

In the model, there is a housing market with two vertically differentiated types of housing, each with fixed supply. Each unit of housing is owned by a single household, or homeowner, and each homeowner has a mortgage contract. Homeowners care about consumption and about the type of house they live in. In each period, some owners are hit by a moving shock, forcing them to either default on their mortgage or to sell their house, in which case their lender sells the house.

At the same time as existing owners are selling their homes, new potential buyers are entering the market. Potential buyers are heterogeneous in their

[1] Survey of Consumer Finances, 2007.

income, wealth, and preference for housing. Because potential buyers have limited wealth, they need to borrow in order to purchase a home. Credit markets are imperfect, and to borrow they must use mortgage contracts where the debt is collateralized against their homes. Different types of mortgage contracts are offered by risk-neutral and competitive lenders. Lenders price each offered contract such that the expected return on the contract equals the opportunity cost of funds. Given the set of offered contracts, potential buyers make purchasing decisions to maximize their expected utility as future homeowners. Owners, buyers and lenders are all forward-looking and have rational expectations. No asymmetric information is assumed between borrowers and lenders.

The housing market is in equilibrium when the demand for homes from potential buyers equals the supply of homes from existing sellers, taking the set of offered mortgage contracts as given. The distribution of buyer heterogeneity can change over time (for example, the housing preferences of buyers can change over time), which introduces stochastic volatility to house prices. The mortgage market is in equilibrium when the expected return on all contracts is equal to the lenders' opportunity cost of funds, taking house prices (and house price volatility) as given.

The model is calibrated using housing and mortgage market data from Los Angeles, for the period 2003 through 2010. The model is able to replicate most of the salient features of the data. In particular, the model can replicate the differential house price growth and decline between low and high-quality homes from 2003 to 2010. The model can also generate realistic patterns of leverage ratios over time, including the sharp dropoff of leverage ratios in 2008, caused by the disappearance of the market for non-agency loans.[2] The model

[2] An agency loan is a loan securitized by one of the three government sponsored enterprises (GSE): Freddie Mac, Fannie Mae and Ginnie Mae. The GSEs carry implicit government guarantees on their credit obligations, and therefore agency loans are usually available at lower interest rates than non-agency loans. However, in order for a loan to qualify as an agency loan, they have to meet certain regulatory guidelines. For example, the size of the loan needs to be below the "conforming loan limit"—a level set by the Federal Housing Finance Agency (FHFA). Because of the limitations of agency loans, the presence of a non-agency market greatly increases the set of contracts available to borrowers.

is also able to replicate the changes to mortgage default rates over time quite well.

The calibrated model is then used to study a variety of counterfactuals related to mortgage contract availability and mortgage market institutions. First, the effect of the disappearing non-agency market is studied. It is shown that the presence of non-agency loans has very significant effects on house prices and on the set of buyers who can afford to buy homes. Without non-agency loans—which are availble at higher leverage ratios than agency loans—low-wealth buyers are unable to purchase homes, forcing house prices down in order to attract high-wealth buyers who have marginally lower preferences for housing. General equilibrium effects are also shown to be important. It is shown, for example, that house price volatility is lower in the presence of a non-agency market, and therefore the offered interest rates on non-agency loans would be lower than if the effect on house price volatility was not taken into account.

Second, I study the effectiveness of the government response to the disappearing non-agency market. In 2008, the government lowered the risk-free rate and increased conforming loan limits as a response to the crisis in the mortgage market. I show that both policies were effective in buoying house prices. Increasing conforming loan limits is shown to have a larger effect on high-quality homes, while lowering interest rates is shown to have an effect for both low and high-quality homes.

Finally, I use the model to study the impact of hypothetical mortgage contracts that share house price appreciation between borrower and lender. Such contracts have been proposed as a solution to reducing the risk of mortgage default.[3] I find that these contracts can improve market efficiency, but the extent depends on the specific designs of the contracts. Contracts that share house price appreciation on only the downside will have low uptake, because most buyers are not willing to trade a higher interest rate for protection against house price declines.[4] Contracts that share house price appreciation

[3]See, for example, Caplin et al. (2007); Shiller (2008); Mian and Sufi (2014).

[4]This is perhaps unsurprising, as borrowers are already implicitly insured against down-

on both the upside and downside, however, would have high uptake. General equilibrium effects are again shown to be important. For example, default risk is eliminated for borrowers who use shared-appreciation mortgages, but default risk may actually increase for borrowers who continue to use traditional fixed-rate mortgages.

Related Literature

This paper is most closely related to papers that model housing market outcomes in the context of a mortgage market. Ortalo-Magné and Rady (2006) studies the role of income shocks and credit constraints in determining housing market outcomes; Campbell and Cocco (2014) study a life-cycle model of mortgage default; Favilukis et al. (2015) study a macroeconomic model of housing with aggregate business cycle risk and limited risk-sharing; Landvoigt et al. (2015) study a model in which relaxation of mortgage credit can explain cross-sectional variation in housing returns; Corbae and Quintin (2015) study the role of leverage and heterogeneous borrowers in explaining patterns of mortgage default. Guren and McQuade (2015) study equilibrium interactions between foreclosures and house prices. The main contributions of the current paper to this literature are, first, the simultaneous determination of house prices, mortgage rates, and leverage ratios, and second, the detailed modeling of long-term mortgage contracts. Because collateral prices, interest rates and leverage ratios are endogenous, the paper is also related to the theoretical literature on collateral equilibrium (i.e. Kiyotaki and Moore (1997); Geanakoplos and Zame (2013)).

The paper is also related to a growing empirical literature on the interactions between housing and mortgage markets. Himmelberg et al. (2005) and Glaeser et al. (2010) explore the extent to which house price appreciation during the boom can be explained by relaxed mortgage credit. Ferreira and Gyourko (2011) explore specifically the timing of local housing booms and whether they can explained by changes to lending standards. Mian and Sufi (2009) study the causes and consequences of subprime mortgage credit

side house price risk through the option to default.

expansion. Favara and Imbs (2015), Adelino et al. (2014) and Kung (2015) use quasi-experimental variation to study the effect of credit availability on house prices. Hurst et al. (2015) consider the extent to which local housing risks are reflected in mortgage pricing. The model presented in this paper highlights some key mechanisms through which housing markets and mortgage markets interact.

Finally, the paper is related to the literature on optimal mortgage design. Although I do not currently use the model to study the optimality of different types of mortgage contracts, the model is flexible enough to consider the impact of introducing mortgage designs that have been proposed as having more desirable properties than fixed-rate mortgages, such as the aforementioned shared-appreciation mortgages or the option-ARM type mortgages proposed in Piskorski and Tchistyi (2010).

The rest of the paper is organized as follows. Section 2 outlines the model. Section 3 gives specific details on how the model is implemented empirically. Section 4 introduces the data to which the model will be calibrated. Section 5 discusses how the model is calibrated, including a discussionon on the sources of identification for key parameters. Section 5 also discusses model fit. Section 6 reports the results of the counterfactual exercises discussed in the introduction. Section 7 concludes.

2 Model

2.1 Housing

Time is discrete. There is a housing market with two house types, $h = 0$ and $h = 1$, which can be thought of as low and high quality homes, respectively. There is a fixed stock μ of each house type, for a total of 2μ housing units altogether. Each unit of housing can be occupied by one and only one household, and each household can occupy only one unit of housing. Let s_t be an aggregate state variable (which I will specify in more detail later). The price of house type h in state s_t is given by $p_h(s_t)$. For now, no restrictions are placed on the state variable except that it evolves over time according to a first-order Markov process.

2.2 Homeowners

Houses are purchased by potential homeowners. The homeowners then live in their houses until they have to move, which occurs each period with probability λ. Homeowners who move out do not re-enter the housing market, so moving is treated as a terminal state.[5] Homeowners care about their consumption flows and about their final wealth at the time of a move. If the amount consumed in a period is c, the utility received that period is $u\left(\theta^h c\right)$, where h is the type of house that the homeowner lives in. $u(c)$ is a CRRA utility function with risk-aversion parameter γ. $\theta > 1$ models the preference that homeowners have for living in high-quality homes.

If the amount of wealth at the time of a move is w, then the terminal utility received is $\beta u(c)$, where β is simply a scale parameter. Homeowners are expected utility maximizers and discount future utility flows using discount parameter $\delta < 1$. The present value of utility flows for a homeowner who consumes c each period and moves after T periods with final wealth w_T is therefore:

$$\sum_{t=0}^{T-1} \delta^t u\left(\theta^h c\right) + \delta^T \beta u(w_T)$$

2.3 Mortgage contracts

Potential homeowners can finance their home purchases via mortgage contracts. A mortgage contract is represented by a vector $z_t = (a_t, r_t, b_t)$ where a_t is the age of the mortgage, r_t is the current interest rate, and b_t is the remaining balance. A contract is additionally described by its type, m. A

[5] The requirement to move out of the housing market can be thought of as either death of the homeowner, or an exogenous job relocation shock. Within-market moves are not considered, though this only matters to the extent that within-market movers also make large trades in terms of housing value. (Within-market moves between two homes of the same value create no net supply or demand.) The extent to which within-market trade-ups and trade-downs is empirically important is explored in the Appendix.

contract's type determines how the interest rate and balances evolve over time and with the state variable. There are M contract types, including $m = 0$ which denotes "no mortgage."

In addition to z_t and the contract type m, a mortgage's behavior also depends on the type of house it is collateralized with, h, and the state variable s_t. Mortgage behavior is defined by three functions. First, let $pay_h^m(z_t, s_t)$ be the payment required from the borrower to stay current on the mortgage. Second, let $\psi_h^m(z_t, s_t)$ define the amount that the lender is able to recover in the event of a default. This may vary by contract type and by the current price of housing. Finally, let $\zeta_h^m(z_t, s_t, s_{t+1})$ define the transition rule for z_t, such that $z_{t+1} = \zeta_h^m(z_t, s_t, s_{t+1})$ (assuming that the borrower stays current on the mortgage by making the per-period payment).[6]

2.4 Homeowners' dynamic decision problem

Homeowners enter each period being described by their income y_i (which is assumed constant over time), their level of liquid savings w_{it}, their mortgage contract (z_{it}, m_{it}), and the type of house they own h_i. For notational convenience, let $x_{it} = (y_i, w_{it}, h_i)$ be the characteristics of the homeowner separate from their mortgage contract.

Moving

In each period, the homeowner has to move with probability λ. If the homeowner moves, it can either pay off its remaining mortgage and sell the house, or it can default on its mortgaeg (in which case the lender repossesses and sells the house). If the homeowner chooses to sell, it simultaneously pays offs its remaining mortgage balance, b_{it}, and receives the current price of the home, $p_{h_i}(s_t)$. The homeowner's utility over final wealth when selling is therefore:

$$V^{sell}(x_{it}, z_{it}, m_{it}, s_t) = \beta u(y_i + w_{it} + p_{h_i}(s_t) - b_{it})$$

[6] I give examples of these functions for various kinds of contracts in the Appendix.

On the other hand, if the homeowner chooses to default, it does not have to pay off its existing mortgage balance, but it forfeits any proceeds from the sale of the house. In addition, the homeowner must pay a default cost c_D. The utility to defaulting is therefore:

$$V^{def}\left(x_{it}, z_{it}, m_{it}, s_t\right) = \beta u\left(y_i + w_{it} - c_D\right)$$

It is easy to see that default only happens if the negative equity of the homeowner is greater than the default cost. Finally, we write

$$V^{move}\left(x_{it}, z_{it}, m_{it}, s_t\right) = \max\left\{V^{sell}\left(x_{it}, z_{it}, m_{it}, s_t\right), V^{def}\left(x_{it}, z_{it}, m_{it}, s_t\right)\right\}$$

as the value function for the homeowner who enters the period having to move.

Staying

With probability $1-\lambda$, the homeowner is not required to move. If the homeowner stays, then it can either continue in its current mortgage contract by making the required payment, or it can refinance into a new contract. After that, the homeowner decides how much to consume and how much to save at a risk-free rate rfr_t, which is part of s_t. Credit markets are imperfect, and homeowners are unable to borrow at the risk-free rate. All borrowing must be done through mortgage contracts.

If the homeowner chooses to continue in its current mortgage, then it must make the required payment. The homeowner's budget constraint is therefore:

$$\begin{aligned} c_{it} + \frac{1}{1+rfr_t} w_{it+1} &= y_i + w_{it} - pay_{h_i}^{m_{it}}\left(z_{it}, s_t\right) \\ w_{it+1} &\geq 0 \end{aligned}$$

and the contract it carries into next period is $z_{it+1} = \zeta_{h_i}^{m_{it}}\left(z_{it}, s_t, s_{t+1}\right)$.

If the homeowner instead chooses to refinance, it first pays a cost of refinancing c_R. Then, the homeowner simultaneously pays off the existing mortgage balance b_{it} and chooses a new contract type m and a new loan amount

b. New originations of mortgage type m and new loan amount b are available at equilibrium interest rate $r^m(b, x_{it}, s_t)$. It is assumed here that lenders can observe all relevant characteristics of the borrower, including collateral type, and are therefore able to price mortgages on those attributes. Additionally, I assume that new originations are restricted to borrowing amounts $b \le \bar{b}^m(x_{it}, s_t)$, which is an object that determines the maximum borrowing amount for given contract type.[7]

Given a refinancing choice of m and b, the new contract terms are given by: $z = (0, r^m(b, x_{it}, s_t), b)$. The budget constraint is therefore:

$$
\begin{aligned}
c_{it} + \frac{1}{1 + rfr_t} w_{it+1} &= y_i + w_{it} - b_{it} + b - pay^m_{h_i}(z, s_t) - c_R \\
w_{it+1} &\ge 0
\end{aligned}
$$

and the contract the homeowner carries into next period is $z_{it+1} = \zeta^m_{h_i}(z, s_t, s_{t+1})$.

Bellman Equations

Let $V^{stay}(x_{it}, z_{it}, m_{it}, s_{it})$ be the value function of a homeowner at the start of a period in which it does not have to move. Let ρ be an indicator for whether or not the homeowner chooses to refinance, and if so, let (m, b) be the new mortgage contract. Let c be the chosen consumption and let w' be the chosen level of savings for next period. The homeowner chooses ρ, m, b, c, w' to solve:

$$
\begin{aligned}
V^{stay}(x_{it}, z_{it}, m_{it}, s_t) = \max \quad & u\left(\theta^{h_i} c\right) + \delta E\Big[(1-\lambda) V^{stay}(x_{it+1}, z', m', s_{t+1}) \\
& + \lambda V^{move}(x_{it+1}, z', m', s_{t+1}) \Big| x_{it}, z_{it}, m_{it}, s_t\Big] \quad (1)
\end{aligned}
$$

[7] Limitations on the maximum borrowing amount may arise, for example, from regulations prohibiting the origination of agency loans greater than the conforming loan limit. Borrowing limits may also arise endogenously if it becomes unprofitable for the lender to lend to certain borrowers in certain situations.

subject to:

$$c + \frac{1}{1 + rfr_t} w' = \begin{cases} y_i + w_{it} - pay_{h_i}^{m_{it}}(z_{it}, s_t) & \text{if } \rho = 0 \\ y_i + w_{it} - b_{it} + b - pay_{h_i}^{m}(z, s_t) & \text{if } \rho = 1 \end{cases} \tag{2}$$

$$w' \geq 0 \tag{3}$$

$$b \leq \bar{b}^m(x_{it}, s_t) \tag{4}$$

$$z' = \begin{cases} \zeta_{h_i}^{m_{it}}(z_{it}, s_t, s_{t+1}) & \text{if } \rho = 0 \\ \zeta_{h_i}^{m}(z, s_t, s_{t+1}) & \text{if } \rho = 1 \end{cases} \tag{5}$$

$$m' = \begin{cases} m_{it} & \text{if } \rho = 0 \\ m & \text{if } \rho = 1 \end{cases} \tag{6}$$

$$z = (0, r^m(b, x_{it}, s_t), b) \tag{7}$$

Constraint (2) is the budget constraint faced by the homeowner, based on whether it decides to refinance or not. Constraint (3) is the no-uncollateralized-borrowing constraint. Constraint (4) is the mortgage borrowing limit. Finally, constraints (5)-(7) are accounting identities that describe the evolution of the mortgage contract. The optimization problem is a contraction mapping, and therefore a unique solution for V^{stay} exists and can be found by iteratively computing (1) (see Stokey et al. (1989)).

2.5 Potential buyers

In each period, a mass 1 of potential buyers enters the market. The buyers are heterogeneous in three dimensions: their income y_i, which is constant over time, their initial wealth w_i, and the utility they would receive from *not* purchasing a home, v_i—in other words, their outside option.[8] Given current aggregate conditions and given their individual heterogeneity, each potential

[8]The outside option can be thought of as the net present value of utility from living in a different housing market, or from renting, which is treated as coming from a separate housing stock.

buyer must decide whether or not to purchase a house (and which type to purchase) or to take their outside option. If a potential buyer decides not to buy a house, it receives a utility equal to v_i, exits the housing market, and does not re-enter.

A potential buyers who buys a house of type h choose sa mortgage contract (m, b) to finance the purchase, and then chooses consumption c and savings w'. It then enters the next period as a homeowner, whose problem we have already described. It is easy to describe the decision problem of the potential buyer in terms of the value functions of the homeowner. A potential buyer who purchases house type h chooses $m, b, c, w'$to maximize:

$$\begin{aligned} V_h^{buy}(y_i, w_i, s_t) \quad &= \max \quad u\left(\theta^h c\right) + \delta E\Big[(1-\lambda) V^{stay}(x_{it+1}, z', m', s_{t+1}) \\ &\qquad + \lambda V^{move}(x_{it+1}, z', m', s_{t+1}) \Big| x_{it}, z, m_{it}, s_t\Big] \end{aligned} \tag{8}$$

subject to:

$$c + \frac{1}{1+rfr_t} w' = y_i + w_i - p_h(s_t) + b - pay_h^m(z, s_t) \tag{9}$$

$$w' \geq 0 \tag{10}$$

$$b \leq \bar{b}^m(x_{it}, s_t) \tag{11}$$

$$z' = \zeta_h^m(z, s_t, s_{t+1}) \tag{12}$$

$$z = (0, r^m(b, x_{it}, s_t), b) \tag{13}$$

The decision problem of the new buyer is therefore similar to the decision problem of the refinancing homeowner. The primary difference is in the budget constraint, where the potential buyer needs to pay for the price of the home it is buying.

A potential buyer will purchase the house type that gives it the most utility, or it will choose not to purchase if neither gives higher utility than the outside option. Ignoring ties, the potential buyer will purchase a house of type h if and only if:

$$V_h^{buy}(y_i, w_i, s_t) = \max\left\{V_0^{buy}(y_i, w_i, s_t),\ V_1^{buy}(y_i, w_i, s_t),\ v_i\right\} \tag{14}$$

2.6 Housing market demand and supply

Let $d_h(y_i, w_i, v_i, s_t)$ be an indicator function for whether a potential buyer buys a house of type h in state s_t, as determined by equation (14). Now, let the distribution of potential buyer heterogeneity in state s_t be given by the probability density function $\Gamma(y_i, w_i, v_i; s_t)$.

The total demand for house type h in state s_t is therefore:

$$D_h(s_t) = \int_y \int_w \int_v d_h(y, w, v, s_t)\, \Gamma(y, w, v; s_t)\, dydwdv \tag{15}$$

The supply of homes for sale in each period is created by existing owners who are moving out. Since a fraction λ of existing owners move out each period, the total mass of homes for sale of each type in each period is $\lambda\mu$. In order for the housing market to clear, demand for each house type must equal the supply on the market. Therefore, in equilibrium, the following must hold:

$$D_h(s_t) = \lambda\mu \text{ for } h = 0, 1 \tag{16}$$

Equation (16) is the housing market clearing condition. It is a simple supply and demand equation from which house prices can be determined in each state. The decision problem of the buyer, as described in equations (8)-(13), clearly shows that the mortgage market, through the mortgage interest rates r^m and contract availability b^m, can shift the demand curve, and thereby house prices.

2.7 Lenders

Each individual mortgage contract is originated by a risk-neutral and competitive lender. Other than the mortgage contract, the lender is able to invest in single-period risk-free bonds with a return of $rfr_t + a_m$. Each lender originates one mortgage and invests future receipts into these single-period bonds. The return on bonds, $rfr_t + a_m$, can be thought of as the opportunity cost of funds for the lender in period t. The cost of funds above the risk-free rate a_m is allowed to vary by contract type, reflecting higher liquidity for certain mortgage products such as agency loans. At the time of origination, the lender sets the mortgage interest rate such that the expected return on the mortgage is equal to the opportunity cost of funds.

Let $\Pi^{move}(x_{it}, z_{it}, m, s_t)$ be the expected present value of receipts from mortgage contract (z_{it}, m) held by borrower x_{it} who has to move. Letting $\tau(x_{it}, z_{it}, m, s_t)$ be the optimal default rule, we can write:

$$\begin{aligned}\Pi^{move}(x_{it}, z_{it}, m, s_t) &= \tau(x_{it}, z_{it}, m, s_t)\,\psi^m_{h_i}(z_{it}, s_t) \\ &\quad + (1 - \tau(x_{it}, z_{it}, m, s_t))\, b_{it}\end{aligned}$$

Now let $\Pi^{stay}(x_{it}, z_{it}, m, s_t)$ be the expected present value of receipts from mortgage contract (z_{it}, m) held by a borrower x_{it} who does not have to move. Letting $\rho(x_{it}, z_{it}, m, s_t)$ be the optimal refinance rule, we write:

$$\begin{aligned}\Pi^{stay}(x_{it}, z_{it}, m, s_t) &= \rho(x_{it}, z_{it}, m, s_t)\, b_{it} \\ &\quad + (1 - \rho(x_{it}, z_{it}, m, s_t))\,\Pi^{norefi}(x_{it}, z_{it}, m, s_t) \quad (17)\end{aligned}$$

where:

$$\begin{aligned}\Pi^{norefi}(x_{it}, z_{it}, m, s_t) &= pay^m_{h_i}(z_{it}, s_t) \\ &\quad + \left(\frac{1}{1 + rfr_t + a_m}\right) E\Big[\lambda \Pi^{move}(x_{it+1}, z', m, s_{t+1}) \\ &\quad + (1-\lambda)\,\Pi^{stay}(x_{it+1}, z', m, s_{t+1}) \Big| x_{it}, z_{it}, m, s_t\Big]\end{aligned}$$

and:

$$z' = \zeta^m_{h_i}(z_{it}, s_t, s_{t+1})$$

Now let $\Pi^{orig}(x_{it}, m, b, s_t)$ be the expected present value of receipts for a new origination (m, b). Since a new mortgage is not refinanced on the same period it is originated, we can write:

$$\Pi^{orig}(x_{it}, m, b, s_t) = \Pi^{norefi}(x_{it}, z, m, s_t)$$

with $z = (0, r^m(b, x_{it}, s_t), b)$. In equilibrium, the expected excess return of the mortgage contract over the opportunity cost of funds is zero, so:

$$\Pi^{orig}(x_{it}, m, b, s_t) - b = 0 \tag{18}$$

2.8 Competitive equilibrium

The economy is in competitive equilibrium when homeowners and potential buyers are behaving optimally, as described by equations (1) and (8), and the housing market and mortgage markets clear. The housing market clearing condition is given by equation (16) and the mortgage market clearing condition is given by equation (18). The equilibrium objects that must be solved for are all the value functions and policy rules described above. However, all the value functions and policy rules can easily be computed as long as the following four objects are known:

1. The equilibrium house prices: $p_h(s_t)$
2. The equilibrium mortgage interest rates: $r^m(b, x_{it}, s_t)$
3. The equilibrium value functions $V^{stay}(x_{it}, z_{it}, m_{it}, s_t)$ and $\Pi^{stay}(x_{it}, z_{it}, m_{it}, s_t)$.

A competitive equilibrium can be found using an iterative procedure with three nests. In the inner nest, p_h and r^m are taken as given, and V^{stay} and Π^{stay} are chosen to satisfy their respective Bellman equations. In the middle nest, p_h is given and r^m is chosen to satisfy the mortgage market clearing condition. In the outer nest, p_h is chosen to satisfy the housing market clearing condition. Each nest is described below:

Inner Nest

p_h and r^m are given

1. Guess V_0^{stay} and Π_0^{stay}. The subscripts here indicate the step in the algorithm.

2. For $iter \geq 0$:

   (a) Compute V_{iter+1}^{stay} by solving (1) using V_{iter}^{stay} on the right-hand-side.

   (b) Compute the optimal policy rules as a result of the solution in (a).

   (c) Compute Π_{iter+1}^{stay} using equation (17), with the policy rules from (b) and Π_{iter}^{stay} on the right-hand-side.

   (d) Repeat until $V_{iter+1}^{stay} = V_{iter}^{stay}$ and $\Pi_{iter+1}^{stay} = \Pi_{iter}^{stay}$, within some tolerance.

Middle Nest

p_h is given

1. Guess r_0^m. The subscript here indicate the step in the algorithm.

2. For $iter \geq 0$

   (a) Compute the **inner nest** until V^{stay} and Π^{stay} reach convergence, taking r_{iter}^m as given.

   (b) For each x_{it}, m, b, s_t, find values $r_{iter+1}^m (b, x_{it}, s_t)$ such that $\Pi^{orig} (x_{it}, m, b, s_t) = b$, using the value functions and policy rules from step (a)

   (c) Repeat until $r_{iter+1}^m = r_{iter}^m$ within some tolerance.

Outer Nest

1. Guess $p_{h,0}$. The subscripts here indicate the step in the algorithm.

2. For $iter \geq 0$

   (a) Compute the **middle nest** until r^m reaches convergence, taking $p_{h,iter}$ as given

(b) For each s_t, find values of $p_{h,iter+1}(s_t)$ until $D_h(s_t) = \lambda\mu$, using the value functions, policy rules, and interest rates from step (a)

(c) Repeat until $p_{h,iter+1} = p_{h,iter}$ within some tolerance

When the outer nest converges, an equilibrium has been found.

3 Implementation

In the previous section, many details of the model were presented abstractly, such as the state variable s_t. The advantage of presenting an abstract view is that it highlights the main structure and economic mechanisms present in the model, without bogging down the exposition in details. In this section, I flesh out the details of the model as it will be used for the rest of the paper.

3.1 Mortgage types

In the baseline model, I allow for three mortgage types. In addition to $m = 0$, "no mortgage", the other two types are $m = 1$: agency loans, and $m = 2$: non-agency loans. Each of these loan types are modeled as 30-year fixed rate loans.[9]

Agency loans are loans that are securitizable by the government-sponsored agencies, Freddie Mac and Fannie Mae. Freddie Mac and Fannie Mae carry implicit government guarantees on their credit obligations, so it is assumed that lenders treat agency loans as if there were no default risk. In practice, this means that $\psi_h^1(z_t, s_t) = b_t$ for agency loans. That is, lenders are compensated fully for the remaining balance on the loan in case of a default.

A mortgage must meet certain criteria in order to qualify as an agency loan. These criteria are set by the Federal Housing Finance Agency (FHFA),

[9] The required payment and transition rules for fixed rate loans are given in the Appendix. Although the baseline model only allows fixed rate loans, the model is readily extendable to include other types of mortgage contracts. In section 6, I consider the effects of introducing alternative mortgage products that share house price appreciation between borrower and lender.

which regulates Freddie Mac and Fannie Mae. First, a loan must have an original balance less than or equal to what is known as the "conforming loan limit", which I denote by cll_t. In addition, the original balance of an agency loan cannot exceed 80% of the collateral value of the home.[10]

In contrast to agency loans, non-agency loans carry no guarantees. In the event of a default, the lender forecloses on the home and recovers a fraction φ of its value. Therefore, $\psi_h^2(z_t, s_t) = \varphi p_h(s_t)$ for non-agency loans. Unlike agency loans, there are no restrictions on the size of a non-agency loan. The only restriction on non-agency loans is that the borrowing amount cannot exceed the collateral value of the home. Because I am interested in modeling the effect of disappearing non-agency market, I also introduce an aggregate state variable, mps_t, which is an indicator for whether non-agency loans are available. If $mps_t = 0$, then I assume that borrowers cannot use non-agency loans, regardless of amount.

Finally, I assume that for both agency and non-agency loans, the mortgage payment cannot exceed 50% of the borrower's income. Table 1 summarizes the borrowing limits for agency and non-agency loans.

Table 1: Modeled Borrowing Limits for Agency and Non-Agency Loans

Agency	**Non-Agency**
Cannot exceed cll_t	Cannot exceed 100% of collateral value
Cannot exceed 80% of collateral value	Payment cannot exceed 50% of income
Payment cannot exceed 50% of income	Unavailable if $mps_t = 0$

3.2 Potential buyer distributions

Potential buyers are heterogeneous in their income y_i, which is constant, their initial wealth w_i, and their outside option v_i. Log-income is normally distributed with mean μ_t^y and variance σ_y^2. The mean of the income distribution

[10] In reality, agency loans can exceed 80% of the collateral value of a home. However, to obtain an agency loan with LTV greater than 80%, one must purchase private mortgage insurance. In the context of the model, I will assume that an agency loan with private mortgage insurance is priced in such a way that it is functionally equivalent to a non-agency loan of the same size.

can change over time, but the variance remains constant.

For potential buyers with income y_i, initial wealth is distributed according to a censored normal distribution:

$$\begin{aligned} w_i^* &= \alpha_0^w + \alpha_1^w y_i + \mathcal{N}\left(0, \sigma_w^2\right) \\ w_i &= \max\left\{0, w_i^*\right\} \end{aligned}$$

I choose a censored normal distribution for wealth rather than a log-normal distribution in order to generate a mass of potential buyers with zero wealth. Such a wealth distribution is able to explain loan-to-value ratio patterns in the data fairly well. Wealth is allowed to be correlated with income to reflect the possibility that high-income buyers are also more likely to have higher initial wealth; but the correlation is not perfect.

Finally, let v_i^* be such that $v_i = u\left(v_i^*\right)$. The transformed variable v_i^* is uniformly distributed between 0 and $\bar{v}_t$. Because the lower bound of the support of v_i^* is zero, there will always be a positive mass of potential buyers who will always buy a house as long as they can afford it. The state variable $\bar{v}_t$ controls the average outside option of potential buyers, and can therefore be thought of as an unobserved demand shock. When $\bar{v}_t$ is high, then the average outside option is high and demand for houses will be low. When $\bar{v}_t$ is low, demand for houses will be high.

3.3 State vector and state transitions

So far I have mentioned five aggregate state variables: (1) the risk free rate rfr_t; (2) the conforming loan limit cll_t; (3) the mean income of potential buyers μ_t^y; (4) the unobserved demand shock $\bar{v}_t$; (5) the availability of non-agency loans mps_t. In addition to these five, I allow for one more state variable, g_t. The variable g_t determines the transition process of the unobserved demand shock $\bar{v}_t$. In particular, conditional on $\bar{v}_t$, $\log\left(\bar{v}_{t+1}\right)$ is given by:

$$\log\left(\bar{v}_{t+1}\right) = g_t + \log\left(\bar{v}_t\right) + \mathcal{N}\left(0, \sigma_v^2\right) \quad (19)$$

Therefore, the state variable g_t controls the evolution and expectation of future demand shocks. I allow g_t to take on two possible values, so that housing demand can either be in a state of growth: $g_t = g_L$; or in 0a state of decline: $g_t = g_H$. (Note that a high rate of growth for the outside option implies declining housing demand.)

The aggregate state vector is therefore given by $s_t = (rfr_t, cll_t, \mu_t^y, mps_t, g_t, \bar{v}_t)$. Besides $\bar{v}_t$, I do not allow any of the other variables to vary stochastically. That is, agents in the economy believe that the other state variables remain constant over time. If these other state variables do change, it is completely unexpected. It is not difficult to relax this assumption, but neither is it a bad assumption for the region and period of time that I will be interested in (Los Angeles 2003-2011). Average incomes in Los Angeles are roughly constant over this period. Moreover, risk-free rates and conforming loan limits do not change much over this period, and when they do (in 2008), it is in response to the unexpected financial crisis. Similarly, the disappearance of non-agency loans ($mps_t = 0$) was a result of the unexpected crisis. However, agents do believe that house prices can change over this period, through the evolution of the unboserved demand shocks.

3.4 Default and refinance costs

For the default and refinance costs, I choose the conceptually appealing case of *ruthless default* ($c_D = 0$) and *no refinancing* ($c_R \gg 0$). Ruthless default here means that owners who are hit by a moving shock default if and only if the remaining balance of their mortgage exceeds the price of their home. Although this particular choice of default and refinance costs may not accurately reproduce all the moments in the data, it is interesting to study how far this simplified model can take us in explaining the data. As it turns out, ruthless default with no refinancing allow us to explain time-variation in default rates by buyer cohort quite well. Allowing refinancing coupled with ruthless default would help explain default rates even more closely. I discuss these points further in section 5.

3.5 Discretization

The model is solved over discrete grids of its variables. I describe exactly how each variable is discretized in the Appendix. For now, special mention should be made of two variables for which I only allow one grid point: the savings of homeowners, w_{it}, and mean log-income μ_t^y.

Only one grid point is used for mean income. What this means is that the mean income of potential buyers is constant. This is not an unrealistic assumption for Los Angeles from 2003 to 2011, because the average real income of Los Angeles residents from 2003 to 2011 was roughly constant at \$55,000 (2012 dollars). Note that the assumption does not imply that the mean income of *actual* buyers has been constant, only the mean income of *potential* buyers. In both the model and the data, the average income of actual buyers is correlated with house prices.

I only use one grid point for savings in order to reduce the computational complexity of the model. With one grid point, homeowners are assumed to save only a minimal amount for precautionary purposes. The results of the paper are robust to this assumption because only households with very high initial wealth relative to income (a small percentage) would have any incentive to save, due to the fact that both income and mortgage payments are constant in the model. Even for the households who do have an incentive to save, they are better off reducing their initial mortgage balance rather than increasing their level of savings. I have also computed a version of the model with two grid points for savings, and found that doing so did not change any results (the large majority of homeowners do not choose to save at a higher rate).

Finally, three other variables with a small number of grid points will be mentioned. First, household income y_i takes one of two values: \$80,000 or \$150,000. These roughly correspond to average buyer income for "low-quality" and "high-quality" homes during the sample period. Second, the risk-free rate rfr_t takes only the values of 0.025 and 0.015. These roughly correspond to the real 10-year treasury rate before 2007 and after 2008. Third, the conforming loan limit cll_t takes only the values \$400,000, \$450,000, and \$750,000. These roughly correspond to the values that the real conforming loan limit took from

2003 thru 2011. Most other variables, such as initial wealth w_i and unboserved demand shock $\bar{v}_t$, have a large number of grid points.

4 Data

Data for the calibration of the model comes from three main sources. The first is an administrative database of housing transactions provided by DataQuick, a real estate consulting company. DataQuick collects data from public records on property transactions. Each time a property is sold, the transaction price, closing date, and any liens against the property are recorded. This allows me to observe the universe of home sale prices and the loan amounts they are purchased with. In addition to sales, DataQuick also contains information about refinances. Each time a new loan is originated against a property, the amount of the loan and the origination date are recorded by DataQuick. DataQuick data for Los Angeles goes back to 1988, and the latest year for which I have data is 2012. Each observation in DataQuick includes a unique property identifier, so it is possible to follow a single property over time and construct an ownership history that includes purchase date, purchase price, loan amount, sale date, sale price, and any refinances along the way. Moreover, DataQuick includes a flag for whether each transaction is part of a distress event, so I can identify the ownership histories that end in a foreclosure.

Using the DataQuick data, I first decompose the L.A. housing market into two segments, which correspond to $h = 0$ and $h = 1$ in my model. To do this, I first run a fixed-effects regression of log sale price on property fixed effects and year fixed effects.[11] I then divide the properties into two groups, based on whether the property's estimated fixed effect is above or below the median fixed effect in the data. If the property has an estimated fixed effect higher than the median, it is assigned $h = 1$. Otherwise it is assigned $h = 0$.

After assigning the properties to two groups, I perform a repeat sales re-

[11] All prices are real house prices, reported in 2012 dollars. Nominal prices are deflated by the CPI-U-national. All interest rates reported in this section are also deflated by 0.018, which is the average inflation rate from 2003 to 2010.

gression using the methodology of Case and Shiller (1989) separately on the two groups. Panel A of Figure 2 reports the resulting price indices with 1999 as the base year. Panel B of Figure 2 reports the implied price levels. Panel A shows that the lower valued homes in Los Angeles appreciated at a considerably higher rate than did the higher value homes. This phenomenon was also observed in San Diego by Landvoigt et al. (2015). Panel B reveals that although lower-valued homes appreciated at a faster rate, this is mostly because they started at a lower base level. In fact, it appears that over this time period, yearly changes to the price levels for the two groups followed each closely. The patterns in Figure 2 can be replicated by the model in this paper, and is best be explained by a model where the price differences between the low and high-valued groups of housing are primarily determined by wealth and borrowing constraints.

In addition to constructing price paths, the DataQuick data is used to construct the average loan-to-value ratios of Los Angeles home buyers from 2003 to 2011. This is done separately for the two groups of housing. Columns 1 and 2 of Table 2 shows the average LTV of buyers by year and house type. Two facts stand out. First, buyers of low-valued housing generally have to borrow more to purchase their homes. This is likely due to them having lower initial wealth. Second, LTVs for both groups dropped considerably after 2008. This is likely due to the disappearance of the non-agency mortgage market. Both facts can be explained by the model.

Besides DataQuick, the two other sources of data are two loan-level databases; the first provided by Freddie Mac and the second provided by BlackBox, a real estate finance consulting company. The Freddie Mac data is a random sample of 30-year fixed rate loans originated between 1999 and 2012, and purchased by Freddie Mac. The database contains important information about each loan contract, including the interest rate. The BlackBox data is a loan-level administrative dataset containing information on all kinds of non-agency mortgage products. The data covers over 90% of all non-agency securitzation pools. The BlackBox data contains a wealth of information about each mortgage's contractual terms, but for the purposes of this paper I am only interested in the contract type and the interest rate. Like the Freddie Mac dataset, the BlackBox data goes back to 1999.

The first thing I would like to do with the mortgage data is to verify that the non-agency market all but disappeared in 2008. Using BlackBox data, column 5 of Table 2 shows the number of non-agency fixed-rate loan originations in Los Angeles from 2003 to 2010 (the results do not change when including other product types). It is clear from this table that non-agency mortgages became unavailable after 2008. This fact is also confirmed by external sources. Figure 1 shows the total volume of agency and non-agency mortgage-backed securities issuance in the U.S., as reported by the Securities Industry and Financial Markets Association. The figure shows that non-agency securitzation had completely died out by 2008.

The second thing I do with the mortgage data is construct average interest rates for agency and non-agency mortgage originations in Los Angeles, from 2003 to 2010. The averages are computed using only 30-year fixed rate loans. The average real interest rates are shown in columns 3 and 4 of Table 2. As expected, non-agency loans carry a higher interest rate than agency loans, on average.

5 Calibration

5.1 Data

The model parameters are calibrated by fitting model predictions to aggregate moments observed in the data. The data available are the following:

$$\left\{rfr_t, cll_t, mps_t, p_{ht}, r_{mt}, \overline{ltv}_{ht}, T_{it}\right\}$$

for $t = 1, \ldots, 8$. That is, I observe the risk-free rate, conforming loan limit, availability of non-agency loans, house prices for each house type, average mortgage interest rate for each contract type (agency/non-agency) among buyers, and average LTV of buyers of each house type. In addition, I also see the duration between purchase and sale, T_{it}, for buyers i who bought in period t.

The 8 periods correspond to the housing market in Los Angeles from 2003 to 2010. The values for some of these data are given in Figure 2 and Table 2. The path of the aggregate state variables: rfr_t, cll_t and mps_t are together given in Table 3. Note that in Table 3, g_H and g_L are parameters to be determined, and the demand shocks $\bar{v}_t$ are not observed. However, given a guess of the model's parameters, the demand shocks can be backed out from the realized price paths by inverting $p_h(s_t)$ in each period.[12]

5.2 Calibration method

The parameters to be calibrated are given in Table 4. The first two parameters of the model, the risk aversion parameter γ and the time-discount factor δ are chosen to be 3 and 0.95. The total mass of each house type, μ, is normalized to 1. The recovery rate on foreclosures φ is chosen to be 0.72. The variance of the log of potential buyer income is 0.9025, which is equal to the average cross-sectional variation in log-income for Los Angeles residents from 2003 to 2011, as computed using data from the American Community Survey.

The first unknown parameter, λ, can be estimated from T_{it} simply by calculating the per-period hazard rate of a homeowner selling his or her home. Doing this yields an estimate of $\lambda = 0.0952$, which corresponds to an average duration between purchase and sale of about 10 years.

The rest of the parameters are calibrated to fit aggregate moments in the data. Given a guess of the parameters, the model is first solved as described in Section 2. Once the function $p_h(s_t)$ is known, $\bar{v}_t$ can be computed for each period by inverting $p_h(s_t)$ and taking the observed state variables as given. Once the state variables in each period are known, the model is simulated for the 8 periods from 2003 to 2010.

[12] Because there is not much change in the aggregate state variables—other than the unobserved demand shocks—from 2003 to 2006, the model will explain most of the price increases from 2003 to 2006 as being driven by $\bar{v}_t$. This paper is therefore unequipped to say much about the causes for rapid house price appreciation in the mid-2000's, although decreases in the risk-free rate and increases in conforming loan limits can be ruled out as the most significant factors. One explanation that the model could potentially be extended to study is the growth in subprime mortgages and their unique contract features.

The target moments are the following:

1. p_{ht}: price levels in Los Angeles, by house type, as given in Figure 2.

2. r_{mt}: average interest rate rate by agency/non-agency among new buyers, as given in Table 2

3. $\overline{ltv}_{ht}$: average LTVs among new buyers, by house type, as given in Table 2

4. Implied transition distribution of the unobserved demand shocks (I elaborate more below)

The simulated house price are computed directly from $p_h(s_t)$. The average interest rate by contract type and the average LTV by house type are calculated by averaging over the simulated choices of the buyers in each year.

5.3 Sources of identification

Although all the parameters will affect all the moments in different ways, it is useful to discuss the ways in which particular parameters might affect particular moments, in order to better understand the sources of identification.

First, the price path of a single house type, say $h = 0$, can be used to identify $\bar{v}_t$ in each period, and then θ is identified off the price differences between $h = 0$ and $h = 1$ houses.

Second, the average interest rates by agency/non-agency are used to identify the cost of funds, a_m. Intuitively, the model predicts an expected return for mortgages observed in the data. If the expected return is higher than the risk-free rate, then the difference identifies a_m.

Third, average LTVs for the two types of housing can be used to identify the parameters governing the wealth distribution, α^w. For example, larger differences in LTV between $h = 0$ and $h = 1$ buyers imply a higher coefficient of income on wealth.

Finally, the parameters governing the evolution of the unobserved demand shock, g_H, g_L and σ_v^2 can also be estimated. For any guess of the parameters (g_H, g_L, σ_v^2), first compute the implied realizations of $\bar{v}_t$ each period by matching the realized price paths. Then, an estimated $\hat{g}_H$, $\hat{g}_L$ and $\hat{\sigma}_v^2$ can be computed from:

$$\hat{g}_j = \frac{1}{8}\sum_{t=1}^{8} 1\left[g_t = g_j\right] \times \log\left(\bar{v}_{t+1}/\bar{v}_t\right) \text{ for } j = H, L$$

$$\hat{\sigma}_v^2 = \frac{1}{7}\sum_{t=1}^{8}\left[\log\left(\bar{v}_{t+1}/\bar{v}_t\right) - g_t\right]^2$$

If g_H, g_L and σ_v^2 are the true parameters that generate the data, then $E\left[\hat{g}_j\right] = g_j$ and $E\left[\hat{\sigma}_v^2\right] = \sigma_v^2$. Therefore, $\hat{g}_j - g_j$ and $\hat{\sigma}_v^2 - \sigma_v^2$ are moments that can be used to estimate g_H, g_L and σ_v^2.

5.4 Results and model fit

Table 5 shows the resulting values for each of the unknown model parameters. Figure 3 shows the resulting model fit for house prices. Figure 4 shows the estimated values of the unboserved demand shock, $\bar{v}_t$, that generates the price paths. The model is able to replicate the path of house prices in the data very well. This is not surprising, as the unobserved demand shock $\bar{v}_t$ is chosen in each period to best match the house prices in that period. However, it is less obvious that both the price paths for high and low quality homes could be replicated by a single $\bar{v}_t$ in each period. The fact that the model matches both price paths well suggests that the price difference between low and high-quality homes can be well explained by a single parameter which is constant over time.

Table 6 shows the model fit for average buyer LTV by house type. The model is able to replicate some of the main features of the data. First, the model is able to replicate the decline in LTVs after 2008, and the feature that LTVs declined more for buyers of high-valued housing than for buyers of low-valued housing. Second, the model is able to replicate the generally higher LTVs for buyers of low-valued housing than for buyers of high-valued housing—however, the extent of this phenomenon appears to be stronger in the actual data than in the simulated data.

Table 7 shows the model fit for average interest rate by mortgage type. The model replicates the generally higher interest rates for non-agency loans compared to agency loans, and replicates the decline in interest rates post-2008. However, the model is unable to explain some of the time-variation in the data, especially for non-agency loans.

Figure 5 shows the model fit of cumulative default rate for buyers of different cohorts. Both the model's simulated default rates and the actual default rates, as computed from DataQuick data, are plotted. The model appears to underpredict the rate of defaults by a constant factor, but predicts changes over time well. In the model, default is entirely driven by underwater homeowners who are hit with a moving shock. Cohort default rates are thus determined by the distribution of initial LTVs in the cohort and the changes to house prices they face over time. This is consistent with the "double trigger" model of default, in which *two* conditions are needed to trigger a default: first that the homeowner has negative equity (otherwise he or she could sell the home instead of defaulting), and a second shock which necessitates a move or reduces liquidity (otherwise the homeowner continues to pay down the mortgage). Figure 5 shows that our model, in which default is triggered by the joint occurrence of negative equity and a moving shock, can explain changes to default rates over time quite well. However, there is still a baseline level of default that the model does not capture. These are likely defaults due to job loss (as opposed to moving shocks) that are not captured in the model, or defaults driven by individual-level house price shocks, which are also not captured in the model.

Overall, the model is able to explain many salient features of the data. Crucially, the model is able to explain the difference in prices between low and high-valued homes, the decline in LTVs after 2008, the difference in LTV between buyers of high and low-valued homes, the difference in mortgage interest rate between agency and non-agency loans, and changes over time to mortgage default risk.

6 Counterfactual exercises

6.1 The impact of non-agency mortgage credit availability

Figure 3 shows that house prices experienced their largest decline from 2007 to 2008. In between these two periods, four aggregate state variables changed. First, the risk-free rate went down. Second, the conforming loan limit went up. Third, the non-agency mortgage market disappeared. Fourth, unobserved demand goes up, as shown in Figure 4. Declining risk-free rate, increasing conforming loan limit, and increasing demand shock should all have the effect of increasing house prices—so the fact that house prices went down implies that the effect of the disappearning non-agency market was dominant. Non-agency mortgages are very important for housing demand because they allows potential buyers with low wealth to borrow at high LTV ratios. Without the availability of high-LTV loans, low-wealth buyers—even if they have a large desire to purchase housing—are priced out of the market.

Figures 6 to 11 illustrate. Figure 6 shows the value functions for potential buyers in 2007, as simulated under the baseline model, and Figure 7 shows the implied housing demand. The figures show that in 2007, low-income buyers with very low-wealth are unable to purchase homes of any type. Because of their low initial wealth, they need to borrow a large amount in order to finance the purchase of even a low-quality home. The mortgage payment required on such a loan would exceed 50% of their income. Low-income buyers with low to moderate wealth are unable to purchase high-quality homes for the same reason, but are able to purchase low-quality homes. Low-income, high-wealth buyers are able to purchase high-quality homes. High-income buyers—even those with very little wealth—are able to purchase high-quality homes. The presence of high-LTV loans in the non-agency market allow them to borrow enough to finance the purchase of expensive homes, and because they have high-income, they are able to afford the mortgage payment on these large loans. Figure 8 shows mortgage demand for buyers in 2007. Low-wealth buyers need to finance their home purchases through the use of high-LTV, non-agency loans. Moderate wealth buyers use agency loans, and very high-wealth buyers are able to purchase their homes using cash only.

Figure 9 shows the value functions for potential buyers in 2008, and Figure 10 shows the implied housing demand. In contrast to 2007, low-wealth buyers of both income groups are unable to purchase homes of any type in 2008. This is due to the unavaiability of high-LTV, non-agency mortgages. Figure 11 shows the mortgage demand profile in 2008, and it shows that moderate-wealth buyers finance their purchases with agency loans, while low-wealth buyers are priced out. Because low-wealth buyers are priced out of the market in 2008, the demand for housing is much lower than in 2007. For the housing market to clear, house prices need to be lower in order to attract more high-wealth, but lower housing preference buyers. Because the mass of buyers with high-wealth is relatively small comapred to the mass of buyers with low-wealth, house prices must go down by a lot in order to attract a greater fraction of high-wealth buyers. Figure 10 shows that prices go down to such an extent that *all* high-wealth, high-income buyers enter the housing market, even those with the highest values of their outside options.

Figures 6 to 11 illustrate the impact that non-agency mortgage availability has on house prices and on the equilibrium allocation of buyers to homes. A natural question to ask would be: "What if the non-agency market did not disappear in 2008?" The model can be used to simulate outcomes under this counterfactual, simply by changing mps_t to 1 for 2008 through 2010. I also keep the risk-free rate and the conforming loan limit at their 2007 levels in the counterfactual, under the assumption that these changes were direct government responses to the exogenous collapse in the non-agency market. The counterfactual outcomes are simulated under the values for $\bar{v}_t$ estimated from the baseline model, as reported in Figure 4.

Figure 12 shows the simulated price path under the counterfactual and compares it to the simualted price path under the baseline model. House prices are significantly higher post-2008 under the counterfactual than in the baseline. The impact of the disappearing non-agency market is therefore very significant in the model.[13] The direct reason is that high-LTV loans are once again available under the counterfactual. Figure 14 shows the housing demand profile in 2008 under the counterfactual, and Figure 15 shows the mortgage demand profile. Crucially, these figures show that high-income, low-wealth buyers are able to purchase homes again, financing their purchase through high-LTV, non-agency mortgages. Interestingly, *more* low-income buyers are priced out of the market in the counterfactual than in the baseline. This is because prices are so much higher, it becomes difficult for low-income buyers to afford the required mortgage payments on large loans. How can the price of low-valued homes be higher when so many low-income buyers are priced out of the market? Because when prices for high-quality homes are much higher, many more low-income but moderate-to-high wealth buyers substitute from high-quality homes to low-quality homes, as can be seen by comparing Figures 14 and 10.

Finally, Figure 13 shows cumulative default rates for various cohorts under the counterfactual. Unsurprisingly, default rates are significantly lower in the counterfactual than in the baseline. This is simply because in the counterfactual, house prices do not collapse, and there are therefore few homeowners who ever find themselves underwater.

6.2 The importance of general equilibrium effects

The above counterfactual can also be used to illustrate the importance of general equilibrium feedback effects between the housing and mortgage markets. Figure 16 shows equilibrium mortgage rates offered to low-income buyers in 2008 for the counterfactual in which non-agency mortgages are available. Figure 17 shows mortgage rates in 2008 for the baseline in which non-agency mortgages are *unavailable* (and there are additionally no government responses via risk-free rate or conforming loan limit). The non-agency mortgage rates reported in Figure 17 are counterfactual in nature. Though non-agency mort-

[13]The importance of it may be overstated in the model because model parameters were calibrated under the assumption that the disappearance of the non-agency market in 2008 was entirely exogenous.

gages are unavailable, Figure 17 reports the rate on non-agency mortgages that would be needed for the lender to earn zero expected profit, *under the equilibrium price-paths and homeowner behavior that prevail when non-agency mortgages are unavailable.* Figure 18 compares non-agency mortgages rates under the two regimes on the same graph.

It is clear from Figure 18 that equilibrium mortgage rates are different when non-agency loans are available vs. unavailable. This is due to general equilibrium feedback effects between the housing and mortgage markets. When non-agency mortgages are made available, their availability at a given interest rate schedule changes equilibrium house prices and homeowner behavior. This in turn feeds back into the interest rate schedule that would be needed for lenders to break even. As shown in Figure 18, the general equilibrium effect of making non-agency mortgages available is to *reduce* interest rates. Ignoring general equilibrium effects would therefore cause one to overstate interest rates in the counterfactual where non-agency mortgages are made available, and to underestimate the effect on house prices.

Figure 19 sheds further light on why break-even non-agency mortgage rates are lower in the counterfactual. Figure 19 plots house prices as a function of the unobserved demand shock, $\bar{v}_t$, under the two regimes where non-agency mortgages are available vs. unavailable. The figure shows that prices are more sensitive to demand shocks when non-agency mortgages are unavailable. This is especially true when demand is high ($\bar{v}_t$ is low), which is the case in 2007 and 2008. The fact that prices are more sensitive to demand shocks when non-agency financing is unavailable is easy to understand in terms of their effects on buyer demand. When non-agency financing is available, demand is more inelastic because many low-wealth buyers who have a high preference for housing (low outside option) are able to afford a home. When non-agency financing is unavailable, buyers are more elastic because many buyers with high housing preference are priced out of the market. Thus, in order to clear the housing market, buyers with a lower housing preference but higher wealth must be attracted into the market by lowering house prices.

When prices are more sensitive to demand shocks, then price volatility is higher. And when price volatility is higher, the risk of default is higher too. This is why the break-even non-agency mortgage rates are higher when non-agency financing is unavailable than when they are available. Figure 19 highlights an important general equilibrium effect of the availability of non-agency mortgage financing: its availability reduces price volatility.

6.3 The effectiveness of government responses

The government responded to the disappearance of the non-agency market in two ways. First, it increased the conforming loan limit for various cities in 2008. For Los Angeles, the nominal conforming loan limit was increased from \$417,000 to \$729,750. Second, it reduced the risk-free rate. I now use the model to evaluate the effectiveness of these responses.

Figure 20 shows the house price path that would have resulted if the government had not increased conforming loan limits in 2008. Increasing conforming loan limits had a large effect on high-priced housing in 2008, but the effect becomes smaller in 2009 and 2010. This is expected, because as price levels go down, the importance of a high conforming loan limit is also reduced. Increasing the conforming loan limit does not appear to have a significant effect on the price of low-quality homes.

Figure 21 shows the house price path that would have resulted if the government had not reduced the risk-free rate in 2008. Reducing the risk-free rate has an effect on the prices of both low and high-quality homes. The effect is larger in 2009 and 2010 than in 2008. This suggests that in 2008, when prices are still relatively high, the ability for buyers to overcome the downpayment requirement may be more binding than the interest rate that they face. In contrast, in 2009 and 2010, when prices are lower, the mortgage interest rate is a relatively more important concern.

I make no general statement about welfare because the effects of increasing the conforming loan limit or reducing the risk-free rate on the government budget and on taxes is not modeled. However, if considering only the welfare effects on home buyers and owners, it can be said that both government responses are welfare-improving. In the model, because housing supply is inelastic, welfare gains are entirely captured by the price increases, and existing owners (not new buyers) are the ones who reap the benefit of higher prices.

6.4 Considering alternative mortgage designs

The model can also be used to consider the impact of introducing new mortgage designs that previously have been unavailable in the mortgage market. Mortgages that share house price risk between the borrower and the lender, sometimes known as "shared-appreciation mortgages" or "continuous-workout mortgages", have been discussed proposed, but no substantial progress has ever been made in the U.S. in introducing them to the market.[14]

The intuition for why such mortgages may be beneficial lies in the inefficiency of mortgage default. Foreclosure is an inefficient process, as reflected in the model by the imperfect recovery rate on foreclosures, $\varphi < 1$.[15] Because of the inefficiencies associated with default and foreclosure, lenders generally have an incentive to work out a mortgage balance reduction with borrowers who have faced house price declines, rather than to have the borrower default. However, adverse selection and moral hazard could make such workouts difficult to practice in reality. The idea of a shared-appreciation mortgage is that when house prices decline, the mortgage balance automatically declines as well. Homeowners are therefore never underwater, and foreclosures will be drastically reduced.

Even without foreclosure inefficiency, there are other reasons to think that shared-appreciation mortgages could be beneficial. One reason would be that risk-averse homeowners are highly exposed to house price risk in their local housing market. Due to the indivisibility of housing and imperfect credit markets, homeowners are unable to hedge the house price risk very well. The

[14] Caplin et al. (2007); Shiller (2008); Mian and Sufi (2014) have all considered shared-appreciation (and similar) mortgages as a solution to preventing defaults in the event of a house price collapse. Caplin et al. (2008) argues that one reason these mortgages have gained no traction in the U.S. mortgage market is because of unfavorable tax treatment.

[15] Other sources of inefficiency due to foreclosures could be due to neighborhood externalities. See Anenberg and Kung (2014) for a recent discussion.

introduction of shared-appreciation mortgages allows homeowners to hedge some of this risk by letting risk-neutral lenders, who are not as exposed to local geographic shocks, bear some of the house price risk as well.

In this section, I consider the effect of introducing shared-appreciation mortgages as a non-agency mortgage product, available from 2003 to 2007. Since they are non-agency mortgages, lenders of shared-appreciation mortgages face a higher cost of funds than lenders of agency mortgages. Non-agency fixed-rate mortgages continue to be available.

I consider first a shared-appreciation mortgage which, like a fixed-rate mortgage, is fully amortized over a period of T years, at an interest rate r. The difference is that the balance in each period grows or shrinks proportionally to house prices. I call this a "fully shared appreciation mortgage" (FSAM). The balance of an FSAM evolves according to:

$$b_t^{FSAM} = \frac{p_t}{p_{t-1}} \left[(1+r)\, b_{t-1}^{FSAM} - m_{t-1}^{FSAM} \right]$$

where m_t is the required payment in period t. The required payments are recomputed each period in order to amortize b_t over the remaining term-to-maturity:

$$m_t^{FSAM} = \frac{r\,(1+r)^{T-t}}{(1+r)^{T-t} - 1} b_t^{FSAM}$$

In the Appendix, I show that such a mortgage is indeed fully amortized over T periods, and that under such a mortgage, the homeowner is never underwater. I also discuss its mathematical relationship to fixed-rate mortgages. It is easy to see that if prices never change, the FSAM behaves exactly as a fixed-rate mortgage of equivalent interest rate.

One problem of the FSAM is that mortgage payments can go up over time. This may be undesirable for borrowers with sticky incomes, as is the case in the model. I therefore also consider a mortgage design which I call "partially shared appreciation mortgage" (PSAM). The PSAM is like the FSAM except the balance only changes when prices go down. The balance of a PSAM evolves according to:

$$b_t^{PSAM} = \min\left\{\frac{p_t}{p_{t-1}}, 1\right\}\left[(1+r)\, b_{t-1}^{PSAM} - m_{t-1}^{PSAM}\right]$$

Again, the required payment m_t is recomputed each period in order to amortize b_t over the remaining term-to-maturity:

$$m_t^{PSAM} = \frac{r\,(1+r)^{T-t}}{(1+r)^{T-t} - 1} b_t^{PSAM}$$

The introduction of PSAMs

I consider first the introduction of PSAMs. Figure 23 shows the counterfactual price paths when PSAMs are made available as a non-agency option from 2003 to 2007. The introduction of PSAMs increases house prices only slightly. This is because uptake remains fairly low in the 2003 to 2007 period. Figure 24 shows the mortgage demand profile in 2005 under the counterfactual. It appears that PSAMs are primarily taken by low-income, low-wealth buyers, as they may be particularly attracted to the potential of mortgage payments declining over time. For that possibility, they pay a higher mortgage interest rate, as shown in Figure 25. The interest rate on PSAMs is only slightly higher than the interest rate on non-agency fixed-rate loans because house prices are expected to appreciate in 2005.

Figure 27 shows, in contrast, what mortgage rates on PSAMs would have to be for lenders to break even in 2007—a year when house prices are no longer expected to appreciate. The interest rates charged are much higher—so high, in fact, that no buyers in 2007 take up any shared-appreciation-mortgages, as shown in Figure 26. Interestingly, house prices in 2007 are higher in the counterfactual than in the baseline, even though there is no uptake of PSAMs. This again illustrates the importance of general equilibrium effects when studying the mortgage market.

Figure 28 shows cumulative default rates for different buyer cohorts under the PSAM counterfactual. Interestingly, default rates actually go up for the

2006 and 2007 cohorts. This shows that, even though PSAM borrowers never default, the presence of PSAMs changes the equilibrium, and may actually increase the default risk of borrowers who do not take up PSAMs. Overall, the picture painted by Figures 23 thru 28 is that PSAMs slightly improve the efficiency of the mortgage market, but uptake will generally be low because most home buyers do not want to pay the higher interest rates on PSAMs.

The introduction of FSAMs

I now consider the introduction of FSAMs. Figure 29 shows the counterfactual price paths when FSAMs are made available as a non-agency option from 2003 to 2007. The introduction of FSAMs increases house prices significantly. Figure 30 shows that in 2005, there is significant uptake of FSAMs, especially among lower-wealth buyers. In fact, FSAMs completely dominate non-agency fixed-rate mortgages. Figure 31 shows that interest rates on FSAMs are much lower than for fixed-rate non-agency loans during periods of price appreciation. They are in fact comparable to the interest rate on agency loans. Although the mortgage payment on FSAMs is expected to go up over time, this is counterbalanced by the lower interest rate on the contract, and many homeowners appear willing to make that tradeoff.

Figure 32 shows the cumulative default rates under the FSAM counterfactual. Because uptake of FSAMs is quite high, default rates are generally lower in the counterfactual than in the baseline. However, the figure does show that default rates would be higher for the 2007 cohort. Again, we see that the presence of shared-appreciation mortgages can have general equilibrium effects on the default rates of buyers who continue to use traditional fixed-rate loans.

To summarize the findings, it appears that the introduction of PSAMs does not change the market much because uptake is low. The introduction of FSAMs, however, has a large effect, as home buyers are willing to trade some of their upside appreciation in return for a lower overall interest rate. General equilibrium effects are shown to be important, as the presence of these mortgages has an effect even if there is no uptake. Both the introduction of PSAMs and FSAMs increases welfare, as evidenced by the house price increase.

However, there are many barriers to the introduction of shared-appreciation mortgages in reality, such as those outlined in Caplin et al. (2008). It is beyond the scope of this paper to address those issues here.

7 Conclusion

I developed an equilibrium model of housing and mortgage markets that fully endogenizes house prices, mortgage interest rates, and equilibrium leverage ratios. The model was used to explore various counterfactuals related to the availability of different kinds of mortgage contracts. It was shown that the presence of high-LTV, non-agency mortgages has extremely large effects on house prices, as their disappearance means that many low-wealth buyers are priced out of the housing market. Government policies that act on the mortgage market, such as a reduction in the risk-free rate or the increase of conforming loan limits, were shown to be effective at buoying house prices. Finally, the impact of introducing shared-appreciation mortgages was explored. It was shown that shared appreciation mortgages improve market efficiency, and that the specific type of equity-sharing has a large effect on interest rates and uptake of the shared-appreciation mortgages.

In all the counterfactuals, general equilibrium feedback effects between the mortgage and housing markets were shown to be important. This is an important point to emphasize, because it shows that one market cannot be analyzed in isolation of the other. Structural models which are used to assess the impact of changes to mortgage market institutions should therefore model both the housing market and mortgage market in equilibrium simultaneously.

The focus of the model was on modeling mortgage contracts realistically. In future work, the model can be applied to assessing the impact of hypothetical new mortgage designs, as illustrated in this paper in the study of shared-appreciation mortgages. The model could also be used to assess the historical impact of exotic mortgage products, such as hybrid-ARMs, that were prevalent during the housing boom of the 2000s.

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Table 2: Summary of Data

Year	Average LTV by house type: High-Value	Average LTV by house type: Low-Value	Average interest rate by contract type: Agency	Average interest rate by contract type: Non-Agency	Non-Agency originations #	Conforming Loan Limit nominal $
2003	0.844	0.756	0.040	0.048	9,673	322,700
2004	0.849	0.760	0.041	0.055	11,349	333,700
2005	0.857	0.760	0.040	0.062	16,039	359,650
2006	0.884	0.779	0.045	0.052	17,240	417,000
2007	0.842	0.723	0.045		7,352	417,000
2008	0.755	0.617	0.043		13	729,750
2009	0.725	0.608	0.033		0	729,750
2010	0.723	0.598	0.031		4	729,750

Notes: This table shows summary statistics for the data from Los Angeles from 2003 to 2010. Data for average LTVs come from DataQuick, and the house types are separated into high and low-valued segments based on the algorithm described in Section 4. Data for interest rates on agency mortgages comes from the Freddie Mac single-family loan level dataset. Data for non-agency interest rates and originations comes from BlackBox. The nominal conforming loan limit is also reported for this time period.

Table 3: Aggregate State Variable Paths used in Calibration

Year	rfr_t	cll_t	mps_t	g_t	$\bar{v}_t$
2003	0.025	0.4	1	g_H	Unobserved
2004	0.025	0.4	1	g_H	$\vdots$
2005	0.025	0.4	1	g_H	$\vdots$
2006	0.025	0.45	1	g_H	$\vdots$
2007	0.025	0.45	1	g_L	$\vdots$
2008	0.015	0.75	0	g_L	$\vdots$
2009	0.015	0.75	0	g_L	$\vdots$
2010	0.015	0.75	0	g_L	$\vdots$

Note: This table shows the aggregate state variable paths used in model estimation. g_H and g_L, and $\bar{v}_t$ for each period are all parameters to be estimated.

Table 4: Parameters in the Model

Parameter	Description	Value
γ	coefficient of relative risk aversion	3
δ	time discounting rate	0.95
μ	total mass of each house type	1
φ	recovery rate on foreclosures	0.72
σ_y^2	variance of potential buyer income	0.9025
λ	per-period probability of moving	Calibrated
β	weight on utility over final wealth	Calibrated
θ	preference for high quality homes	Calibrated
a_m	opportunity cost of funds (over risk-free rate)	Calibrated
$(\alpha_0^w, \alpha_1^w, \sigma_w^2)$	parameters governing wealth distribution	Calibrated
g_L, g_H, σ_v^2	evolution of unobserved demand shock	Calibrated

Note: This table lists the free parameters of the model and what their values are set to. If the parameter is to be calibrated from data, the calibrations are given in Table 5.

Table 5: Calibration Results

Parameter	Description	Estimate
β	weight on utility over final wealth	0.13
θ	preference for high quality homes	1.3
a_1	cost of funds for agency loans	0.02
a_2	cost of funds for non-agency loans	0.035
α_0^w	wealth distribution (constant)	-0.094
α_1^w	wealth dist. (coeff. on income)	1.1
σ_w^2	wealth dist. (variance)	0.193
g_L	demand shock growth (decline)	0
g_H	demand shock growth (growth)	-0.13
σ_v^2	demand shock growth (variance)	0.15

Note: This table shows results from the calibration as described in Section 5.

Table 6: Model Fit: LTVs of Home Buyers

	Real Data		Simulated Data	
Year	Low-Valued	High-Valued	Low-Valued	High-Valued
2003	0.844	0.756	0.882	0.794
2004	0.849	0.760	0.884	0.816
2005	0.857	0.760	0.867	0.873
2006	0.884	0.779	0.820	0.837
2007	0.842	0.723	0.795	0.806
2008	0.755	0.617	0.726	0.661
2009	0.725	0.608	0.698	0.629
2010	0.723	0.598	0.698	0.629

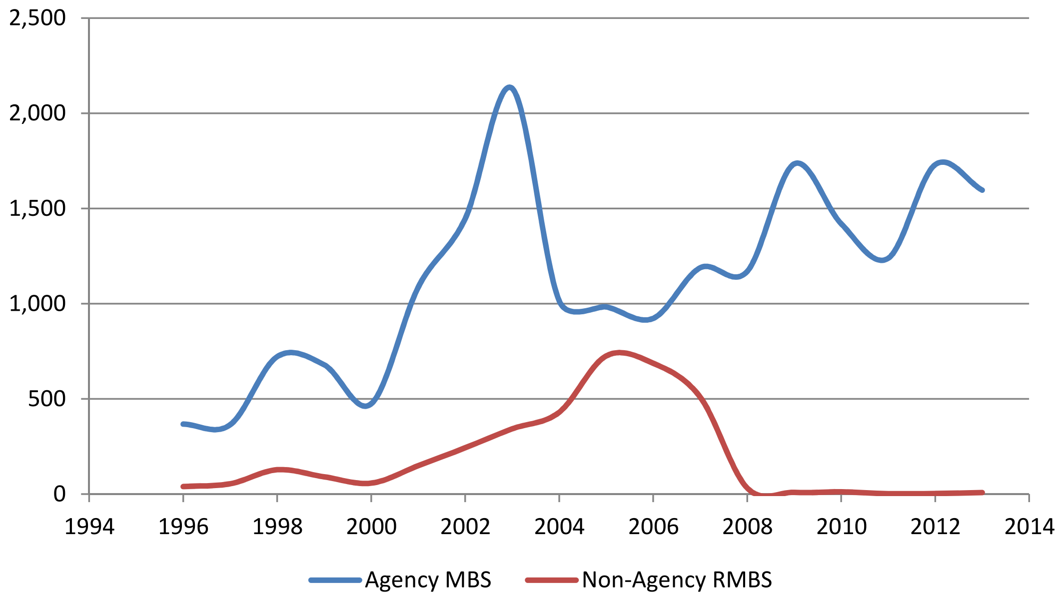
Note: This table compares the average LTVs by house type in the actual data and in the simulated data under the calibrated parameters.

Table 7: Model Fit: Mortgage Interest Rates

	Real Data		Simulated Data	
Year	Agency	Non-Agency	Agency	Non-Agency
2003	0.040	0.048	0.045	0.0575
2004	0.041	0.055	0.045	0.0575
2005	0.040	0.062	0.045	0.0575
2006	0.045	0.069	0.045	0.0575
2007	0.045	0.052	0.045	0.0616
2008	0.043		0.035	
2009	0.033		0.035	
2010	0.032		0.035	

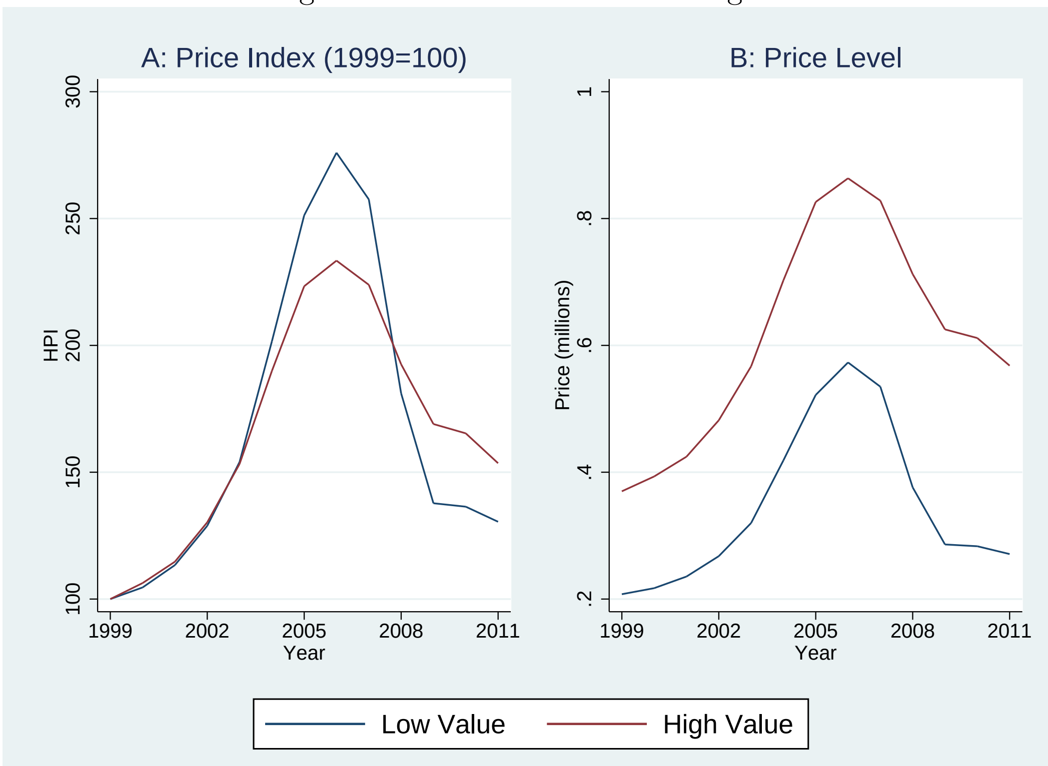
Note: This table compares the average interest rates by mortgage type in the actual data and in the simulated data under calibrated parameters.

Figure 1: Agency and Non-Agency MBS Issuance (USD Billions)



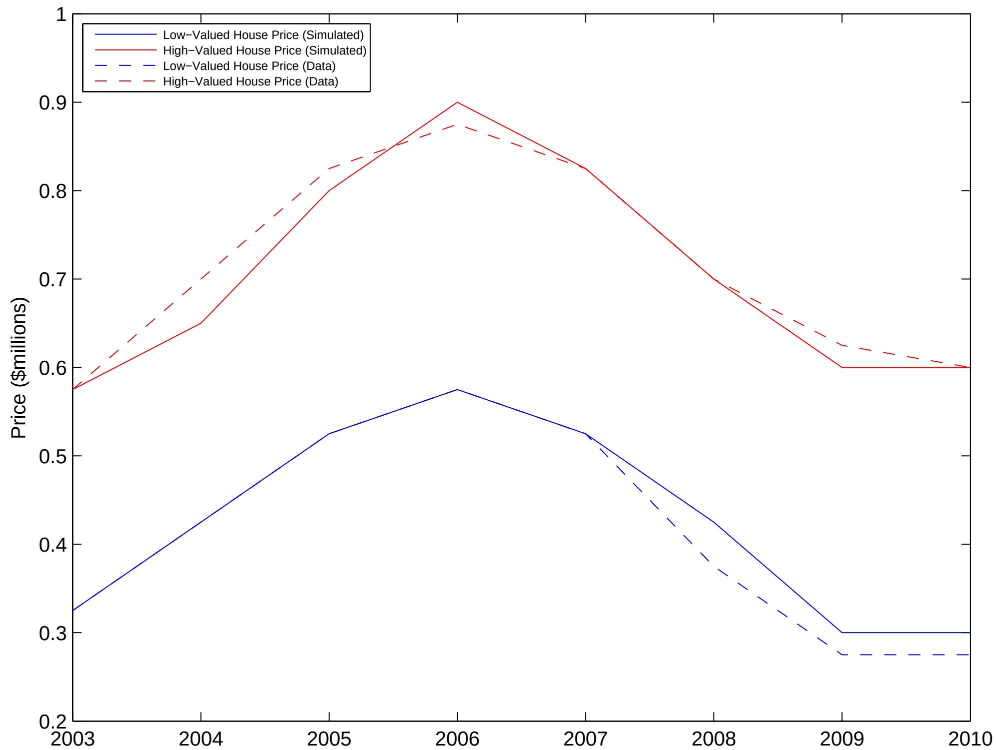
Notes: This graph shows the total volume of agency and non-agency mortgage backed securities issuance from 1994 to 2013. Source: SIFMA. Data can be found at https://www.sifma.org/uploadedfiles/research/statistics/statisticsfiles/sf-us-mortgage-related-sifma.xls. Date last accessed: 8/29/2014.

Figure 2: House Prices in Los Angeles



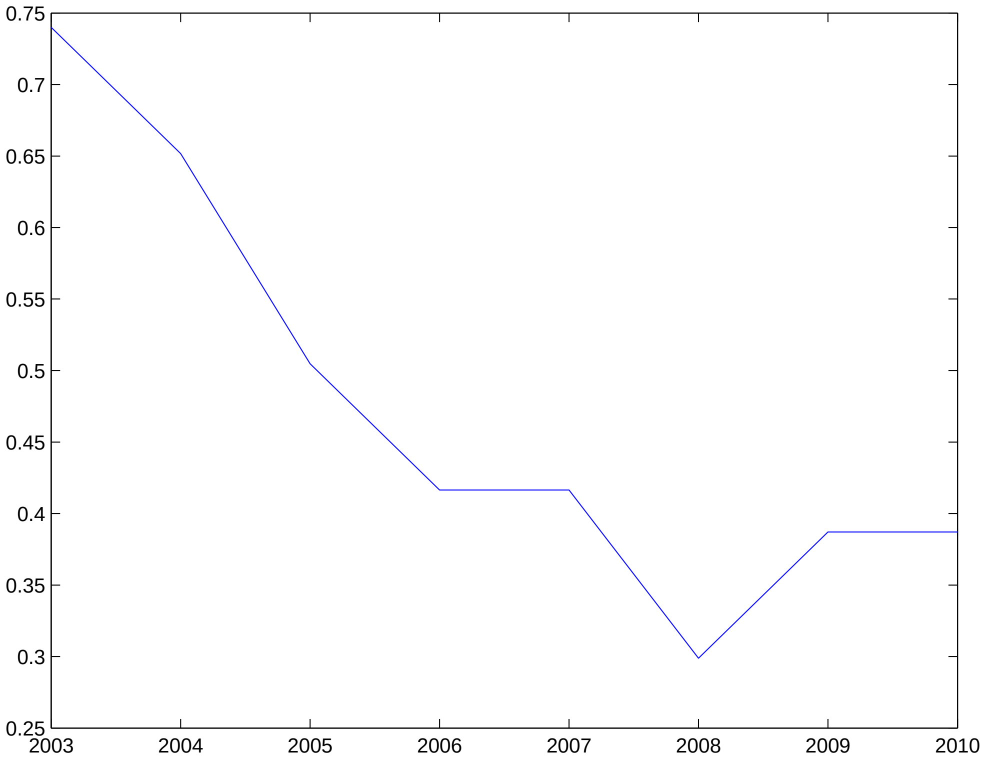
Note: Panel A shows the repeat-sales price index computed using DataQuick data for the two housing segments as described in Section 4. Panel B shows the price levels implied by the repeat-sales index.

Figure 3: Model Fit: House Prices



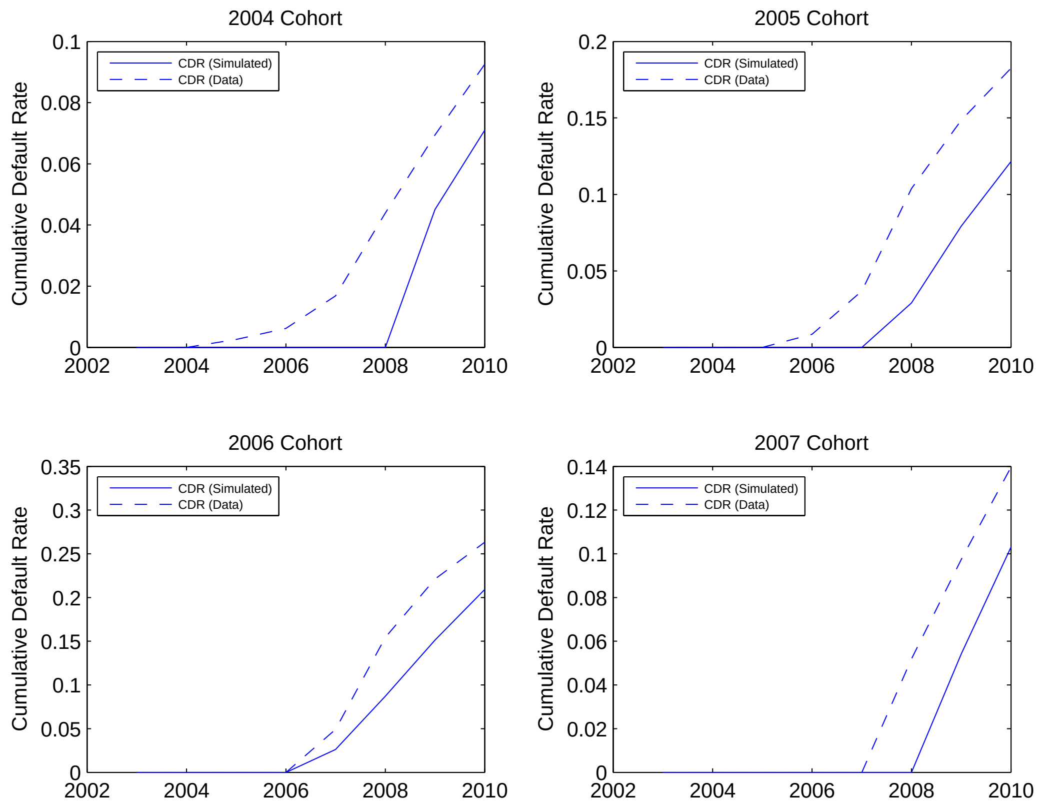
Note: This figure compares simulated prices to house prices in the data using the calibrations given in Table 5. The model is shown to match the price paths in the data quite well.

Figure 4: Path of the Unobserved Demand Shock $\bar{v}_t$



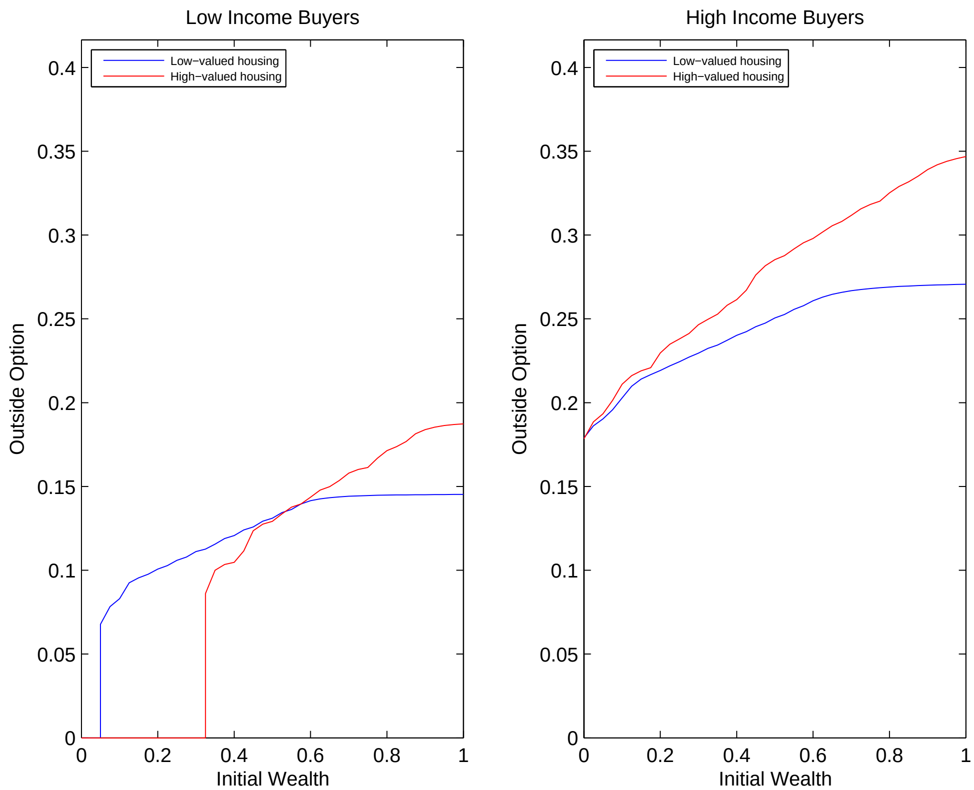
Note: This figure shows the estimated path of the demand shocks $\bar{v}_t$. A higher level of $\bar{v}_t$ means a higher average outside option, meaning lower demand. So the highest level of demand is actually estimated to be in 2008, and the lowest level in 2003.

Figure 5: Model Fit: Cumulative Default Rates



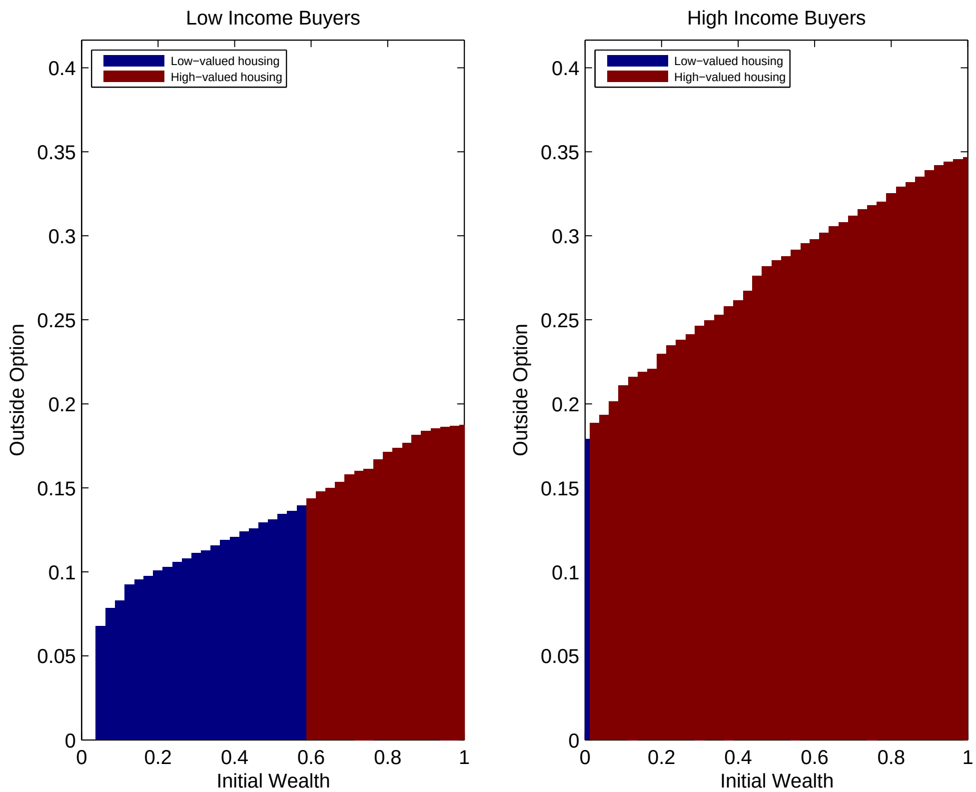
Note: This figure shows the cumulative default rate over time for various cohorts of buyers. The dashed line shows the cumulative default rates for buyers in the data, as computed from DataQuick, and the solid line shows the model's simulations. The model is shown to reflect the time-trend of default rates quite well, but tends to underestimate default rates by a constant factor.

Figure 6: Buyer Value Functions in 2007 (Baseline)



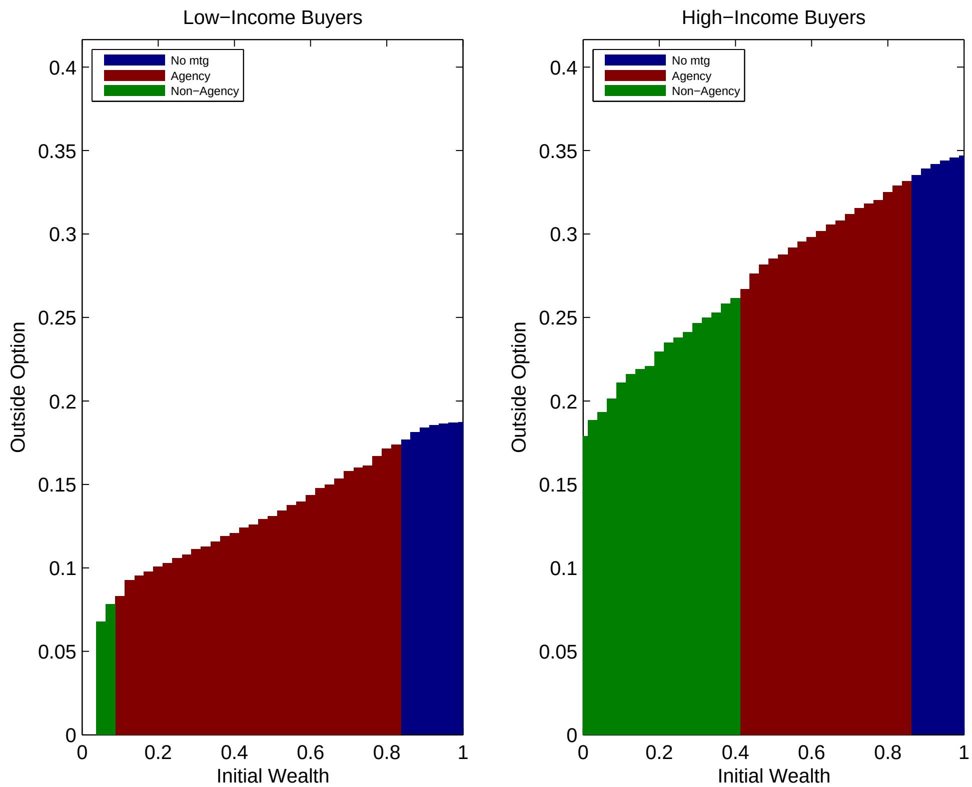
Note: This figure shows V_h^{buy} for low and high-income buyers, at varying levels of initial wealth. Low-income buyers with very low wealth are unable to purchase homes of any quality because they cannot afford to make the mortgage payments on the size of the loan necessary for them to purchase. Low-income buyers with moderate wealth are able to buy low-valued homes but not high-valued homes for the same reason. High-income buyers are able to purchase homes of any type, even if they have zero initial wealth. This is because high-LTV non-agency loans are available in 2007.

Figure 7: Housing Demand Profile in 2007 (Baseline)



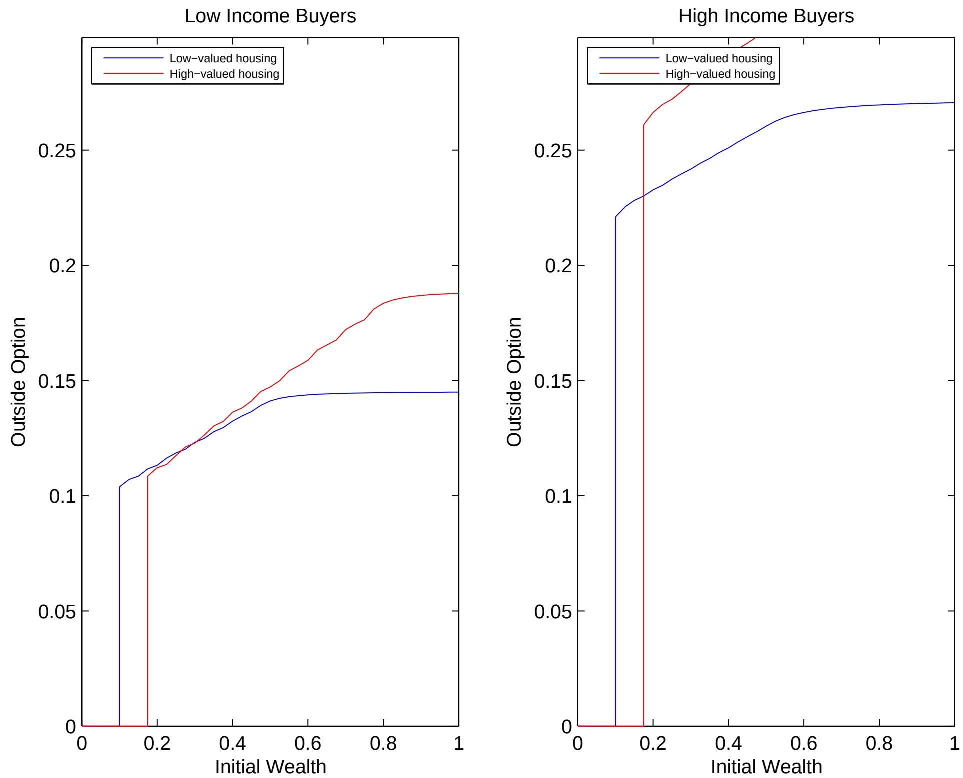
Note: This figure shows housing demand by buyer type in 2007. It fills in the area underneath the value functions shown in Figure 6. Low-income, and low-to-moderate wealth buyers purchase low-quality homes. Low-income, high-wealth and high-income buyers purchase high-quality homes. In equilibrium, the blue and red-shaded areas (weighted by the buyer distribution function) is each equal to $\lambda\mu$.

Figure 8: Mortgage Demand Profile in 2007 (Baseline)



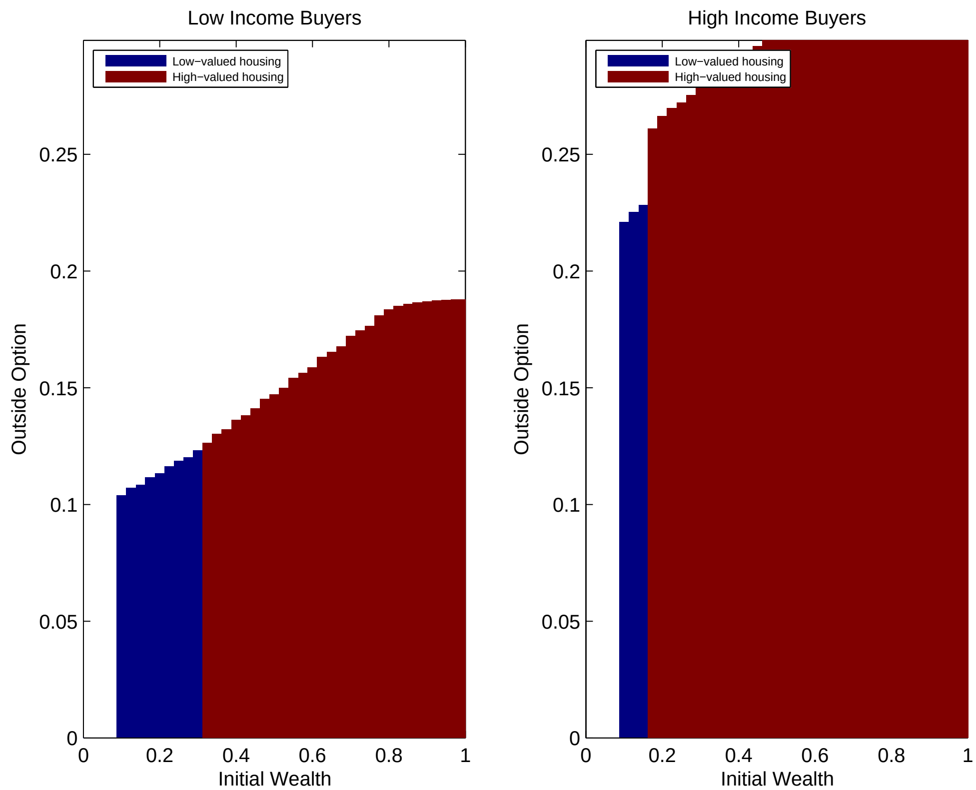
Note: This figure shows mortgage demand by buyer type in 2007. Low-income, low-wealth buyers finance purchases of low-quality homes using non-agency mortgages. Low-income, moderate-wealth buyers finance purchases of both low-quality and high-quality homes using agency mortgages. High-income, low-wealth buyers finance purchases of high-quality homes using non-agency mortgages. High-income, moderate-wealth buyers finance purchases of high-quality homes using agency mortgages. Very high wealth buyers of both income groups buy high-quality homes with cash.

Figure 9: Buyer Value Functions in 2008 (Baseline)



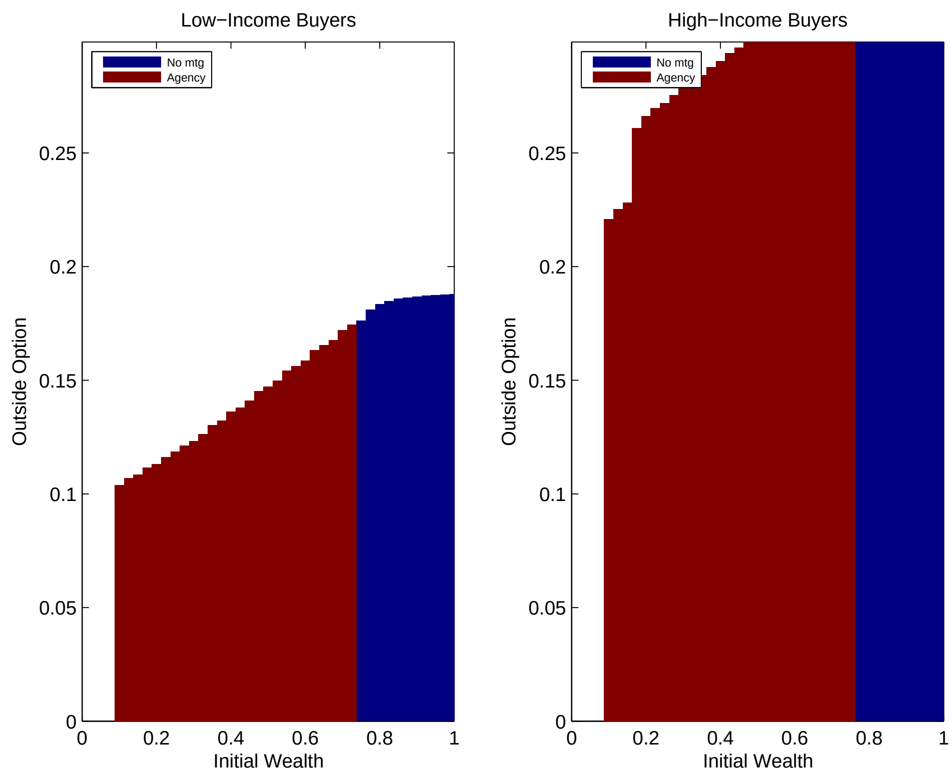
Note: This figure shows V_h^{buy} for low and high-income buyers, at varying levels of initial wealth. Because high-LTV loans are unavailable, low-wealth buyers are unable to purchase homes regardless of their income. In order for the housing market to clear, house prices need to be lowered in order to induce more of the high-wealth buyers high outside-option to enter the market and purchase a home.

Figure 10: Housing Demand Profile in 2008 (Baseline)



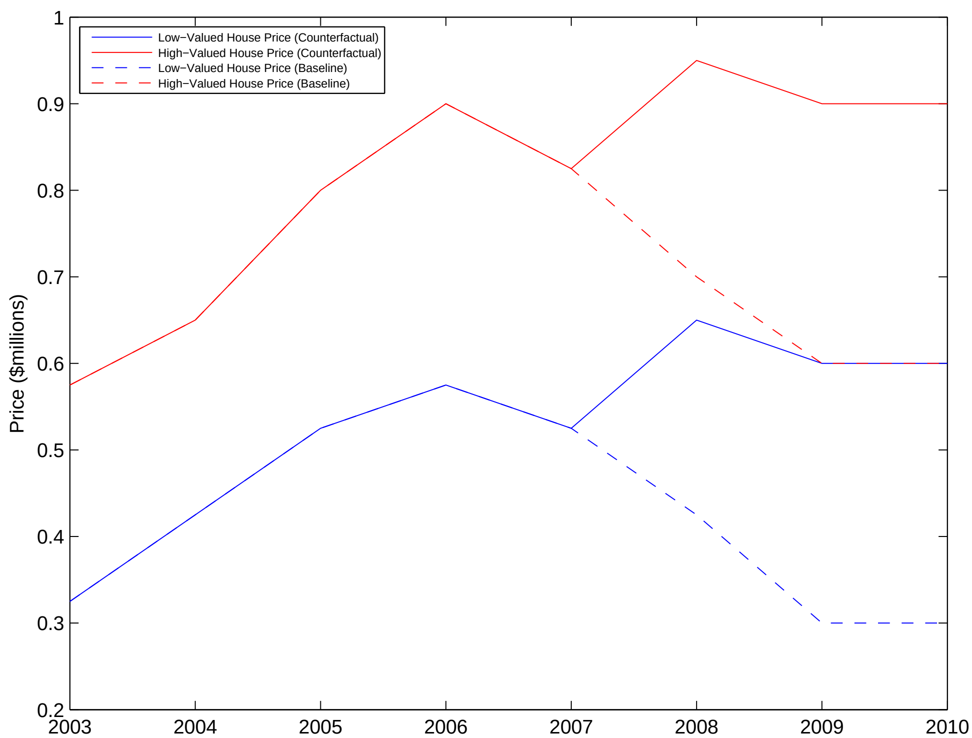
Note: This figure shows housing demand by buyer type in 2008. It fills in the area underneath the value functions shown in Figure 9. Because high-LTV loans are unavailable, low-wealth buyers are unable to purchase homes regardless of their income. In order for the housing market to clear, house prices need to be lowered in order to induce more of the high-wealth buyers high outside-option to enter the market and purchase a home.

Figure 11: Mortgage Demand Profile in 2008 (Baseline)



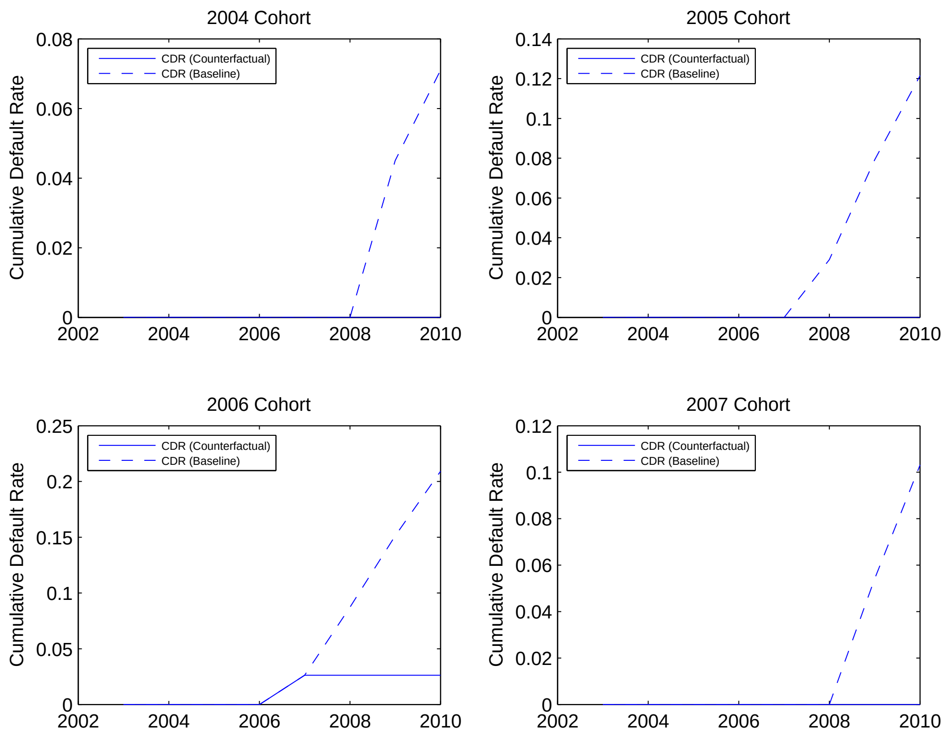
Note: This figure shows mortgage demand by buyer type in 2008. Non-agency mortgages are unavailable, pricing out low-wealth buyers from the market. Only moderate to high-wealth buyers are able to afford to purchase a home, financing their purchases with agency mortgages. Very high-wealth buyers continue to purchase homes using cash only.

Figure 12: House Price Paths if Non-Agency Mortgages Available in 2008-2010



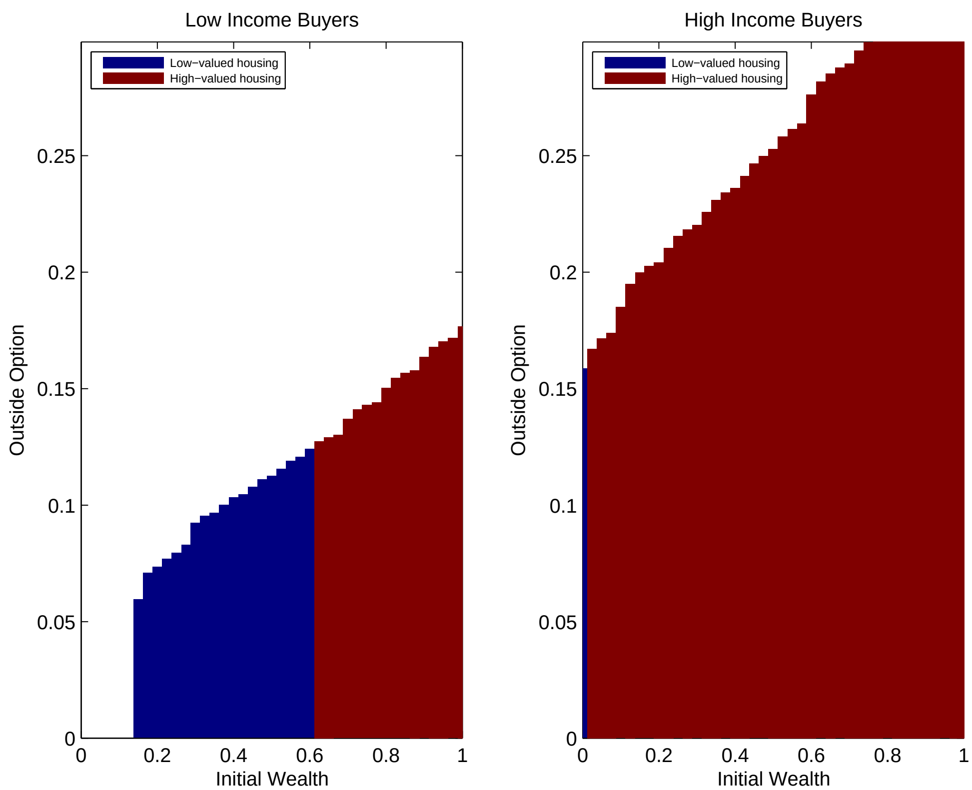
Note: This graph reports counterfactual and baseline price paths for the counterfactual exercise in which non-agency mortgage financing is made available from 2008 onwards. The solid lines show the simulated price paths under the counterfactual, while the dotted line shows the price paths under the baseline model simulation.

Figure 13: Cumulative Default Rates if Non-Agency Mortgages Available in 2008-2010



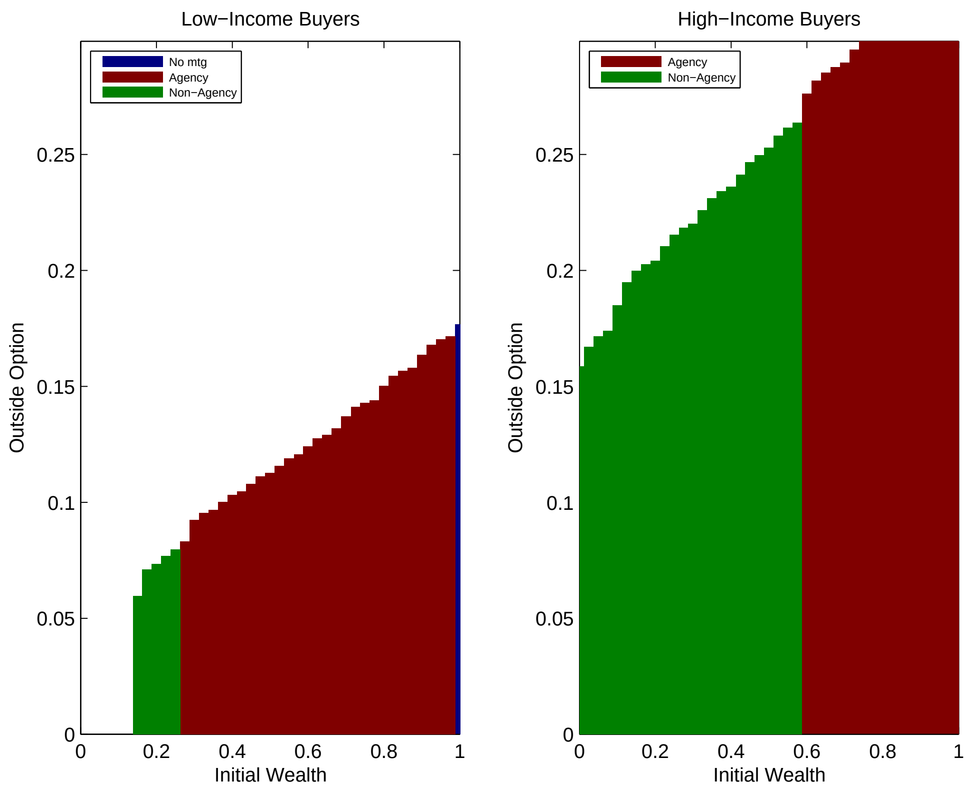
Note: This figure shows the cumulative default rate over time for various cohorts of buyers. The dashed line shows the cumulative default rates for buyers as simulated under the baseline model. The solid line shows cumulative default rates for buyers simulated under the counterfactual in which non-agency mortgages are available from 2008 onwards.

Figure 14: Housing Demand Profile in 2008 if Non-Agency Mortgages Available in 2008-2010



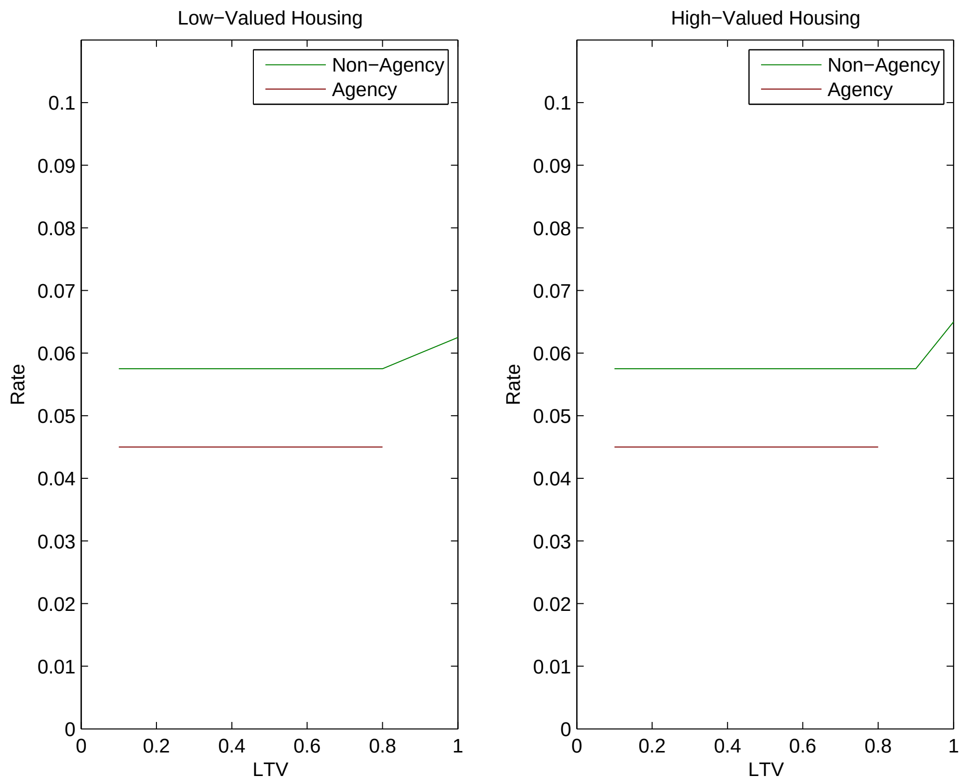
Note: This figure shows housing demand by buyer type in 2008 under the counterfactual in which non-agency mortgages are made available from 2008 onwards.

Figure 15: Mortgage Demand Profile in 2008 if Non-Agency Mortgages Available in 2008-2010



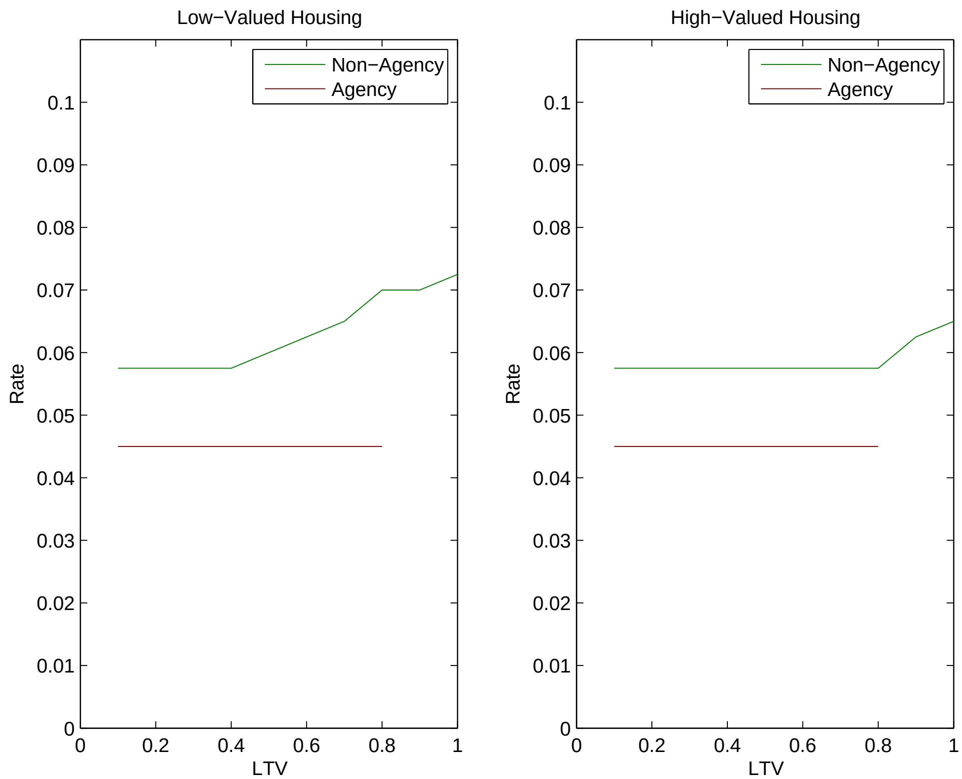
Note: This figure shows mortgage demand by buyer type in 2008 for the counterfactual in which non-agency mortgages are made available from 2008 onwards.

Figure 16: Mortgage Rates in 2008 if Non-Agency Mortgages Available 2008-2010



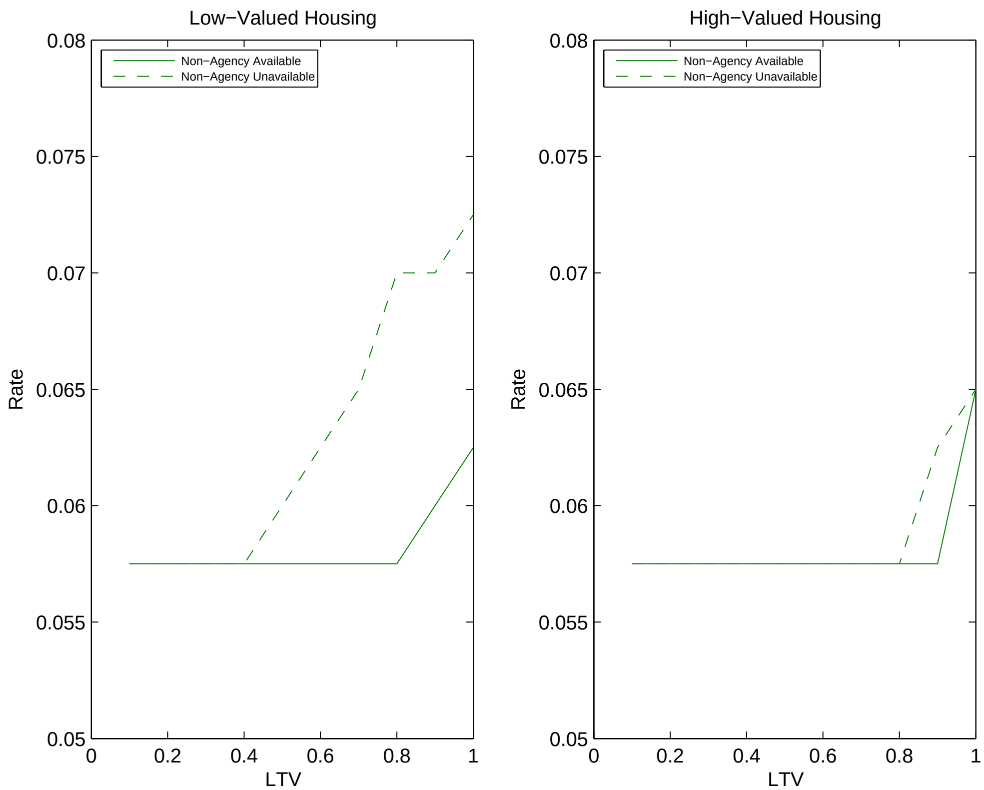
Note: This figure shows mortgages rates by LTV for low-income buyers in 2008, for the counterfactual in which non-agency mortgages are available from 2008 onwards. There is a slight increase in rates as the LTV approaches 100%, reflecting the higher default risk of high-LTV loans.

Figure 17: Mortgage Rates in 2008 if Non-Agency Mortgages Unavailable 2008-2010



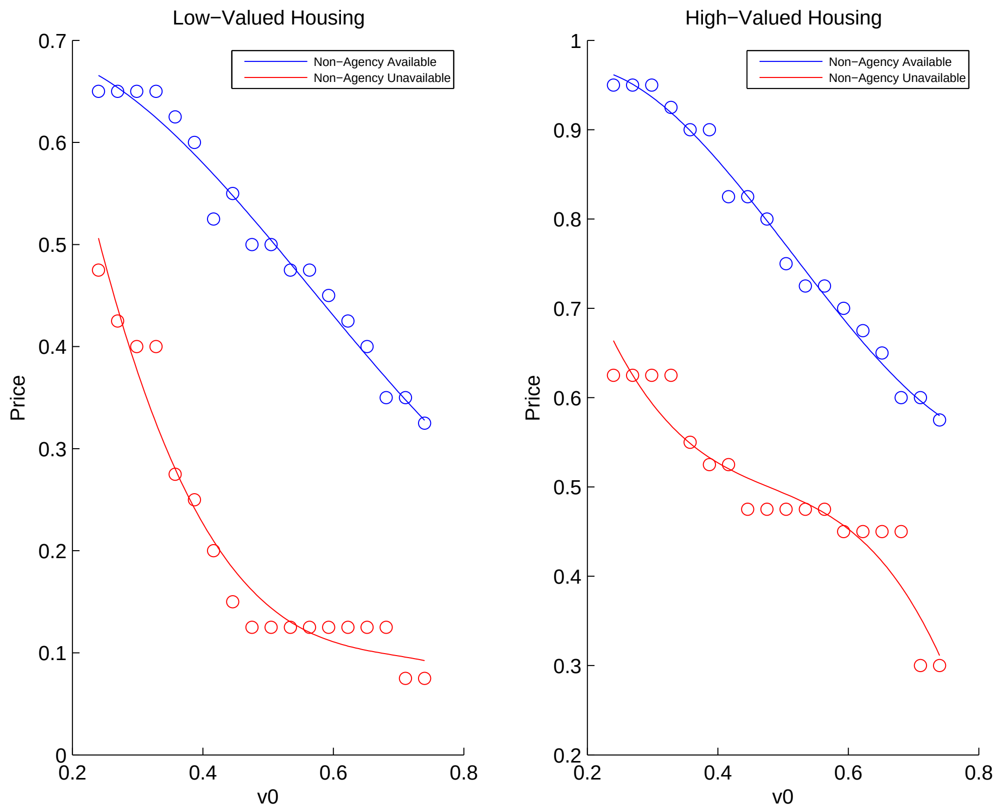
Note: This figure shows mortgages rates by LTV for low-income buyers in 2008, when non-agency mortgages are unavailable from 2008 onwards. The non-agency mortgage rates are purely counterfactual—they are the mortgage rates which would earn the lender zero expected profits, *under the equilibrium price-paths and homeowner behavior that prevail when non-agency mortgages are unavailable.*

Figure 18: Non-Agency Mortgage Rates in 2008, when Non-Agency is Available vs. Unavailable



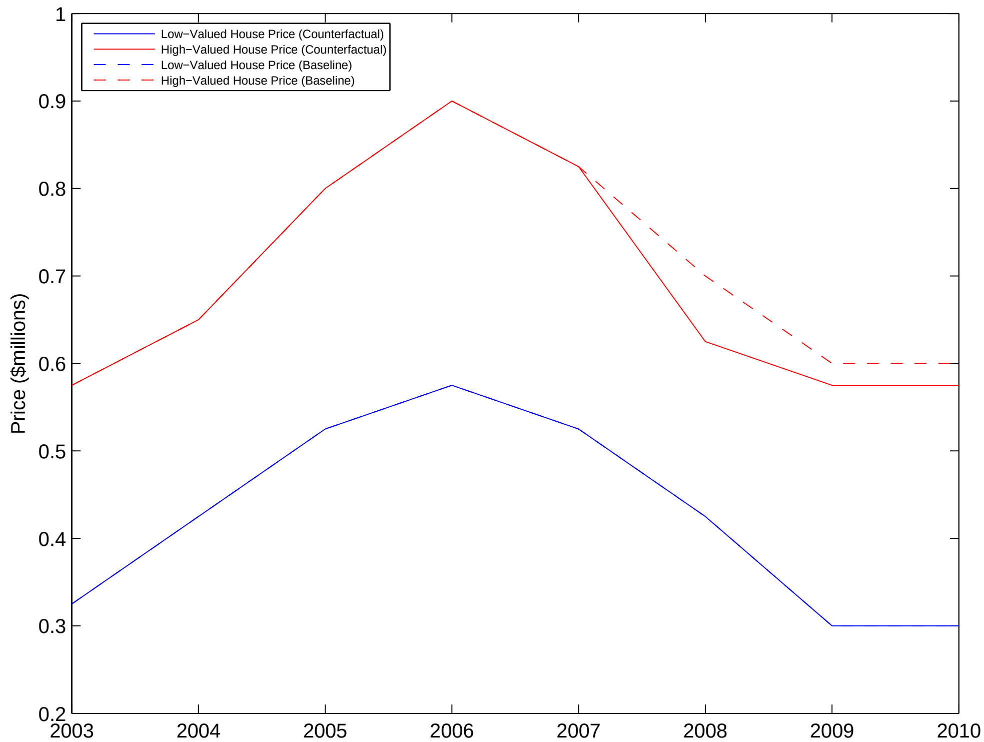
Note: This figure compares the non-agency mortgage rates in 2008 when non-agency mortgages are available vs. unavailable. The solid line shows equilibrium non-agency mortgage rates when non-agency mortgages are available. The dashed line shows non-agency mortgage rates when non-agency mortgages are unavailable. The dashed line is purely counterfactual—it is the mortgage rate that would earn the lender zero expected profits, *under the equilibrium price-paths and homeowner behavior that prevail when non-agency mortgages are unavailble.* The figure illustrates the importance of considering general equilibrium feedback between the housing and mortgage market. When non-agency mortgages go from being unavailable to available, one must recompute the equilibrium interest rates for non-agency mortgages because equilibrium house prices and homeowner behavior also changes. If one were to use the non-agency rates that would cause the lender to break even in the equilibrium where non-agency is unavailable, one would overstate the mortgage interest rates charged by the lender.

Figure 19: Sensitivity of Prices to Demand Shocks



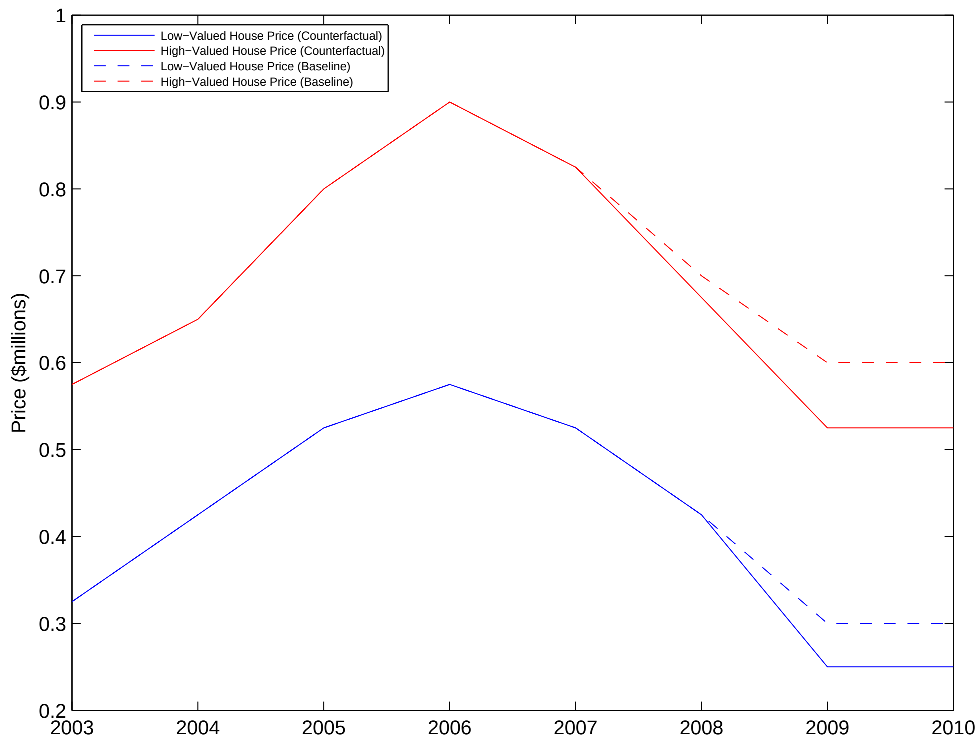
Note: This figure shows the sensitivity of house prices to the unobserved demand shocks, under two regimes. In the first regime, non-agency mortgages are available. In the second regime, non-agency mortgages are unavailable. All other state variables (i.e. risk-free rate, conforming loan limit), are the same across the regimes. The figure shows that the availability of non-agency mortgages actually makes prices less sensitive to the unobserved demand shocks. So the presence of high-LTV loans can reduce house price volatility.

Figure 20: House Price Paths if No CLL Response in 2008



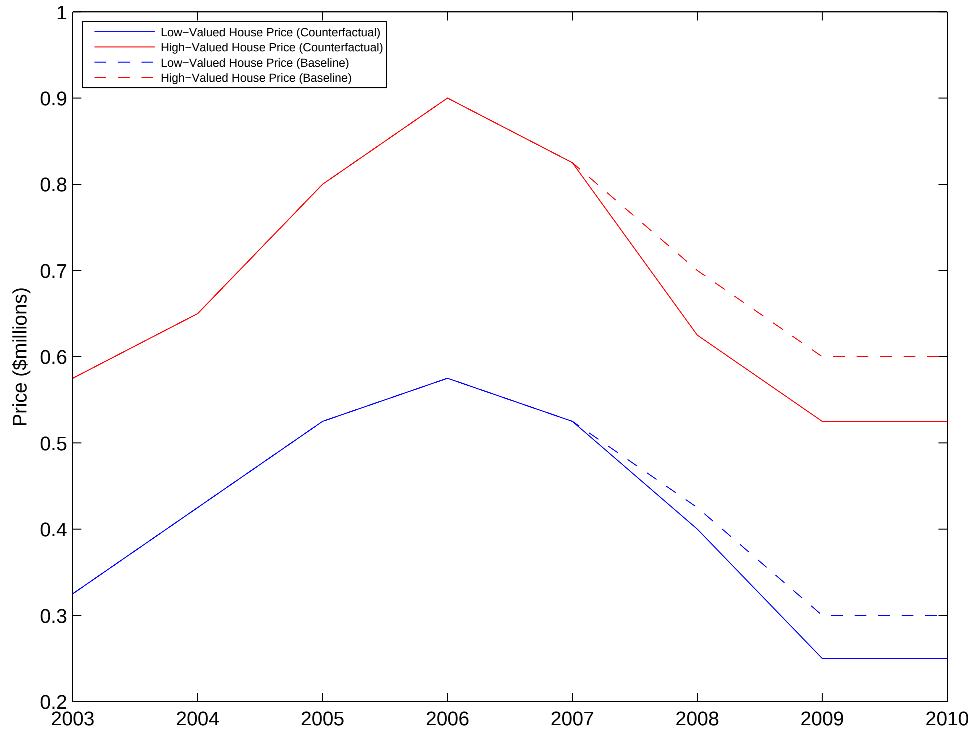
Note: This figure shows counterfactual and baseline price paths for the counterfactual in which conforming loan limits are not increased in 2008. The solid lines show the simulated price paths under the counterfactual, while the dotted line shows the price paths under the baseline model simulation.

Figure 21: House Price Paths if No Interest Rate Response in 2008



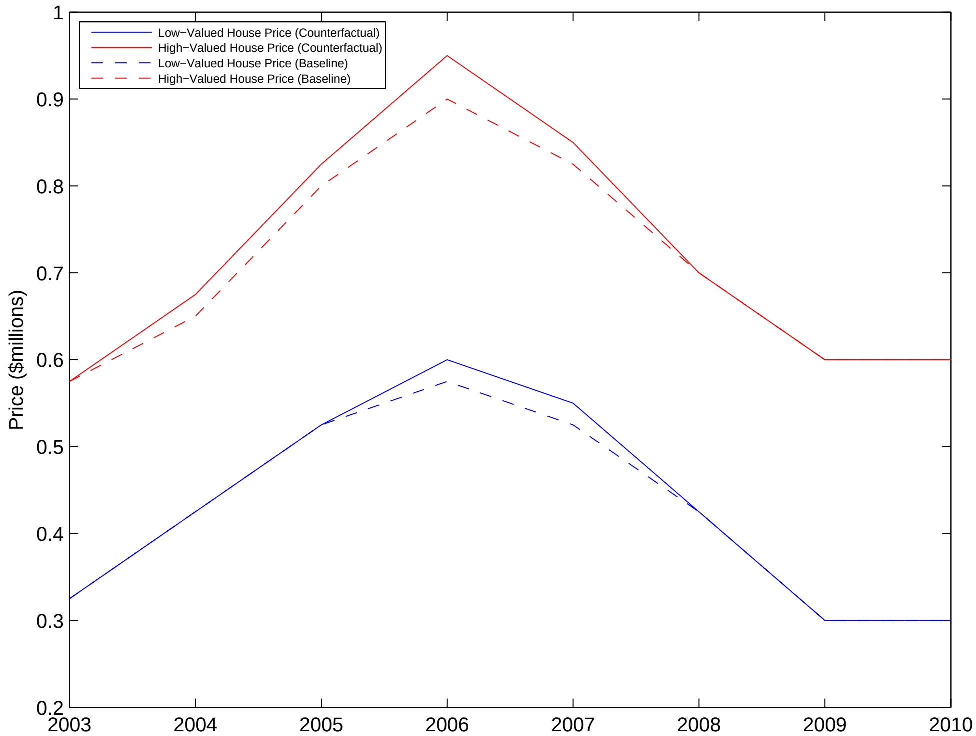
Note: This figure shows counterfactual and baseline price paths for the counterfactual in which the risk free rate is not reduced in 2008. The solid lines show the simulated price paths under the counterfactual, while the dotted line shows the price paths under the baseline model simulation.

Figure 22: House Price Paths if No Government Response in 2008



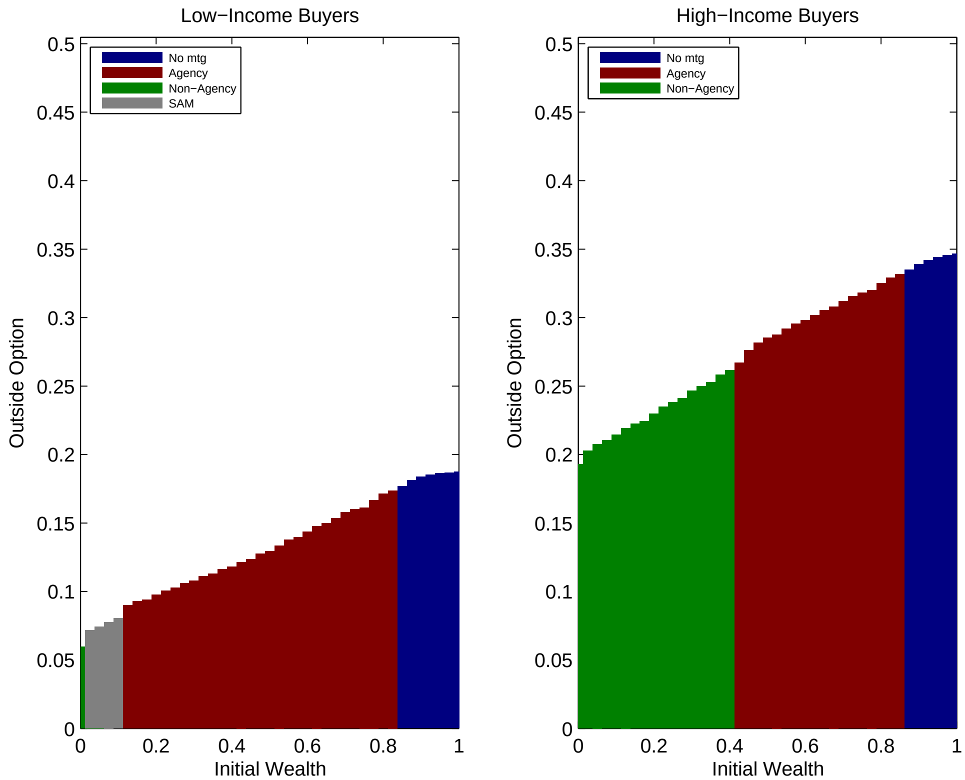
Note: This figure shows counterfactual and baseline price paths for the counterfactual in which the risk free rate is not reduced and the conforming loan limit is not increased in 2008. The solid lines show the simulated price paths under the counterfactual, while the dotted line shows the price paths under the baseline model simulation.

Figure 23: House Price Paths if PSAMs Available 2003-2007



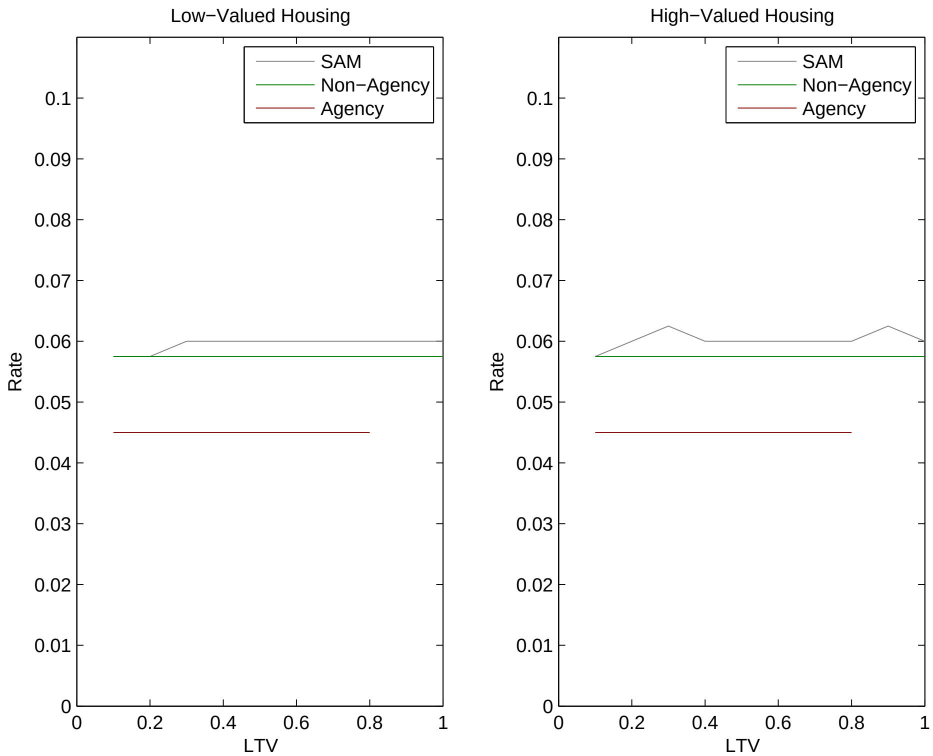
Note: This figure shows counterfactual and baseline price paths for the counterfactual in which PSAMs are available from 2003 to 2007. The solid lines show the simulated price paths under the counterfactual, while the dotted line shows the price paths under the baseline model simulation.

Figure 24: Mortgage Demand Profile in 2005, if PSAMs Available 2003-2007



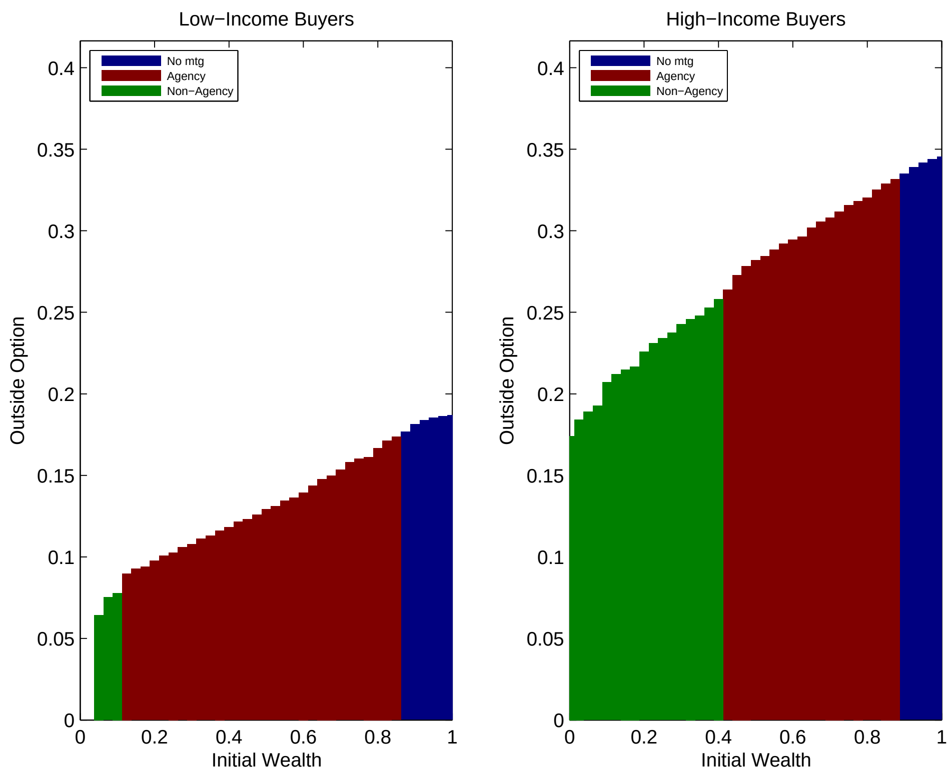
Note: This figure shows the mortgage demand profile in 2005 under the counterfactual where PSAMs are available from 2003 to 2007.

Figure 25: Mortgage Rates in 2005, if PSAMs Available 2003-2007



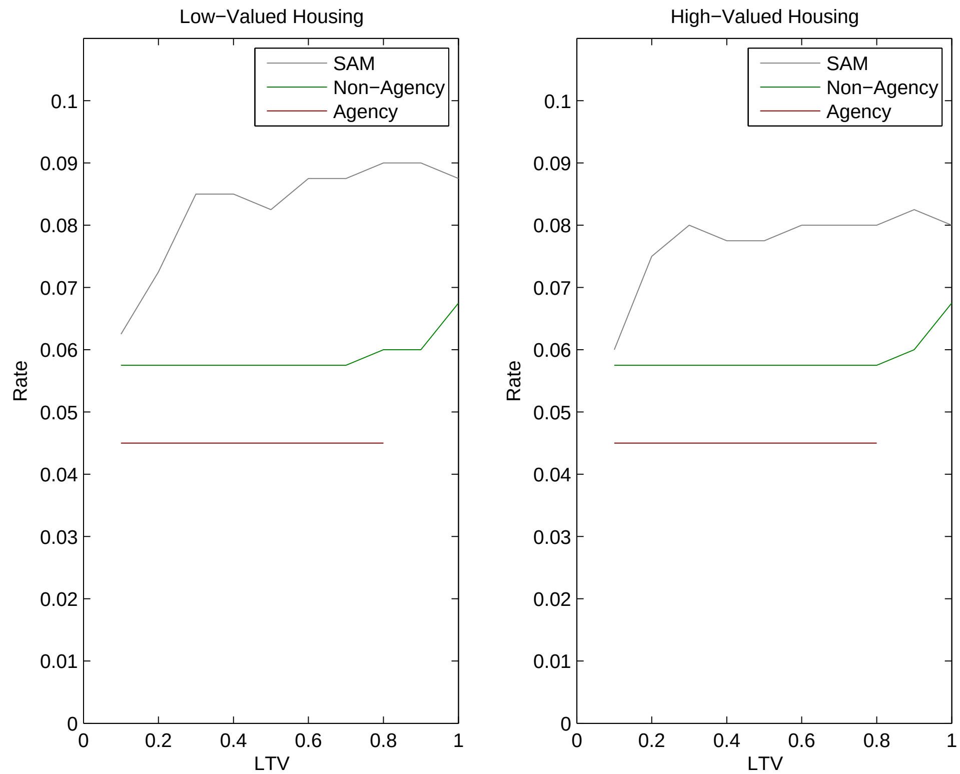
Note: This figure shows the mortgage rates profile in 2005 under the counterfactual where PSAMs are available from 2003 to 2007.

Figure 26: Mortgage Demand Profile in 2007, if PSAMs Available 2003-2007



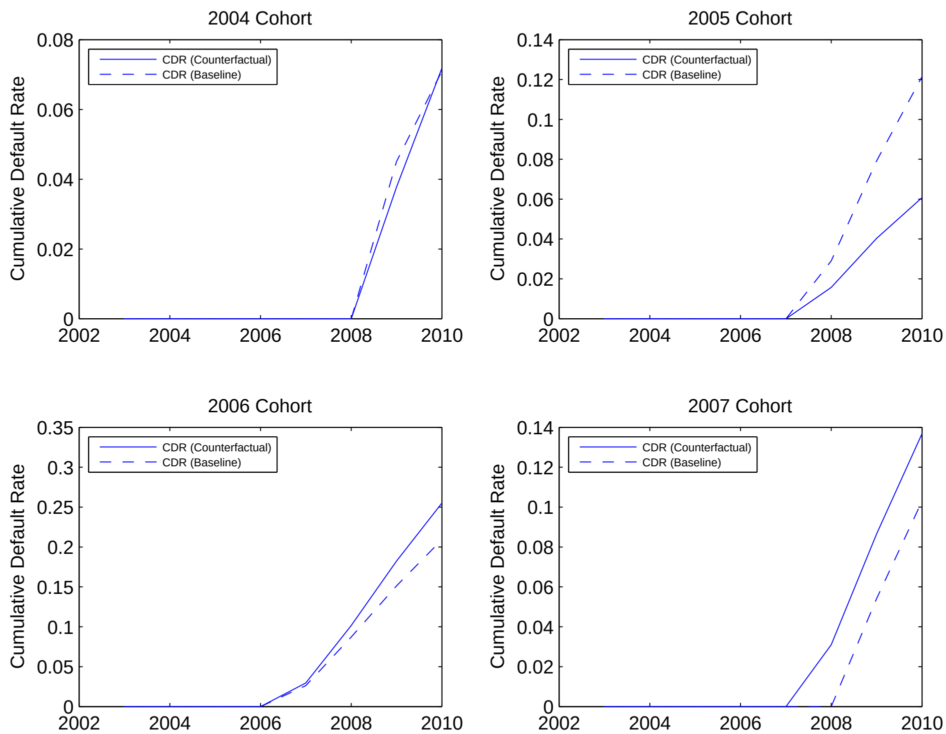
Note: This figure shows the mortgage demand profile in 2007 under the counterfactual where PSAMs are available from 2003 to 2007.

Figure 27: Mortgage Rates in 2007, if PSAMs Available 2003-2007



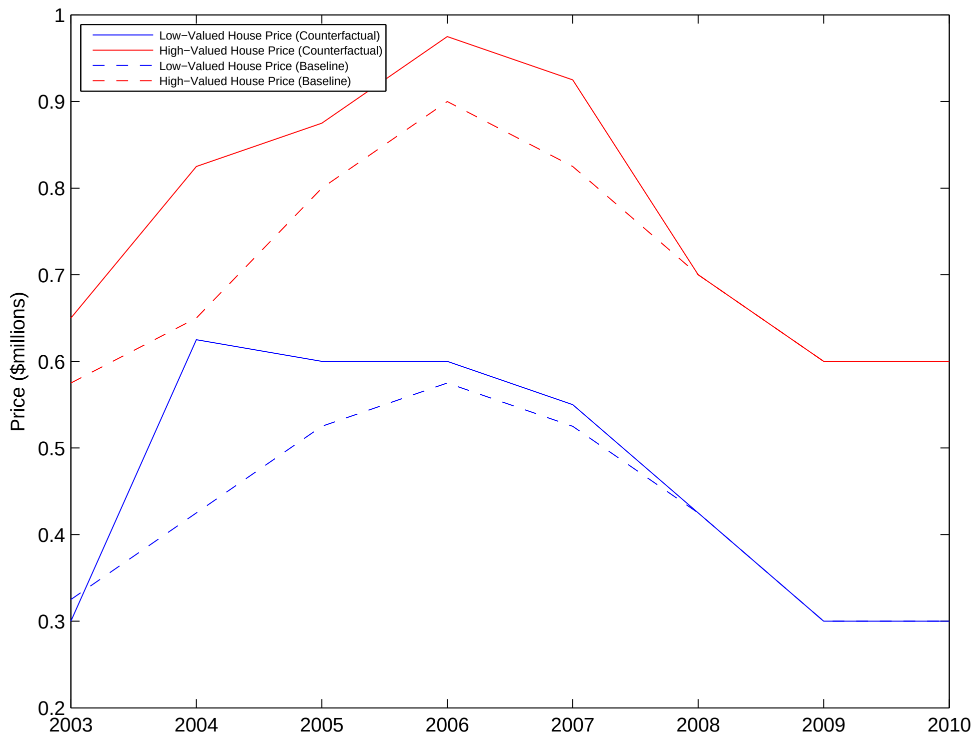
Note: This figure shows the mortgage rates profile in 2007 under the counterfactual where PSAMs are available from 2003 to 2007.

Figure 28: Cumulative Default Rates, if PSAMs Available 2003-2007



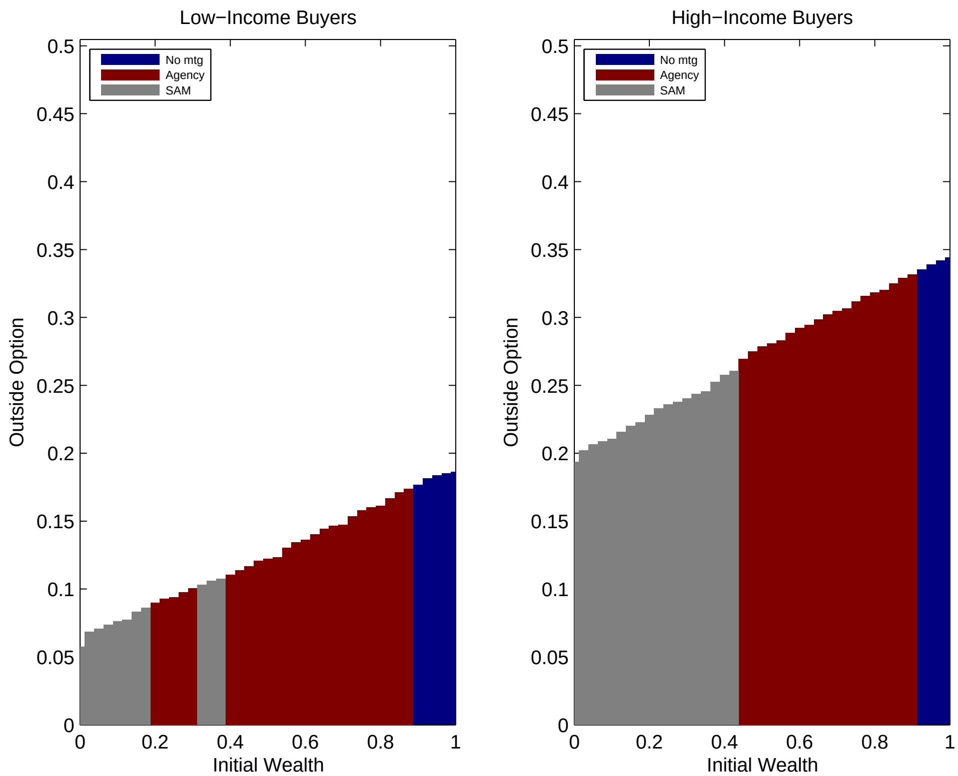
Note: This figure shows the cumulative default rates for different cohorts of buyers, under the counterfactual where PSAMs are available from 2003 to 2007.

Figure 29: House Price Paths if FSAMs Available 2003-2007



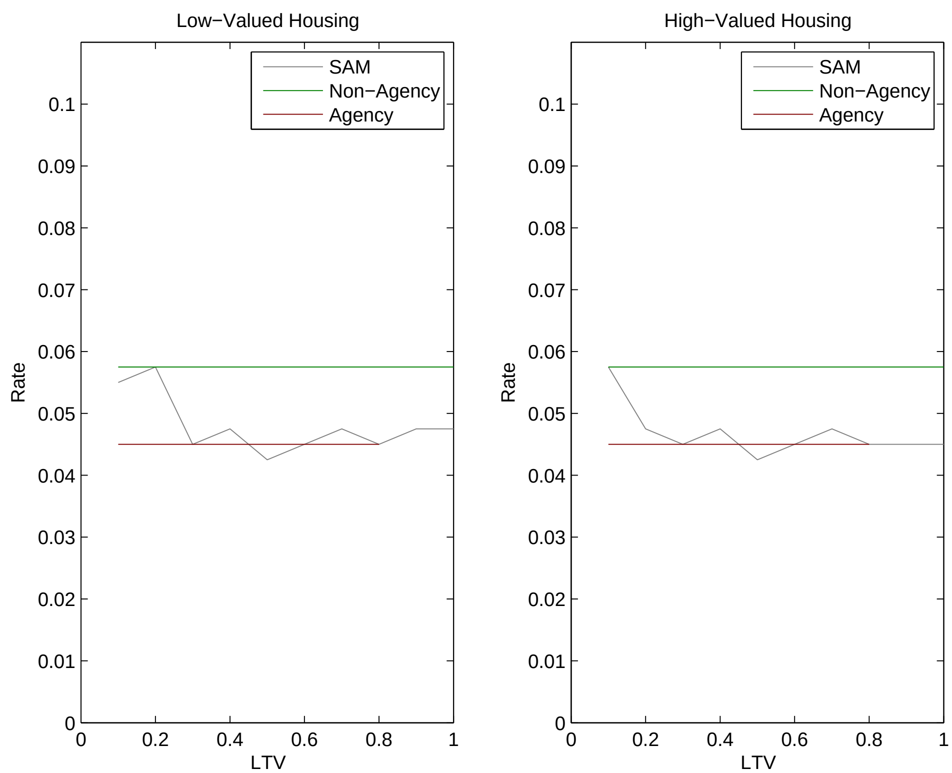
Note: This figure shows counterfactual and baseline price paths for the counterfactual in which FSAMs are available from 2003 to 2007. The solid lines show the simulated price paths under the counterfactual, while the dotted line shows the price paths under the baseline model simulation.

Figure 30: Mortgage Demand Profile in 2005, if FSAMs Available 2003-2007



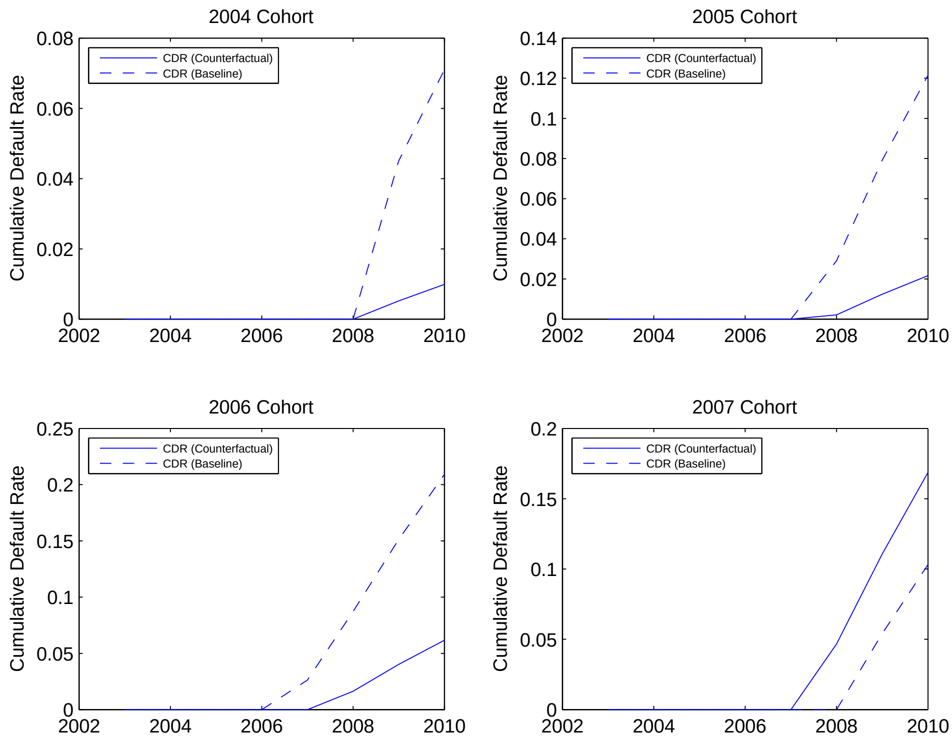
Note: This figure shows the mortgage demand profile in 2005 under the counterfactual where FSAMs are available from 2003 to 2007.

Figure 31: Mortgage Rates in 2005, if FSAMs Available 2003-2007



Note: This figure shows the mortgage rates profile in 2005 under the counterfactual where FSAMs are available from 2003 to 2007.

Figure 32: Cumulative Default Rates, if FSAMs Available 2003-2007



Note: This figure shows the cumulative default rates for different cohorts of buyers, under the counterfactual where FSAMs are available from 2003 to 2007.