The Life-Cycle Effects of House Price Changes

Wenli Li and Rui Yao*

February 2006

ABSTRACT

We develop a life-cycle model to study the effects of house price changes on household consumption and welfare. The model explicitly incorporates the dual feature of housing as both a consumption good and an investment asset and allows for costly adjustments in housing and mortgage positions. Our analysis indicates that although house price changes have small aggregate effects, their consumption and welfare consequences on individual households vary significantly. In particular, the non-housing consumption of young and old homeowners is much more sensitive to house price changes than that of middle-aged homeowners. More importantly, while house price appreciation increases the net worth and consumption of all homeowners, it only improves the welfare of old homeowners. Renters and young homeowners are worse off due to higher lifetime housing consumption costs.

KEY WORDS: Life-cycle Model, Consumption, Savings, Housing, Mortgage
JEL CLASSIFICATION CODES: E21, R21

*We gratefully acknowledge the Pittsburgh Supercomputing Center (PSC) for providing computing resources. We thank Mitchell Berlin, Don Haurin, Victor Rios-Rull, Pierre-Daniel Sarte, Nancy Wallace, Neng Wang, Kei-Mu Yi, Harold Zhang, as well as seminar participants at Baruch College's Department of Finance and Economics, Ohio State University's Department of Economics, the University of California at Berkeley's Haas School of Business, the University of Pennsylvania's Wharton School of Business, the 2004 Society of Economic Dynamics Summer Meeting in Rome, the 2004 Bank of Canada Housing and the Macroeconomy Conference in Ottawa, the 2005 Federal Reserve Bank of Atlanta "Housing, Mortgage Finance, and the Macroeconomy" Conference in Atlanta, and the 2005 American Real Estate and Urban Economics (AREUEA) Annual Meeting in Philadelphia for their comments. We especially thank two anonymous referees whose suggestions and comments greatly improved the paper. The views expressed are those of the authors and do not necessarily reflect those of the Federal Reserve Bank of Philadelphia, or the Federal Reserve System. Wenli Li can be reached at Department of Research, Federal Reserve Bank of Philadelphia, Ten Independence Mall, Philadelphia, PA 19106, Email: wenli.li@phil.frb.org. Rui Yao can be reached at Department of Economics and Finance, Baruch College, Zicklin School of Business, One Bernard Baruch Way, Box B10-225, New York, NY 10010, Email: rui_yao@baruch.cuny.edu.

1. Introduction

The economics of housing is a subject of increasing interest to economists as well as policy makers. For a typical household in the U.S., housing is not only the single most important consumption good but also the dominant component of wealth. Recent research has focused on the link between house price changes and consumption allocations. This literature, however, has been mostly empirical and cannot address the welfare consequences of house price changes for individual households.[1]

When markets are complete, households can fully insure against their intertemporal consumption and income risks. House price changes will not have a significant impact on their consumption and welfare. In reality, however, lacking proper financial products to generate full risk-sharing, households are exposed to house price uncertainties. Owning a home can alleviate the problem by purchasing future housing services at today's price. The hedging, however, is imperfect. Institutional and borrowing constraints frequently prevent young households with low levels of cash in hand from purchasing a house that matches their lifetime consumption need. Senior homeowners, in the meantime, are often forced to hold an equity position in their houses that lasts longer than their expected length of occupancy. This mismatch between life-cycle housing consumption need and housing investment position is worsened by the presence of lumpy adjustment costs in housing and mortgage markets.

In this paper, we investigate the effects of house price changes on household consumption and welfare, both at the aggregate level and over the life cycle. Using simulations under our parameterization, we show that although house price changes have limited net aggregate effects, their consumption and welfare consequences vary substantially at the individual household level and depend crucially on a household's age and housing position. Specifically, the non-housing consumption of a young or old homeowner is more sensitive to house price changes than that of a middle-aged homeowner. More importantly, although house price appreciation increases the net worth and consumption of all homeowners, it only improves the welfare of old homeowners. Renters and young homeowners are worse off.

[1]See Case, Quigley, and Shiller (2003), Benjamin, Chinloy, and Jud (2004), and Campbell and Cocco (2005). Bajari, Benkard, and Krainer (2005) investigate aggregate welfare implications of house price changes in a complete market setting with perfect information.

These results stem from two key features of the model: the households' inability to insure against their lifetime income risks, and their inability to separate the dual role of housing as both a consumption good and an investment asset. A young homeowner is often liquidity-constrained because of his steep income profile and lack of access to credit. He is therefore more likely to take advantage of the relaxed collateral borrowing constraint afforded by house price appreciation and increase his non-housing consumption. An old homeowner has a short expected life horizon. Hence, he is more likely to capture the house wealth gains and increase his non-housing consumption accordingly. By contrast, a middle-aged homeowner has accumulated enough liquid savings to overcome the liquidity constraint and faces a relatively long expected life horizon. His consumption is thus least responsive to changes in house prices.

From the perspective of household welfare, house price appreciation does not lead to welfare improvement for all homeowners in our model simulation. Young homeowners expect to upgrade their housing services as their income and wealth increase. A positive house price shock, therefore, incurs net welfare losses for them, since the rise in the value of their existing homes is not large enough to compensate them for the rise in their lifetime housing costs. House price appreciation also lowers a renter's lifetime welfare, since he suffers from higher costs in acquiring housing services and yet does not receive any housing wealth gains. Only old homeowners receive net welfare gains.

Our paper in spirit is related to the earlier housing literature exemplified by Artle and Varaiya (1978), which provided a theoretical model and closed-form solutions to a life-cycle optimization problem with housing. This paper significantly extends this early literature by incorporating uninsurable labor income, endogenizing tenure decisions, and allowing for borrowing against housing asset. In doing so, the paper also adds to the more recent life-cycle consumption and savings literature that incorporates non-tradable labor income but abstracts from durable housing (see for example, Zeldes 1989, Deaton 1991, and Carroll 1997). Our modeling strategy follows most closely that of Campbell and Cocco (2003), Cocco (2005), Fernandez-Villaverde and Krueger (2002), and Yao and Zhang (2005). While Campbell and Cocco (2003) examine a household's mortgage choice between a fixed rate loan and an adjustable rate loan, Cocco (2005) and Yao and Zhang (2005) study the effects of housing positions and house price risk on the portfolio allocation of liquid assets between stocks and

bonds. Fernandez-Villaverde and Krueger (2002) investigate the role of durable goods in households' consumption and savings decisions in steady state.

Our paper complements the recent empirical work devoted to the study of the effects of house price changes on consumption changes by explicitly modeling their theoretical relationships at both the aggregate and household levels in a stochastic life-cycle economy. While confirming the positive effects of housing wealth gains on aggregate consumption found in the literature, we demonstrate that these positive net worth and consumption gains vary substantially across households and have large heterogeneous welfare consequences.[2] In addition, we also contribute to the literature that investigates the effects of house price uncertainties on housing demand by extending the existing stylized models to a realistic life-cycle setting. We find that while house price uncertainties encourage earlier exit from home ownership among senior homeowners, their impacts on young households depend on the curvature parameter of utility functions. Only when the curvature parameter is sufficiently high will house price uncertainties induce earlier home ownership.

It is worth noting that the exact quantitative magnitude of our welfare and consumption results depend on our model assumptions and parameterizations. Yet the main results of the paper on the heterogenous impacts of house price changes on households with different housing positions and at various stages of the life-cycle mainly arise from the nonseparable dual role of housing as both a consumption good and an investment vehicle and the credit market frictions. Hence the qualitative results remain robust to various model perturbations.

The rest of the paper is organized as follows. Section 2 introduces the model economy. Section 3 characterizes households' consumption, housing, and mortgage decisions. Section 4 analyzes the effects of a permanent house price shock on household consumption and welfare and contrasts the results with those derived from liquid wealth gains. We also investigate the effects of house price uncertainties on housing demand in this section. Section 5 concludes.

[2]Other related recent papers include Flavin and Yamashita (2002), Gervais (2002), Chambers, Garriga, and Schlagenhauf (2004), Davis and Heathcote (2003), Hurst and Stafford (2004), Ortalo-Magne and Rady (2005), Sinai and Souleles (2005), and Haurin and Rosenthal (2005).

2. The Model Economy

2.1. Preferences and Endowments

We consider an economy where a household lives at most for the length of time T ($T > 0$). The probability that the household lives up to period t is given by the following survival function,

$$F(t) = \prod_{j=0}^{t} \lambda_j, \quad 0 \leq t \leq T, \tag{1}$$

where λ_j is the probability that the household is alive at time j conditional on being alive at time $j-1$, $j = 0, ..., T$. We set $\lambda_0 = 1$, $\lambda_T = 0$, and $0 < \lambda_j < 1$ for all $0 < j < T$.

The household derives utility from consuming a numeraire good C_t and housing services H_t, as well as from bequeathing wealth Q_t. H_t here indicates the size of house, which should be interpreted broadly as reflecting not only the physical size but also its quality. We denote the within-period utility function as $U(C_t, H_t; N_t)$, where N_t denotes the exogenously given effective family size, which captures the economies of scale in household consumption as argued in Lazear and Michael (1980). We denote the bequest function as $B(Q_t; L)$, where L controls the strength of bequest motives.

In each period, the household receives income Y_t. Prior to the retirement age, which is set exogenously at $t = J$ ($0 < J < T$), Y_t represents labor income and is given by

$$Y_t = P_t^Y \varepsilon_t, \tag{2}$$

where

$$P_t^Y = \exp\{f(t, Z_t)\} P_{t-1}^Y \nu_t \tag{3}$$

is the permanent labor income at time t. P_t^Y has a deterministic component $f(t, Z_t)$, which is a function of household age and other characteristics. ν_t represents the shock to permanent labor income. ε_t is the transitory shock to Y_t. We assume that $\{\ln \varepsilon_t, \ln \nu_t\}$ are independently and identically normally distributed with mean $\{-0.5\sigma_\varepsilon^2, -0.5\sigma_\nu^2\}$, and variance $\{\sigma_\varepsilon^2, \sigma_\nu^2\}$, respectively. Thus, $\ln P_t^Y$ follows a random walk with a deterministic drift.

After retirement, the household receives an income that constitutes a constant fraction θ $(0 < \theta < 1)$ of its preretirement permanent labor income,

$$Y_t = \theta P_J^Y, \quad \text{for } t = J, ..., T. \tag{4}$$

2.2. Housing and Mortgage Contracts

A household can acquire housing services through either renting or owning. A renter has a house tenure $D_t^o = 0$, and a homeowner has a house tenure $D_t^o = 1$. To rent, the household pays a fraction α $(0 < \alpha < 1)$ of the market value of the rental house. To become a homeowner, the household pays a portion ρ $(0 < \rho < 1)$ of the house value as closing costs to secure the title and mortgage. The house price appreciation rate $\tilde{r}_t^H$ follows an i.i.d. normal process with mean μ_H and variance σ_H^2. The shock to house prices is thus permanent and exogenous.[3] A household can finance home purchases with a fixed rate nominal mortgage contract. We assume that a mortgage loan initiated at time t matures at T. This specification of mortgage loan term follows Campbell and Cocco (2003) and eliminates time-to-maturity as a separable state variable and considerably simplifies the model solution.[4]

The real mortgage balance denoted by M_t needs to satisfy the following collateral constraint,

$$0 \leq M_t \leq (1 - \delta) P_t^H H_t, \tag{5}$$

where $0 \leq \delta \leq 1$. The real borrowing rate r is time-invariant and the same as the real lending rate.[5] A homeowner is required to spend a fraction ψ $(0 \leq \psi \leq 1)$ of the house value on repair, maintenance, and property tax in order to keep the house quality constant.

[3]Flavin and Yamashita (2002), Campbell and Cocco (2003), Cocco (2005), and Yao and Zhang (2005) also assume that shocks to house prices are *i.i.d.* and permanent.

[4]An unappealing implication of this assumption is that achieving home ownership becomes easier for young households, since they can amortize their mortgage loans over a longer time period. Also their mortgage loan to value ratio comes down more slowly than those observed in the data. This effect can be partially offset by introducing a deterministic inflation in our model.

[5]By applying collateral constraints to both newly initiated mortgages and ongoing loans as in Fernandez-Villaverde and Krueger (2002), Cocco (2005), Yao and Zhang (2005), and Lustig and Nieuwerburgh (2005), we effectively rule out default, which justifies equal lending and borrowing rates. Default on mortgages is relatively rare in reality. According to the Mortgage Bankers Association, the seasonally adjusted three-month default rate for a prime fixed-rate mortgage loan is around 2 percent.

At the beginning of each period, the household receives a moving shock, D_t^m, that takes a value of 1 if the household has to move for reasons that are not modeled here and 0 otherwise. The moving shock does not affect a renter's housing choice, since moving does not incur any cost for him. When a homeowner receives a moving shock ($D_t^m = 1$), he is forced to sell his house. House prices per unit of housing services in the old and new locations are assumed to be the same.[6] A homeowner who does not have to move for exogenous reasons can choose to liquidate his house voluntarily. The selling decision, D_t^s, is 1 if the homeowner sells and 0 otherwise. Selling a house incurs a transaction cost that is a fraction ϕ ($0 \leq \phi \leq 1$) of the market value of the existing house. Additionally, the full mortgage balance becomes due upon the sale of the home. Following a home sale, a homeowner faces the same decisions as a renter coming into period t.

If the homeowner does not have to move for exogenous reasons and chooses to stay in the house, he has the option to convert some home equity to liquid wealth through a "cash-out" mortgage refinancing. D_t^r denotes the refinancing decision by the homeowner that takes a value of 1 if the homeowner refinances his mortgage and 0 otherwise. Refinancing requires a cost that is a fraction τ ($0 \leq \tau \leq 1$) of the house value. If the household decides not to refinance, it needs to pay down its mortgage balance according to the fixed-rate mortgage amortization schedule set at the mortgage initiation, subject to the collateral borrowing constraint (equation 5).

[6] In practice, some households can move to a different geographic area with a very different level of house prices, as modeled in Flavin and Nakagawa (2005) and Sinai and Souleles (2005). Doing so, however, will introduce another continuous state variable in our numerical solution.

To capture the "mortgage tilt" effect, we introduce a constant inflation rate of π.[7] The nominal mortgage rate r_m then satisfies $r_m = (1+r)(1+\pi) - 1$ and the evolution of the real mortgage balance follows:[8]

$$\begin{aligned} M_t &= \frac{1}{1+\pi}\left[M_{t-1}(1+r_m) - \frac{M_{t-1}}{\sum_{j=t}^{T}(1+r_m)^{t-j-1}}\right] \\ &= M_{t-1}(1+r)\left[1 - \frac{r_m/(1+r_m)}{1-(1+r_m)^{t-T-1}}\right]. \end{aligned} \tag{6}$$

We use $\bar{l}_t = \frac{M_{t-1}(1+r)}{P_t^H H_{t-1}}$ to denote the household's beginning-of-the-period mortgage loan-to-value ratio, and $l_t = \frac{M_t}{P_t^H H_t}$ to denote the mortgage loan-to-value ratio upon mortgage initiation, mortgage payment, or refinancing.

2.3. Liquid Assets

In addition to holding home equity, a household can save in liquid assets, which earns the same constant real riskfree rate r as the real mortgage borrowing rate. As a result, all mortgage refinances in our model are for consumption purposes only.[9] We denote the liquid savings as S_t and assume that households cannot borrow non-collateralized debt, i.e.,

$$S_t \geq 0, \quad \text{for } t = 0, ..., T. \tag{7}$$

A direct implication of this assumption is that credit card debt is not allowed and, hence, there are no portfolio allocation issues for households in the economy.

[7] Mortgage "tilt" refers to the fact that the economic burden of repaying a fix-rated mortgage declines over time because the amount of monthly payment measured in real terms is effectively eroded by inflation. We thank an anonymous referee for suggesting modeling the effects of inflation on nominal mortgage contract.

[8] Note that with an equal lending and borrowing rate, when refinancing is costly, a household always wishes to carry the maximum mortgage balance allowed by the mortgage amortization schedule or collateral borrowing constraint.

[9] Here implicitly we assume that the after-tax rate of return on the riskless bond is the same as the after-tax mortgage rate. Incorporating tax considerations explicitly by introducing the tax deductibility of interest payments would obviously encourage mortgage borrowing as well as home ownership as pointed out in Gervais (2002). However, we expect the qualitative results of our paper continue to hold given that the driving forces of our main results are not affected by this additional feature.

2.4. Wealth Accumulation and Budget Constraints

We denote the household's spendable resources or "wealth" upon home sale by Q_t.[10] It follows that for a renter ($D^o_{t-1} = 0$),

$$S_{t-1}(1+r) + P^Y_{t-1}\exp\{f(t,Z_t)\}\nu_t\varepsilon_t = Q_t. \tag{8}$$

In other words, a renter's spendable resources consists of his liquid savings and his period income. For a homeowner ($D^o_{t-1} = 1$), in addition to savings and period income, he also holds equity in the house, which is equal to the house value net of mortgage and house selling cost, i.e.,

$$S_{t-1}(1+r) + P^Y_{t-1}\exp\{f(t,Z_t)\}\nu_t\varepsilon_t + P^H_{t-1}H_{t-1}(1+\tilde{r}^H_t)(1-\phi) - M_{t-1}(1+r) = Q_t. \tag{9}$$

The intertemporal budget constraint for a household, therefore, can be written as follows:

(1) For a renter or a homeowner who decides to sell his house, if he chooses to rent in the current period ($D^o_{t-1} = D^o_t = 0$, or $D^o_{t-1} = D^s_t = 1$ and $D^o_t = 0$):

$$Q_t = C_t + S_t + \alpha P^H_t H_t, \tag{10}$$

where $\alpha P^H_t H_t$ is the rental cost.

(2) For a renter or a homeowner who decides to sell his house, if he chooses to buy a home in the current period ($D^o_{t-1} = 0$ and $D^o_t = 1$, or $D^o_{t-1} = D^s_t = D^o_t = 1$):

$$Q_t = C_t + S_t + (1 - l_t + \rho + \psi)P^H_t H_t, \tag{11}$$

where $(1-l_t)P^H_t H_t$ is the down payment on the newly purchased house, and $(\rho+\psi)P^H_t H_t$ is the house purchase and maintenance costs.

(3) For a homeowner who decides to stay in the existing house without refinancing his mortgage in the current period ($D^o_{t-1} = D^o_t = 1$ and $D^s_t = D^r_t = 0$),

$$Q_t = C_t + S_t + (1 - l_t + \psi - \phi)P^H_t H_{t-1}, \tag{12}$$

[10] Under this definition, conditional on selling his house, a homeowner's problem is identical to that of a renter and depends only on his age t, permanent income P^Y_t, house price P^H_t, and liquidated wealth Q_t.

where l_t needs to satisfy the mortgage amortization schedule for a fixed-rate mortgage loan (equation 6). The homeowner could not adjust the level of housing services without selling his house, i.e., $H_t = H_{t-1}$. Also we subtract house selling cost $\phi P_t^H H_{t-1}$—which is not incurred when one chooses to stay in the existing house—from the expenses on the right-hand side of the equation, since spendable resources Q_t is defined as net of the house selling cost.

(4) For a homeowner who decides to stay in the existing house and refinance his mortgage in the current period ($D_{t-1}^o = D_t^o = D_t^r = 1$ and $D_t^s = 0$),

$$Q_t = C_t + S_t + (1 - l_t + \psi - \phi + \tau) P_t^H H_{t-1}, \tag{13}$$

where $l_t \leq (1 - \delta)$. The right-hand side of the equation is similar to the previous case, except for an additional term, $\tau P_t^H H_{t-1}$, which captures the mortgage refinance cost.

2.5. The Optimization Problem

We assume that upon death, a household distributes its spendable resources Q_t among "L" beneficiaries to finance their numeraire good consumption and housing services through renting for one period. Parameter "L" thus controls the strength of bequest motives.

The household solves the following optimization problem at time $t = 0$, given its house tenure status (D_{-1}^o), after-labor income wealth (Q_0), permanent labor income (P_0^Y), house price (P_0^H), housing stock (H_{-1}), and mortgage balance ($M_{-1}(1 + r)$):

$$\max_{\{C_t, H_t, S_t, D_t^o, D_t^s, D_t^r\}} E \sum_{t=0}^{T} \beta^t \Big\{ F(t)\, U(C_t, H_t; N_t) + [F(t-1) - F(t)]\, B(Q_t; L) \Big\}, \tag{14}$$

subject to the mortgage collateral borrowing constraint (equation 5), the mortgage amortization schedule (equation 6), the liquid asset borrowing constraint (equation 7), wealth processes (equations 8 and 9), and the intertemporal budget constraints (equations 10 to 13). β is the time discount factor. $F(t)$ is the probability of being alive at period t as defined in equation (1).[11]

[11] The introduction of survival probability makes the model more realistic, especially for old households, but it is not crucial for our results.

3. Model Calibration

In this section, we first calibrate the model parameters according to the U.S. economy. We then discuss the optimal decision rules for renters and homeowners, followed by the simulated life-cycle profiles of household consumption and savings.

3.1. Model Parameterization

The decision frequency is annual. A household enters the economy at age 20 ($t = 0$) and lives to a maximum of age 90 ($T = 70$). The mandatory retirement age is 65 ($J = 45$). The conditional survival rates are taken from the 1998 life tables of the U.S. National Center for Health Statistics (Anderson 2001). For our benchmark analysis, we set the effective family size at each age to be a constant.[12] Moving probabilities are calibrated to the average migration rates for non-housing-related reasons between March 2001 and March 2002 in the Current Population Survey (CPS), as reported by the U.S. Census Bureau (2004).

Following many in the literature (Campbell and Cocco 2005, Chambers, Garriga, and Schlagenhauf 2004, Davis and Heathcote 2003, and Gervais 2002), we assume that a household has preferences of the following modified Cobb-Douglas functional form:[13]

$$U(C_t, H_t; N_t) = N_t \frac{[(\frac{C_t}{N_t})^{1-\omega}(\frac{H_t}{N_t})^{\omega}]^{1-\gamma}}{1-\gamma} = N_t^{\gamma} \frac{(C_t^{1-\omega} H_t^{\omega})^{1-\gamma}}{1-\gamma}. \tag{15}$$

The parameter ω determines the share of housing services in the composite consumption good. γ controls the curvature of the utility function with respect to the composite good. In our

[12] We do so due to dispersions in the calculation of effective family size in the literature. Robustness analysis indicates that our qualitative results are strengthened when we use effective family size calculated from the Survey of Consumer Finances.

[13] Cobb-Douglas utility implies an elasticity of intratemporal substitution of one between housing and non-housing consumption. The empirical literature is divided regarding the magnitude of this parameter. Piazzesi, Schneider, and Tuzel (2005) estimate it to be 1.27 with a standard deviation of 0.16. Davis and Martin (2005) also find that, in order to be consistent with U.S. housing stock and price data, the intratemporal elasticity of substitution between housing services and non-housing consumption has to be greater than 1.25. Flavin and Nakagawa (2005), however, report estimates ranging from 0.13 to 0.5 depending on whether there is habit persistence. The assumption of Cobb-Douglas preferences allows us to reduce the dimension of the state space by one through normalization and significantly simplifies numerical simulations. It should be noted that either adjustment cost or low rate of intratemporal substitution can lead to empirical lacks of housing adjustments in response to house price changes. Interestingly, if one ignored house adjustment cost in estimating the intratemporal substitution parameter using simulated data under our baseline parameterization, he would come up with an empirical estimate of 0.88. This value is significantly lower than the true model parameter of 1.0 assumed in the Cobb-Douglas utility function.

setup, the coefficient of relative risk aversion demonstrated by the households generally does not coincide with the parameter governing the curvature of the instantaneous utility function due to the presence of lumpy adjustment costs. For this reason, the parameter γ will be referred to as "the curvature parameter" rather than "the risk aversion parameter." We set ω at 0.20, the average share of household housing expenditures found in the 2001 Consumer Expenditure Survey, and γ at 2, a number widely used in the literature.

The parameters for income process are as reported in Cocco, Gomes, and Maenhout (2005) for a high school graduate. In particular, the standard deviation of the permanent shock σ_ν is 0.1 and the standard deviation of the transitory shock σ_ε prior to retirement is 0.27. Income replacement ratio at retirement is set at 0.68.[14] Storesletten, Telmer, and Yaron (2004) report similar estimates for labor income processes.

The real riskfree rate r is set at 0.03, approximately the average annualized post-WWII real return available on T-bills. The inflation rate π is set at 3 percent, slightly below the average annual inflation rate calculated using the personal consumption expenditure price index between 1960 (the first available data point) and 2004, yet a bit higher than the forward looking inflation rate. For parameters that capture institutional features of the housing market, we set the annual rental cost α at 7.5 percent of the current house value. The annual maintenance and depreciation cost ψ is set at 3.0 percent of the house value. The house purchase cost ρ is set at 3.0 percent of the house value to capture buyers' search cost and mortgage initiation costs. The house selling cost ϕ is set at 6.0 percent of the market value of the house, consistent with ongoing brokerage fees. The mortgage collateral constraint is set at 80 percent.[15] The refinancing cost τ is set at a relatively low 0.5 percent of the house value

[14]Cocco, Gomes, and Maenhout (2005) used the Panel Study of Income Dynamics (PSID) to estimate equations (2) and (3). The function $f(t, Z_t)$ is assumed to be additively separable in t and Z_t, where Z_t represents personal characteristics other than age and the fixed household effect, including marital status and household composition. The measurement of labor income is broadly defined to include unemployment compensation, welfare, and transfers. The logarithm of labor income is then regressed on dummies for age, family, and marital status, and on household composition. A third-order polynomial is fitted to the age dummies to obtain the labor income profiles, which is adopted in our numerical solution. The replacement ratio is calibrated as the ratio of the average of labor income for retirees to the average of labor income in the last working-year prior to retirement. The error structure of the labor income process is estimated using the variance decomposition technique as described in Carroll and Samwick (1997). See Appendix B of their paper for additional technical details.

[15]Using the 1995 American Housing Survey, Chambers, Garriga, and Schlagenhauf (2004) calculate that the down payment fraction for first-time home purchases is 0.1979, while the fraction for households that previously owned a home is 0.2462.

to implicitly allow for accessing home equity through home equity loans or home equity lines of credit in addition to mortgage refinances.

We assume that the housing appreciation rate $\tilde{r}_t^H$ is serially uncorrelated and has a mean of zero, which fell within the empirical range estimated by Goetzmann and Spiegel (2002).[16] The housing return volatility σ_H is set at 0.10, similar to estimates in Campbell and Cocco (2003) and Flavin and Yamashita (2002). We further assume that there is no correlation between housing returns and shocks to labor income in order to isolate the effects of house price changes in our consumption and welfare analysis.

Finally, we choose the subjective time discount rate parameter β, and the bequest strength parameter L to match the average wealth-labor income ratios and home ownership rates over the representative household's life cycle as observed in the U.S. economy. The Cobb-Douglas utility assumption results in the beneficiary's expenditure on numeraire good and housing service consumption at a fixed proportion ($\frac{1-\omega}{\omega}$). Then the bequest function is defined by

$$B(Q_t) = L^{\gamma} \frac{[Q_t(\omega/\alpha P_t^H)^{\omega}(1-\omega)^{1-\omega}]^{1-\gamma}}{(1-\gamma)}. \tag{16}$$

Table 1 summarizes our model parameterization. Details on obtaining a numerical solution are provided in Appendix A. To gain further insights of the model, we now turn to households' optimal decision rules, followed by simulated life-cycle consumption and savings profiles.

3.2. Optimal Housing and Consumption Decision Rules

3.2.1. A Renter's Optimal Decisions

A household entering the current period as a renter is described by its age (t) and wealth-permanent labor income ratio ($\frac{Q_t}{P_t^Y}$). Figure 1 presents the renter's optimal house tenure choice. The solid line represents the wealth-labor income ratio at which the household is indifferent between renting and owning. The household buys a home when its wealth-labor income ratio is above this line and continues to rent otherwise. Under our parameterization, on average, renting costs more per period than owning the same house, i.e., $\alpha > r + \psi$. However, due

[16] Based on 80 quarters of housing index data between March 1980 and March 1999, Goetzmann and Spiegel (2002) estimate that the real housing returns for the 12 largest metropolitan statistical areas (MSAs) vary from -1.0 percent to 3.46 percent.

to house purchasing and selling costs, a household prefers to own a house that matches its life-cycle income and wealth profiles so that the expected tenure in the house is sufficiently long. A household with a large amount of wealth on hand can afford the down payment for a house of desired value and therefore benefits more from home ownership.

The wealth-income ratio that triggers home ownership initially decreases with the household's age. This result is driven by the household's life-cycle income and mobility profiles. Since a young household faces high income growth rates, its desired house is large relative to its *current* income. A higher wealth-labor income ratio is needed to satisfy the house down payment requirement to trigger home ownership. Additionally, young households have higher exogenous mobility rates that also raise the cost of owning. As the household approaches the terminal period, the threshold wealth-income ratio for home ownership moves up sharply, reflecting the increasing incentives to preserve wealth liquidity and to avoid mandatory house liquidation costs upon death.[17]

A renter's consumption and savings functions are similar to those identified in the precautionary savings literature with liquidity constraints (figures 2 and 3). At low wealth levels, a renter continues to rent and spends all of his wealth on numeraire goods and rent payments. At slightly higher wealth levels, a renter saves a fraction of the wealth in liquid assets for intertemporal consumption smoothing and housing down payment. Note, upon making a down payment toward purchasing a home, the household's liquid savings drop substantially.

3.2.2. A Homeowner's Optimal Decisions

A household entering the current period as a homeowner is characterized by its age (t), wealth-income ratio ($\frac{Q_t}{P_t^Y}$), house value-income ratio ($\frac{P_t^H H_{t-1}}{P_t^Y}$), and mortgage leverage ratio ($\frac{M_{t-1}(1+r)}{P_t^H H_{t-1}}$). Figure 4 plots a homeowner's endogenous house liquidation and mortgage refinancing decisions as a function of the household's beginning-of-the-period mortgage loan-to-value ratio and house value-income ratio while holding his wealth-income ratio constant.[18] A homeowner that receives an exogenous positive moving shock ($D_t^m = 1$) has to sell the house, and his subsequent consumption and housing decisions are identical to those of a renter. Otherwise, there are four

[17] Recall bequeathed wealth is defined as net of house liquidation costs.

[18] For figures 4, 5, and 6, we hold the household age at 50 and the wealth-income ratio at 1.5.

regions of (in)actions: (1) the non-admissible region (N.A.)—the homeowner's mortgage loan-to-value ratio and house value-income ratio cannot take combinations in this region; (2) the stay region (STAY)—the homeowner stays in his existing house without mortgage refinancing; (3) the stay and refinance region (REFI)—the homeowner stays in his house and refinances his mortgage; and (4) the sell region (SELL)—the homeowner sells his house.

Since a homeowner cannot take on unsecured debt, the value of his home equity cannot exceed his total wealth. The boundary of the non-admissible region is defined by $(1 - \bar{l}_t - \phi)P_t^H H_{t-1} = Q_t$. The homeowner stays in the house when his house value-labor income ratio is not too far from the optimal level he would have chosen as a renter.[19]

For a homeowner who stays in his house, the composition of his wealth affects his non-housing consumption. More precisely, for a given house value-income ratio, as his leverage ratio decreases, the homeowner's liquid savings drop (figure 6), which in turn reduces his non-housing consumption (figure 5). When the level of liquid assets becomes too low, the homeowner refinances his mortgage to gain access to illiquid home equity. The additional "cash" leads to immediate increases in both non-housing consumption and liquid savings. This occurs when the homeowner's home equity ties up a large fraction of his total wealth, i.e., when his mortgage loan-to-value ratio is low or when his house value-wealth ratio is high.

3.3. Simulated Life-Cycle Housing and Consumption Choices

We now examine a household's average life-cycle consumption and wealth accumulation through simulation. To do so, we first simulate labor incomes, house prices, and moving shocks according to their respective governing stochastic processes. Then, we update state variables each period according to the optimal decision rules. For all simulated paths, households start at age 20 as a renter with zero liquid wealth and a permanent income of \$15,000. We generate time-series profiles by taking the average of two million simulations from $t = 0$ (age 20) to $t = 70$ (age 90).

[19]The house liquidation decision also depends on a homeowner's mortgage loan–to–value ratio, especially at low levels of wealth–income ratio (figure not shown). A homeowner is less willing to liquidate at high mortgage leverage ratio—upper boundary is higher yet lower boundary is lower—since a large mortgage balance improves liquidity, holding the total wealth constant.

The life-cycle profiles generated in our calibrated economy (figure 7) are similar to those found in the data (figure 8).[20] Specifically, the home ownership rate is hump-shaped over age (figure 7a), while mortgage leverage decreases steadily with age (figure 7b). Compared to the data, however, the home ownership rate in our simulated economy increases more rapidly among young households. In addition, the average mortgage loan-to-value ratio generated by our model decreases more slowly prior to retirement than that in the data. These differences arise mainly due to the long amortization schedule assumed for the mortgage contract in the model, which reduces the mortgage payments for young mortgage borrowers and makes home ownership more affordable.

In our simulation, the refinancing rate demonstrates a bimodal pattern, with the first peak reached in the household's late 30s and the second peak reached in its early 80s (figure 7c). A young household is more likely to be liquidity–constrained, since it does not have a large amount of liquid wealth to buffer negative income shocks. Therefore, it benefits most from mortgage refinancing. These households, however, will not refinance immediately after home purchase, since they need to accumulate a significant amount of home equity to make it worthwhile to pay the refinancing cost. Overtime, home equity is accumulated through mortgage principal payment and/or positive shocks to house prices.[21] A middle-aged household is able to absorb negative income shocks by temporarily depleting its liquid savings, lessening the need of costly refinancing. Indeed the refinancing rate falls to almost zero around retirement when the household has the most liquid wealth reserves.[22]

After retirement, the household starts to run down its wealth to supplement its retirement income. To defer house liquidation costs and refinancing charges, the household first draws upon its liquid assets. Once the household has depleted its liquid savings, it resorts to its illiquid home equity. Through "cash-out" mortgage refinancing, a homeowner can further

[20] Appendix B provides details on the empirical estimations of the life-cycle profiles of home ownership rate, mortgage leverage ratio, house value, and home equity-net worth ratio using a pseudo-panel constructed from the 1992-2001 Survey of Consumer Finances.

[21] The refinancing rate among homeowners experiencing house price appreciation is 2-3 times higher than those experiencing depreciation in our baseline simulation.

[22] Using micro data from the Panel Study of Income Dynamics, Hurst and Stafford (2004) find similar refinancing patterns. They show that households who have experienced a spell of unemployment and who have little liquid assets are much more likely to refinance to liquify home equity than otherwise similar households. These households also tend to be relatively young. Furthermore, the propensity to refinance and remove equity for households who experienced a negative income shock declines as their liquid asset holdings increase.

defer house selling costs and avoid the more expensive alternative means of acquiring housing services through renting.[23] If a household's relative housing value deviates too much from its consumption need, however, selling and then renting becomes a better alternative. By age 80, less than 2 percent of homeowners have exited home ownership. By the terminal period, about 37 percent of all households in our simulation have sold their houses and moved to renting. The low rate of home equity liquidation is consistent with findings documented in Venti and Wise (2000).

As in the consumption literature with liquidity constraint and precautionary savings motives, non-housing consumption exhibits a hump shape (figure 7d). Simulated housing consumption also demonstrates a hump shape over the life-cycle, matching the pattern observed in the data (figure 7f and figure 8c).[24] However, due to significant adjustment costs in the housing market, housing consumption does not drop as quickly as non-housing consumption after peaking in the household's early 60s.

The proportion of net worth tied up in home equity exhibits a U-shaped pattern over the life-cycle, consistent with empirical evidence (see figure 8d). Intuitively, when the household is young, most of its wealth is committed to its house. As the household ages, liquid assets gradually surpass home equity as a primary vehicle of saving. After retirement, the household draws down its liquid assets first to supplement retirement income in order to defer mortgage refinancing and house selling charges. Eventually, as a last resort, the household accesses housing wealth through mortgage refinancing or home sales to finance its retirement consumption.

Summary aggregate statistics for the benchmark model economy and their data counterparts are reported in Table 2. Our model generates statistics that replicate the targeted numbers reasonably well.

[23] Early empirical work finds that the elderly rarely refinance or take on reverse mortgages (Feinstein and McFadden 1989). Yet recent studies suggest that seniors do take money out of their homes through reduced expenditures on routine maintenance, alterations, and repairs. (Gyourko and Tracy 2003, and Davidoff 2004).

[24] The hump shape pattern is even more significant when life-cycle demographic composition is incorporated.

4. Results

We now investigate the effects of house price changes on household consumption and welfare at both the aggregate levels and across individual households at different stages of the life-cycle, using our calibrated model. Then we examine the relative importance of several key features of the housing market in affecting these results, specifically the lumpy transaction costs, the dual role of housing as both a consumption good and an investment asset, and the unhedgeable house price risks.

To obtain the average effects of a permanent house price change on a household's consumption and welfare, for each age t, we separate households in our simulated economy into two groups: those who experienced a house price appreciation and those who experienced a house price depreciation.[25] The two groups so constructed only differ in the house price shocks they receive at age t. Effectively, one can view the exercise as comparing the behavior of ex ante identical households in two different economic environments, one receiving a positive house price shock and the other receiving a negative house price shock.[26][27]

We focus on three economic variables: the average home ownership rate, the marginal propensity to consume (MPC) out of housing wealth, and the household welfare. The MPC is calculated as the ratio of the mean consumption difference between homeowners in the two different economic environments to their mean housing wealth difference.

Our welfare metric is defined as the necessary compensation to the households experiencing negative housing shocks that can bring their mean lifetime utility to the mean utility of

[25] In our numerical solution, we approximate shocks to house price growth rate with an *i.i.d.* binomial distribution. Hence households experiencing house price appreciation (depreciation) have a shock to the house price growth rate equal to one positive (negative) standard deviation. The shocks to future house price growth rate are not affected.

[26] Recall that in each period, the stochastic shocks to moving, housing returns, and permanent and temporary components of labor incomes are approximated by a sixteen-state Markov chain. The shocks are assumed to be independent of each other and uncorrelated over time. Therefore, with a large number of simulations, the *ex ante* distribution of the state variables—home ownership status, wealth-income ratio, house value-income ratio, and mortgage loan-to-value ratios—-should be identical for households experiencing either positive or negative house price shocks *ex post*.

[27] We separate households based on the shocks to the house price growth rate, instead of house price levels. Given our Cobb-Douglas preference, households' housing expenditure decision ($P_t^H H_t$) does not vary with respect to house price (P_t^H) in our economy. Specifically, a renter responds to house price shocks by adjusting the level of housing service flows (H_t) while keeping housing expenditure ($\alpha P_t^H H_t$) unchanged. A homeowner's house liquidation decision depends on the value of the existing house ($P_t^H H_t$).

households experiencing a positive house price shock. The compensation is in the form of a proportional increase in durable and non-durable consumptions for the remaining life span, as well as the bequeathed wealth upon death. Aiyagari and McGrattan (1998) adopt a similar measure of welfare in an infinite horizon economy. Specifically, we first calculate by age the sum of value functions for the households experiencing a positive shock and a negative shock:

$$\overline{V}_t^j = \sum_{i=1}^{K_t^j} V_t^{ij} = \sum_{i=1}^{K_t^j} \left[v_t^{ij} \left(P_t^{Y\ ij} / (P_t^{H\ ij})^{\omega} \right)^{1-\gamma} \right], \quad t = 0, ..., T, \quad \text{and} \quad j = up,\ dn, \tag{17}$$

where j is the index for the realization of shocks to house price growth rate, and i is the index for the heterogeneous agents in state j. K_t^j is the total number of agents at time t that fall in the j-th state of housing returns. v_t^{ij} is the normalized value functions as defined in Appendix A. Our utility cost measure can then be calculated as:

$$\Omega_t = \left(\frac{\overline{V}_t^{up}}{\overline{V}_t^{dn}} \right)^{\frac{1}{1-\gamma}} - 1. \tag{18}$$

4.1. The Effects of House Price Changes on Consumption and Welfare

Table 3 reports the effects of house price changes on aggregate consumption and welfare. The statistics reported take into account the survival probability of households at different ages. A 10 percent increase in house price has a rather limited effect on aggregate home ownership rate and total household welfare in comparison to a 10 percent decrease, with home ownership rate decreasing by 0.19 percentage point and the aggregate welfare decreasing by 1.43 percentage point. The aggregate MPC, at 3.26 percent, is within the range of empirical estimates, albeit at the lower end.[28] The effects of house price changes in a household's net savings position, i.e., the difference between liquid savings and mortgage borrowing ($S_t - M_t$), depend on their decisions to realize housing wealth gains. Among those who sold their residence, the households experiencing a 10 percent house price shock accumulate a net savings position that is, on average, \$21,743 higher than those households experiencing a 10 percent house price depreciation. Among those who did not sell, the net savings position is, on average, \$40

[28]Case, Quigley, and Shiller (2003) find that an additional dollar of house wealth increases household consumption by 3 to 15 cents. Benjamin, Chinloy, and Judd (2004) find the effect of housing wealth on household consumption of similar magnitude – 8 cents out of a dollar.

lower. The unconditional net change is an increase in savings of $1,453, or about 4.15 percent of the average total savings of $34,997.[29]

The effects of permanent house price changes on individual households, however, vary significantly as depicted in figure 9. Here we examine, by age, changes in housing positions along both the extensive margin and the intensive margin, and changes in non-housing consumption, net worth, and total welfare.

Figure 9a presents home ownership transitions upon the realization of the house price shock for homeowners at the beginning of the period, and figure 9b presents housing positions conditional on a household being a homeowner both before ("in") and after ("out") housing adjustments for the current period. In our simulation, young homeowners are more likely to exit home ownership after a negative house price shock ("down") than after a positive price shock ("up"). This is because if the household experiencing a negative house price shock is forced to move and sell the house for exogenous reasons, its wealth-income ratio is more likely to fall below the triggering level for home ownership. By contrast, for middle-aged homeowners, the proportion of households exiting home ownership is not sensitive to house price changes. These households have accumulated significant wealth and can sustain home ownership despite losses in housing wealth. The home ownership exit patterns for senior homeowners are just the opposite. The households experiencing positive house price gains are more likely to liquidate to lock in housing wealth gains and switch to renting.

Young homeowners who choose to stay as homeowners tend to upgrade to bigger houses after a negative house price shock and do not actively adjust their house sizes after a positive house price shock. Middle-aged and old homeowners, on the other hand, tend to downgrade to smaller houses after a positive house price shock and do not change housing sizes after a negative house price shock. This asymmetry is primarily driven by the hump-shaped life-cycle housing consumption profile. A house price appreciation substitutes for active house upsizing for young homeowners and accelerates downsizing for old homeowners. A house price depreciation, in comparison, substitutes for active house downsizing for old homeowners and accelerates upsizing for young homeowners.

[29]Due to the partial equilibrium nature of our model economy, the housing market does not clear, and there can be a net house selling (buying) after a house price appreciation (depreciation).

Figures 9c and 9d depict the impact of housing wealth gains on homeowners' non-housing consumption. Not surprisingly, across all ages, those who experienced a permanent house price appreciation spend more on non-housing consumption than those who experienced a permanent house price depreciation. Interestingly, the non-housing consumption of young and old homeowners is more sensitive to house price changes than that of the middle-aged homeowners (figure 9e). As discussed earlier, young households are more likely to be liquidity-constrained. Housing appreciation, by increasing the collateral value, helps to relax young homeowners' borrowing constraints and increase their non-housing consumption. Old homeowners have a short life horizon. They thus are more likely to capture the gains and increase their non-housing consumption and bequest accordingly. By contrast, middle-aged homeowners have accumulated enough liquid savings to overcome liquidity constraints. They also face a relatively long expected life span. Their consumption is, therefore, least responsive to house price changes.

Figure 9f presents the welfare consequences of house price changes for renters, homeowners, and all households combined, at different stages of the life-cycle. Observe that house price appreciation unambiguously lowers renters' welfare, since they have to bear the higher cost of acquiring lifetime housing services without receiving any housing wealth gains. According to our calculation, for renters, a positive house price shock of 10 percent leads to a welfare loss of around 3.9 percent, relative to the case of a negative house price shock of the same magnitude.

Surprisingly, although house price appreciation raises the non-housing consumption and net worth positions for all homeowners, these consumption increases do not always translate into welfare gains. In particular, a positive housing shock incurs about a 1.2 percent utility loss for young homeowners in their 30s and 40s. This result arises because young homeowners face a long horizon of future housing consumption and, on average, are expecting to move up in the housing ladder. Thus, their investment gains from existing housing positions together with the consumption gains in the current period resulting from the relaxed borrowing constraints are not sufficient to compensate them for the increase in their lifetime housing consumption

costs.[30] In our simulation, the break-even age for welfare is reached around age 60. Only households beyond the age of 75 receive a welfare gain exceeding 1 percent.

4.2. The Role of Adjustment Costs

Housing market features lumpy adjustment costs. To explore the quantitative impact of these transaction costs, we now set the costs of house purchasing and selling, as well as mortgage refinancing, to zero. The new economy thus resembles that of Fernandez-Villaverde and Krueger (2002). The results are presented in figure 10.

In the absence of adjustment costs, the effects of house price changes on home ownership is much larger. 4.09 percentage point more households exit from home ownership after a 10 percent house price depreciation than after a 10 percent appreciation, versus 0.19 in the benchmark case (see table 3). Furthermore, the total welfare change is much less negative at -0.51 percent, versus -1.43 percent in the baseline case. The welfare difference between two economies is smaller for homeowners, at -0.22 percent versus -0.42 percent.

In our economy, house price appreciation affects a homeowner's welfare through three channels. First, it increases the household's net worth position. Second it raises future housing consumption costs by increasing (1) the unit price of housing service flows; (2) house maintenance costs; (3) house selling costs and mortgage refinancing charges. While a homeowner's wealth gains exactly offset the high unit costs of housing service flows for the existing house, higher adjustment and maintenance costs represent a deadweight loss in the economy. Yet, facing a new price vector, a household can reallocate its housing and non-housing expenditures. When housing adjustment costs are absent, the household can more easily re-optimize over their consumption bundle, which leads to a less negative aggregate welfare effect.

The differences in individual effects from the benchmark economy are very noticeable. Without housing adjustment costs, young households become homeowners much earlier, but they are also much more likely to switch back to renting after experiencing a negative house

[30]It is worth noting that the net welfare loss among young homeowners after house price gains does not suggest that young households should not pursue home ownership. To the contrary, the renting alternative will cause an even large welfare loss. Hence, in addition to the conventional rationales that home ownership offers externalities and encourages building wealth, public policy may also promote home ownership to protect young and low-income families from house price appreciation and higher future housing consumption costs.

price shock (figure 10a). Old households never switch back to renting, even after receiving exogenous moving shocks, since house liquidation upon death is now costless. As seen in figures 10b and 10c, the life-cycle profile of housing consumption now follows more closely that of non-housing consumption and demonstrates a pronounced hump. In addition, homeowners' non-housing consumption is much more responsive to changes in their housing wealth compared to the benchmark case. The MPCs out of housing wealth are much higher and range from 15 percent for the very young to 5 percent for households in their 50s.

In terms of welfare, renters and young homeowners remain worse off with the house price appreciation. Homeowners, however, on average, break even at a much younger age than the benchmark case. Overall, the welfare loss for young households are significantly lower (figure 10f. This is due to the fact that earlier home ownership affords more households an opportunity to at least partially hedge house price risks. The flexibility of costless "re-balancing" between two consumption goods mitigates the adverse consequences of permanently higher house prices.

4.3. The Dual Role of Housing as Both a Consumption Good and an Investment Vehicle

To investigate the effect of the dual purpose of housing as both a consumption good and an investment asset, we compare the effects of wealth gains from housing to that from a liquid asset. The only liquid asset in our model is a riskless bond with a constant rate of return. We, therefore, study the effects of gains in liquid assets through a temporary income shock, since a household is indifferent between a one-dollar gain from a liquid asset and a one-dollar gain from transitory income in our economy.[31] The results are reported in figure 11.

Wealth gains from the liquid asset always lead to gains in both housing and non-housing consumption. The MPCs out of liquid wealth range from 8 percent for young homeowners to around 7 percent for homeowners approaching retirement, much higher than the average MPC out of housing wealth gains in our benchmark economy. The MPCs over the life-cycle remain U-shaped, reflecting the importance of liquidity and the finite life horizon. The most

[31]Since retired households no longer face any income risk, we restrict our discussion to households under age 65.

interesting result concerns the welfare consequences. The wealth gains in liquid assets now lead to welfare improvements for all households. The reason is obvious. Unlike housing wealth gains, liquid asset gains are not accompanied by an increase in housing consumption costs.

In summary, our analysis suggests that although house price fluctuations have small aggregate effects, as argued in Sinai and Souleles (2005) and Bajari, Benkard, and Krainer (2005), they can create large distributional effects and these effects depend crucially on households' age and housing positions. More specifically, under our parameterization, young and old homeowners' non-housing consumption is more sensitive to house price changes than that of middle-aged homeowners. From a welfare perspective, while old homeowners benefit from a permanent house price appreciation, young homeowners and renters are worse off. While housing and mortgage adjustment costs do not change the basic qualitative distributional pattern predicted by the model, their effects on household consumption and welfare are quantitatively very significant.

4.4. The Effects of House Price Uncertainty on Housing Demand

We now examine how levels of house price risks affect housing demand, a topic that has attracted much attention recently.[32] Current institutional arrangements in the housing market do not provide appropriate financial assets to hedge and diversify house price risk. The lumpiness of housing transaction costs further complicate households' risk management by making a home purchase decision costly to reverse in the future.

There has been a growing literature that strives to document empirical evidence on the effects of house price uncertainty. For example, Rosen, Rosen and Holtz-Eakin (1984) use a national time series data set and find a negative relationship between uncertainty and home ownership. Turner (2003) uses a repeated cross-section household level data set and concludes that house price volatility discourages housing demand. Contrary to these findings, Sinai and Souleles (2005) use household level data from the Current Population Survey and report a positive relationship between rental price risk and home ownership. Banks, Blundell, Oldfield, and Smith (2004) also show that a mean-preserving spread in the variance of house

[32]We thank an anonymous referee for suggesting this model application.

prices would increase the ownership rate at an early age using household level data from both England and the U.S.

Our model provides a natural test ground to analyze this issue. Unlike the stylized models in the previous literature (see Sinai and Souleles 2005 and Banks et al. 2004), we endogenously derive home ownership and housing demand in a realistic life-cycle model with housing and mortgage adjustment costs as well as credit market frictions. Interestingly, we find that the relationship can be either positive or negative, depending on how risk averse households are. In figure 12, we present the renting versus owning boundary, home ownership rate, and home value over the life-cycle under alternative parameterizations. The left panels use a curvature parameter of 2 and the right panels use 5, both within the range in the literature. In each panel, we depict the benchmark case of 10 percent annual house return volatility and the alternative case of 1 percent volatility.

At a relatively high curvature parameter of 5, in the presence of high house price risk, the consumption hedging effect dominates the investment risk effect for young households. They tend to buy houses early and buy bigger houses. The opposite holds for old households. Facing a short horizon, old households are more concerned with the asset return risk than with the house consumption risk. They, therefore, exit from home ownership earlier and downsize to a smaller home faster when house price risk is high.

At a relatively low curvature parameter of 2, the trend of earlier home ownership exit and faster downsizing in the presence of high house price uncertainties remains the same for older households. However the pattern for young households is reversed. Young households delay transition to home ownership when they face high house price uncertainties. This reversal can be explained by the difference in households' consumption and savings pattern under two different curvature parameters. At a low curvature parameter, households' precautionary savings incentive is not as strong, and they are more concerned with immediate consumption. More uncertain house prices lead to a higher likelihood of a significantly depreciated house value, which constrains collateral borrowing. At a high curvature parameter, households save more in the form of liquid assets for precautionary purpose and are thus less concerned with depreciated house prices.

5. Conclusions

In this paper, we developed a life-cycle model to study the effects of house price changes on household consumption and welfare. Several key features distinguish the model from the existing literature. First, we model housing choices along both the extensive margin of owning versus renting and the intensive margin of house value. Second, we introduce a long-term fixed-rate mortgage contract with a collateral requirement for financing house purchases. Third, we explicitly distinguish between liquid savings and illiquid home equity by accounting for house liquidation and mortgage refinancing costs.

Our analysis indicates that although the aggregate consumption and welfare effects of house price changes are small, their effects at the individual household level vary significantly, depending on a household's age and home ownership status. Specifically, the non-housing consumption of young and old homeowners is more responsive to house price changes than that of middle-aged homeowners. More importantly, while old homeowners benefit from house price appreciation, renters and young homeowners are worse off.

Our analysis also points out that housing adjustment costs are important quantitatively in explaining the large distributional effects. A complete elimination of the distributional effects, however, requires innovative financial products that separate the dual role of housing as both a consumption good and an investment asset. Future extensions to this paper should consider more general utility function forms and endogenous house prices.

References

Aiyagari, R. S., and Ellen McGrattan, 1998, The Optimal Quantity of Debt, *Journal of Monetary Economics*, 42(3), 847-69.

Anderson, Robert N., 2001, United States Life Tables 1998, *National Vital Statistics Reports*, 48, 1-40.

Artle, Roland, and Varaiya Pravin, 1978, Life Cycle Consumption and Homeownership, *Journal of Economic Theory*, 18(1), 38-58.

Bajari, Patrick, C. Lanier Benkard, and John Krainer, 2005, House Prices and Consumer Welfare, *Journal of Urban Economics*, 58, 474-487.

Banks, James, Richard Blundell, Zoe Oldfield, and James P. Smith, 2004, House Price Volatility and Housing Ownership over the Life-Cycle, University of College London discussion paper 04-09.

Benjamin, John, Peter Chinloy, and Donald G. Jud, 2004, Real Estate Versus Financial Wealth in Consumption, *Journal of Real Estate Finance and Economics*, 29(3), 341-54.

Campbell, John, and Joao F. Cocco, 2003, Household Risk Management and Optimal Mortgage Choice, *Quarterly Journal of Economics*, 118, 1149-1194.

Campbell, John, and Joao F. Cocco, 2005, How Do House Prices Affect Consumption? Evidence from Micro Data, *Journal of Monetary Economics*, forthcoming.

Carroll, Christopher D., 1997, Buffer Stock Saving and the Life Cycle/Permanent Income Hypothesis, *Quarterly Journal of Economics*, 112(1), 1-55.

Carroll, Christopher D., and Andrew A. Samwick, 1997, The Nature of Precautionary Wealth, *Journal of Monetary Economics*, 40, 41-71.

Case, Karl E., John M. Quigley, and Robert T. Shiller, 2003, Comparing Wealth Effects: The Stock Market versus the Housing Market, working paper, University of California, Berkeley.

Chambers, Matthew, Carlos Garriga, and Don E. Schlagenhauf, 2004, Accounting for Changes in the Homeownership Rate, working paper, Florida State University.

Cocco, Joao F., 2005, Portfolio Choice in the Presence of Housing, *Review of Financial Studies*, 18, 535-567.

Cocco, Joao F., Francisco J. Gomes, and Pascal J. Maenhout, 2005, Consumption and Portfolio Choice over the Life-Cycle, *Review of Financial Studies*, 18, 491-533.

Davidoff, Thomas, 2004, Maintenance and the Home Equity of the Elderly, working paper, University of California at Berkeley.

Davis, Morris, and Jonathan Heathcote, 2005, Housing and the Business Cycle, *International Economic Review*, 46(3), 751-84.

Davis, Morris, and Robert Martin, 2005, Housing, House Prices and the Equity Premium Puzzle, Manuscript.

Deaton, Angus, 1991, Saving and Liquidity Constraints, *Econometrica*, 59 (5), 1221-48.

Deaton, Angus, 1997, The Analysis of Households Surveys: A Microeconomic Approach to Development Policy. Baltimore and London: Johns Hopkins University Press for the World Bank.

Feinstein, Jonathan, and Daniel McFadden, 1989, The Dynamics of Housing Demand by the Elderly: Wealth, Cash Flow, and Demographic Effects, The Economics of Aging, National Bureau of Economic Research Project Report Series Chicago and London: University of Chicago Press, 55-86.

Fernandez-Villaverde, Jesus, and Dirk Krueger, 2002, Consumption and Saving over the Life Cycle: How Important Are Consumer Durables? *Proceedings of the 2002 North American Summer Meetings of the Econometeric Society.*

Flavin, Marjorie, and Takashi Yamashita, 2002, Owner-Occupied Housing and the Composition of the Household Portfolio over the Life-cycle, *American Economic Review*, 92, 345-362.

Flavin, Marjorie, and Shinobu Yamashita, 2005, A Model of Housing in the Presence of Adjustment Costs: A Structural Interpretation of Habit Persistence, NBER working paper no. 10458.

Gervais, Martin, 2002, Housing Taxation and Capital Accumulation, *Journal of Monetary Economics*, 49(7), 1461-89.

Goetzmann, William N., and Matthew Spiegel, 2002, The Policy Implication of Portfolio Choice in Underserved Mortgage Markets, *Low Income Homeownership: Examining the Unexamined Goal*, The Brookings Institution.

Gyourko, Joseph, and Joseph Tracey, 2003, Using Home Maintenance and Repairs to Smooth Consumption, working paper, Wharton School, University of Pennsylvania.

Haurin, Donald, and Stuart S. Rosenthal, 2005, The Impact of House Price Appreciation on Portfolio Composition and Savings, working paper, Department of Economics, Ohio State University.

Hurst, Erik, and Frank Stafford, 2004, Home Is Where the Equity Is: Liquidity Constraints, Refinancing, and Consumption, *Journal of Money, Credit and Banking*, 36(6), 986-1004.

Lazear, Edward P., and Robert T. Michael, 1980, Family Size and the Distribution of Real Per Capita Income, *American Economic Review*, 70(1), 91-107.

Lustig, Hanno, and Stigin Van Nieuwerburgh, 2005, Housing Collateral Consumption Insurance and Risk Premia: An Empirical Perspective, *Journal of Finance*, 60(3), 1167-1219.

Ortalo-Magné, François, and Sven Rady, 2005, Housing Market Dynamics: On the Contribution of Income Shocks and Credit Constraints, forthcoming, *Review of Economic Studies*

Piazzesi, Monica, Martin Schneider, and Selale Tuzel, 2004, Housing, Consumption and Asset Pricing, working paper, New York University.

Rosen, Harvey S., Kenneth T. Rosen, and Douglas Holtz-Eakin, 1984, Housing Tenure, Uncertainty and Taxation, *Review of Economics and Statistics*, 66(3), 405-16.

Sinai, Todd, and Nicholas S. Souleles, 2005, Owner-Occupied Housing as a Hedge Against Rent Risk, *Quarterly Journal of Economics*, forthcoming.

Speckman, P., 1988, Kernel Smoothing in Partial Linear Models, *Journal of the Royal Statistical Society*, 50, 413-36.

Storesletten, Kjetil, Chris Telmer, and Amir Yaron, 2004, Consumption and Risk Sharing over the Life Cycle, *Journal of Monetary Economics*, 51, 609-633.

Tauchen, George, and Robert Hussey, 1991, Quadrature-Based Methods for Obtaining Approximate Solutions for Nonlinear Asset Pricing Models, *Econometrica*, 59, 371-396.

Turner, Tracy M., 2003, Does Investment Risk Affect the Housing Decisions of Families? *Economic Inquiry*, 41(4), 675-91.

U.S. Department of Labor, Bureau of Labor Statistics, 2003, Consumer Expenditures in 2001, Report 966.

U.S. Census Bureau, Population Division, 2004, Geographic Mobility: March 2001 to March 2002.

Venti, Steven, and David Wise, 2000, Aging and Housing Equity, NBER working paper 7882.

Yao, Rui, and Harold H. Zhang, 2005, Optimal Consumption and Portfolio Choices with Risky Housing and Borrowing Constraints, *Review of Financial Studies*, 18, 197–239.

Zeldes, Stephen P., 1989, Optimal Consumption with Stochastic Income: Deviations from Certainty Equivalence, *Quarterly Journal of Economics*, 104(2), 275-98.

Appendix A: Model Simplifications and Numerical Solutions

An analytical solution for our problem does not exist. We thus derive numerical solutions through value function iterations. Given the recursive nature of the problem, we can rewrite the intertemporal consumption and investment problem as follows:

$$V_t(X_t) = \max_{A_t} \left\{ \lambda_t \left[N_t^{\gamma} \frac{(C_t^{1-\omega} H_t^{\omega})^{1-\gamma}}{1-\gamma} + \beta E_t[V_{t+1}(X_{t+1})] \right] + (1-\lambda_t) B(Q_t) \right\}, \tag{19}$$

where $X_t = \{D^o_{t-1}, P^Y_t, P^H_t, H_{t-1}, M_{t-1}, Q_t\}$ is the vector of endogenous state variables, and $A_t = \{C_t, H_t, S_t, D^o_t, D^s_t, D^r_t\}$ is the vector of choice variables.

We simplify the household's optimization problem by exploiting the scale-independence of the problem and normalize the household's continuous state and choice variables by its permanent income P^Y_t or house value $P^H_t H_t$. The vector of endogenous state variables is transformed to $x_t = \{D^o_{t-1}, q_t, \overline{h}_t, \bar{l}_t\}$, where $q_t = \frac{Q_t}{P^Y_t}$ is the household's wealth-permanent labor income ratio, $\overline{h}_t = \frac{P^H_t H_{t-1}}{P^Y_t}$ is the beginning-of-period house value to permanent income ratio, and $\bar{l}_t = \frac{M_{t-1}(1+r)}{P^H_t H_{t-1}}$ is the beginning-of-period mortgage loan-to-value ratio. Let $c_t = \frac{C_t}{P^Y_t}$ be the consumption-permanent income ratio, $h_t = \frac{P^H_t H_t}{P^Y_t}$ be the house value-permanent income ratio, $s_t = \frac{S_t}{P^Y_t}$ be the liquid asset-permanent income ratio, and $l_t = \frac{M_t}{P^H_t H_t}$be the mortgage loan-to-value ratio. The evolution of normalized endogenous state variables is then governed by:

$$q_{t+1} = \frac{s_t(1+r) + D^o_t h_t (1+\tilde{r}^H_{t+1})[1 - l_t(1+r)/(1+\tilde{r}^H_{t+1}) - \phi]}{\exp\{f(t+1, Z_{t+1})\}\nu_{t+1}} + \varepsilon_{t+1}, \tag{20}$$

$$\overline{h}_{t+1} = D^o_t h_t \left[\frac{1+\tilde{r}^H_{t+1}}{\exp\{f(t+1, Z_{t+1})\}\nu_{t+1}} \right], \tag{21}$$

$$\bar{l}_{t+1} = l_t \left[\frac{1+r}{1+\tilde{r}^H_{t+1}} \right]. \tag{22}$$

The household's budget constraints (10) to (13) can then be written as

$$q_t = c_t + s_t + \alpha h_t, \tag{23}$$

$$q_t = c_t + s_t + (1 - l_t + \rho + \psi) h_t, \tag{24}$$

$$q_t = c_t + s_t + (1 - l_t + \psi - \phi) \overline{h}_t, \tag{25}$$

$$q_t = c_t + s_t + (1 - l_t + \psi - \phi + \tau) \overline{h}_t. \tag{26}$$

Define $v_t(x_t) = \frac{V_t(X_t)}{[P_t^Y/(P_t^H)^\omega]^{1-\gamma}}$ to be the normalized value function, then the recursive optimization problem (19) can be rewritten as,

$$v_t(x_t) = \max_{a_t} \Bigg\{ \lambda_t \left[N_t^\gamma \frac{(c_t^{1-\omega} h_t^\omega)^{1-\gamma}}{1-\gamma} + \beta E_t[v_{t+1}(x_{t+1})(\exp\{f(t+1, Z_{t+1})\}\nu_{t+1}/(1+\tilde{r}_{t+1}^H)^\omega)^{1-\gamma}] \right] + (1-\lambda_t) L^\gamma \frac{[q_t(\omega/\alpha)^\omega(1-\omega)^{1-\omega}]^{1-\gamma}}{1-\gamma} \Bigg\},$$

subject to

$$c_t > 0, \quad h_t > 0, \quad s_t \geq 0, \quad l_t \leq 1-\delta,$$

and equations (21) to (26), where $a_t = \{c_t, h_t, l_t, s_t, D_t^o, D_t^s, D_t^r\}$ is the normalized vector of choice variables. Hence the normalization reduces the number of continuous state variables to three with P_t^Y no longer serving as a state variable and P_t^H and H_{t-1} combining into $P_t^H H_{t-1}$.

We discretize the wealth–labor-income ratio (q_t) into 160 grids equally spaced in the logarithm of the ratio, and the house value-labor income ratio ($\overline{h}_t$) and the mortgage loan-to-value ratio ($\bar{l}_t$) into equally-spaced grids of 160. Due to the non-negativity constraint for the holdings of the liquid asset, the state space is not a cube for a homeowner since the liquidated home equity value cannot be larger than the value of the total wealth; i.e., only states that satisfy $\overline{h}_t(1-\bar{l}_t-\phi) \leq q_t$ are admissible. The boundaries for the grids are chosen to be wide enough so that our simulated time series path always falls within the defined state space.

Under the assumption that only liquidated wealth will be passed along to beneficiaries, the household's house tenure status and housing and mortgage positions do not enter the bequest function. At the terminal date T, $\lambda_T = 0$, and the household's value function coincides with the bequest function,

$$v_T(x_T) = L^\gamma \frac{[q_T(\omega/\alpha)^\omega(1-\omega)^{1-\omega}]^{1-\gamma}}{(1-\gamma)}.$$

The value function at date T is then used to solve for the optimal decision rules for all admissible points on the state space at date $T-1$.

For a household coming into period t as a renter ($D_{t-1} = 0$), we perform two separate optimizations conditional on house tenure decision – renting or owning – for the current period. A renter's optimal house tenure choice for the current period is then determined by comparing the contingent value functions of renting and owning. If a renter keeps renting,

he optimizes over only one choice variable c_t, since $h_t = \frac{c_t \omega}{\alpha(1-\omega)}$. If a renter initiates home ownership in the current period, he needs to choose the optimal c_t and h_t simultaneously. To calculate the expected next period's value function, we use two discrete states to approximate the realizations of each of the three continuous exogenous state variables ($\ln \varepsilon, \ln \nu$, and $\tilde{r}_t^H$) by Gaussian quadrature (Tauchen and Hussey 1991). Together with two states for the realizations of moving shocks, the procedure results in sixteen discrete exogenous states for numerical integration. For points that lie between grid points in the state space, depending on the household's current period house tenure choice, we use either a one-dimensional or three-dimensional cubic spline interpolation to approximate the value function.

For a household coming into period t as a homeowner, we perform two separate optimizations conditional on its refinancing decision for the current period. In both cases, the household cannot adjust its house value-income ratio, i.e. $h_t = \overline{h}_t$, but can adjust its numeraire consumption. We take the higher value of the two optimized value functions as the value function contingent on staying. The value function contingent on moving—either endogenously or exogenously—is the same as the value function of a renter who is endowed with the same wealth-income ratio (q_t) because the entire mortgage balance is due upon home sales and q_t is defined as net of house selling costs. We compare the value functions contingent on moving and staying to determine the optimal house liquidation decision. A homeowner who cannot afford the minimum mortgage payment and house maintenance cost has to sell his home. Under our assumption and parameterization, a homeowner always has a positive amount of equity in his house after home sales and thus has no incentive to default. This procedure is repeated recursively for each period until the solution for date $t = 0$ is found.

Appendix B: Empirical Analysis

This appendix describes data sources and explains the non-parametric regressions used to construct our empirical regularities summarized in figure 8.

Our data come from the Survey of Consumer Finances (SCF), collected by the Federal Reserve Board. The SCF is a triennial survey of the balance sheet, pension, income, and other demographic characteristics of U.S. families. Our sample years include 1992, 1995, 1998, and 2001. The term "household" used in the paper corresponds to the term "family" used in the SCF.[33] The term "household age" used in the paper corresponds to the age of the family head in the SCF.

Following Fernandez-Villaverde and Krueger (2002), we exploit the repeated nature of the survey to build a pseudo panel. New households entering the survey are a large randomly chosen sample of the U.S. population, and, consequently, they contain information about the means (home ownership, mortgage loan-to-value ratio, etc.) of the groups they belong to. This information can be exploited by interpreting the observed group means as a panel for estimation purposes. This method is known as the pseudo panel or synthetic cohort technique. We define 68 cohorts according to the birth year of the household (1902 to 1972) and follow them through the sample, generating a balanced panel. The average size of cells for all households is 334, and the average size of cells for homeowners is 240.

To relate age and household housing decisions, we estimate the partial linear model

$$y_{it} = constant + \beta_i cohort_i + \beta_t \gamma_t + m(age_{it}) + \epsilon_{it}, \tag{27}$$

where $cohort_i$ is a dummy for each cohort except the youngest one, and γ_t a dummy for each survey year except 1992, $m(age_{it}) = E(y_{it}|age_{it})$ is a smooth non-parametric function of age_{it}.

To identify the separate effects of time, age, and cohort effects, we assume that time effects are orthogonal to a time trend and that their sum is normalized to zero, i.e., we attribute linear trends in the data to a combination of age and cohort effects (Deaton 1997).

[33] "Household" is reserved by the SCF to denote the set of the "family" (technically known as the "primary economic unit") and any other individual who lives in the same household but is economically independent.

The partial linear model is estimated using the two-step estimator proposed by Speckman (1988). The non-linear part is estimated using the Gaussian Kernel with a bandwidth of 5. We regress y_{it} on $m(age_{it})$ to obtain residuals and then we project the residuals on the time and cohort effects. The constructed new adjusted values for y_{it} are non-parametrically regressed on age.

Table 1
Baseline Model Parameters

Parameter	Symbol	Value
Demographics		
Maximum life-cycle period	T	70
Mandatory retirement period	J	45
Preferences		
Curvature parameter of utility function	γ	2
Bequest strength	L	5
Discount rate	β	0.955
Housing preference	ω	0.200
Labor Income and House Price Processes		
Standard deviation of permanent income shock	σ_v	0.103
Standard deviation of temporary income shock	σ_ε	0.272
Income replacement ratio after retirement	θ	0.682
Mean real housing return	μ_H	0.000
Standard deviation of housing return	σ_H	0.100
Liquid Savings		
Risk-free interest rate	r	0.030
Housing and Mortgage		
Rental cost	α	0.075
Down payment requirement	δ	0.200
House selling cost	ϕ	0.060
Maintenance and depreciation cost	ψ	0.030
House purchasing cost	ρ	0.030
Mortgage refinancing cost	τ	0.005
Inflation rate	π	0.030

Table 2
The Baseline Model Economy

Statistics	U.S. Data	Baseline Model	No adjustment cost
Average Home Ownership Rate	0.67	0.74	0.92
Average Net Worth-Labor Income Ratio	3.10	3.09	3.26
Homeowner	4.29	3.95	3.47
Renter	0.76	0.45	0.02
Average House Value-Labor Income Ratio	2.77	2.85	3.11

Note: The average statistics for the U.S. data are calculated for a representative household over its life cycle using the synthetic cohort technique outlined in Appendix B. Data source: Survey of Consumer Finances, 1995-2001.

Table 3
The Effects of House Price Changes on Consumption and Welfare

Statistics	Benchmark	No adjustment cost
Changes in Home Ownership Rate (%)	-0.19	-4.09
Marginal Propensity to Consume (%)	3.26	6.73
Changes in Welfare (All households) (%)	-1.43	-0.51
Homeowner only	-0.42	-0.22
Renter	-3.93	-3.93

Note: The percentages measure effects of a positive house price shock relative to that of a negative house price shock. The effects on home ownership rate and marginal propensity to save are for those households who own their residence at the beginning of the period.

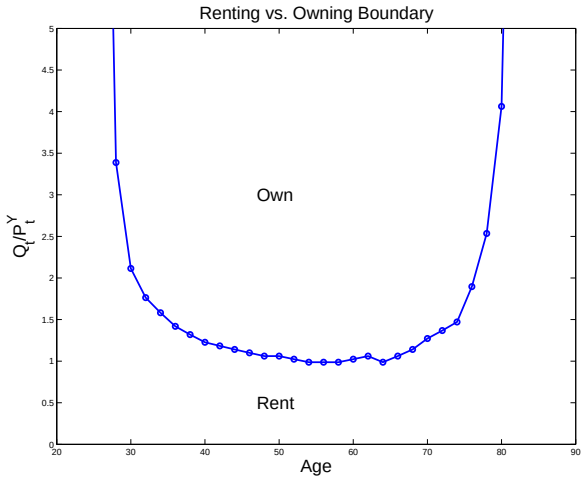


Figure 1. A Renter's House Tenure Decision as a Function of His Age and Net Worth-Permanent Labor Income Ratio

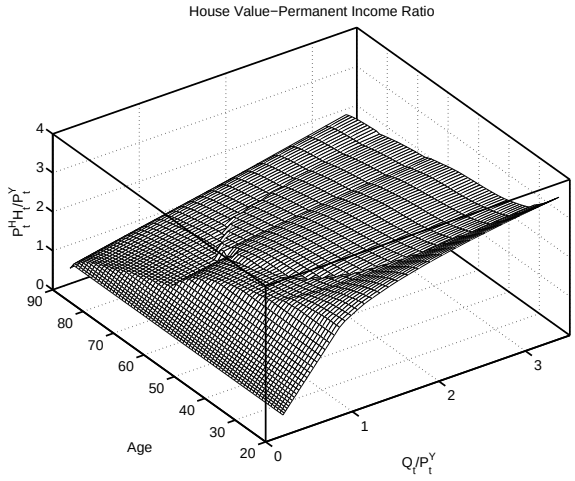


Figure 2. A Renter's Optimal Housing Consumption

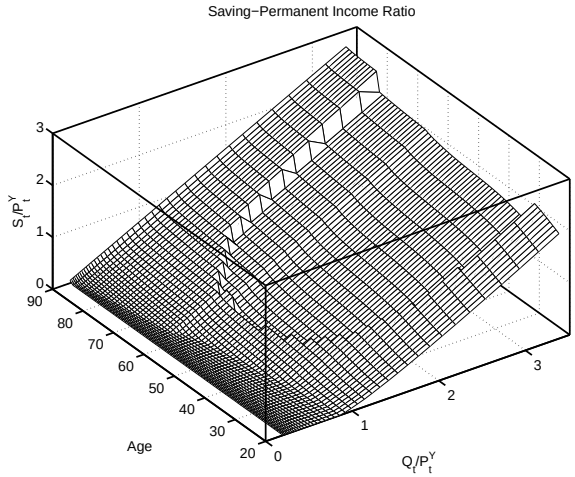


Figure 3. A Renter's Optimal Liquid Saving Decision

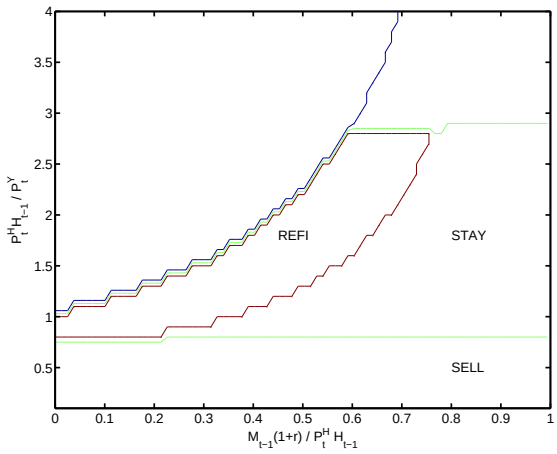


Figure 4. A Homeowner's Optimal House Tenure Choice

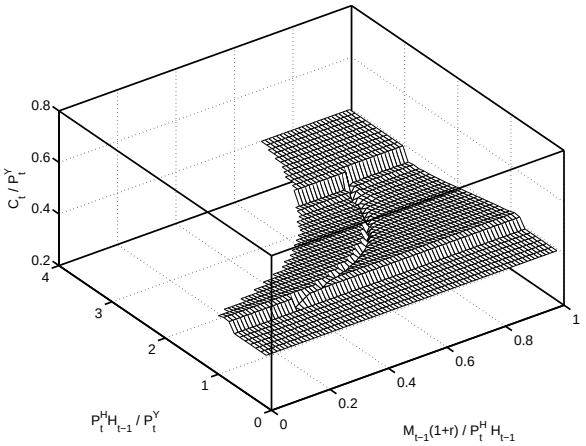


Figure 5. A Homeowner's Optimal Numeraire Good Consumption

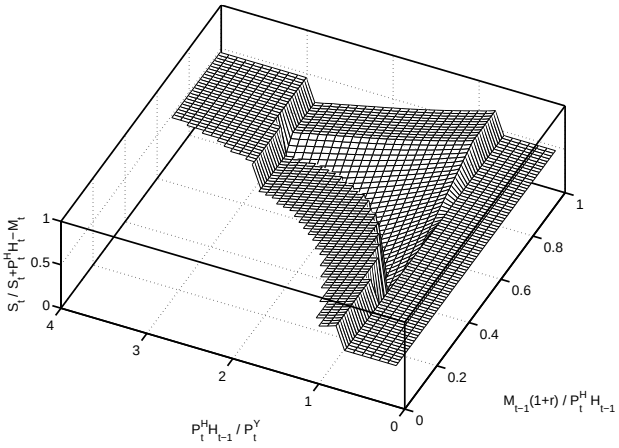


Figure 6. A Homeowner's Liquid Savings

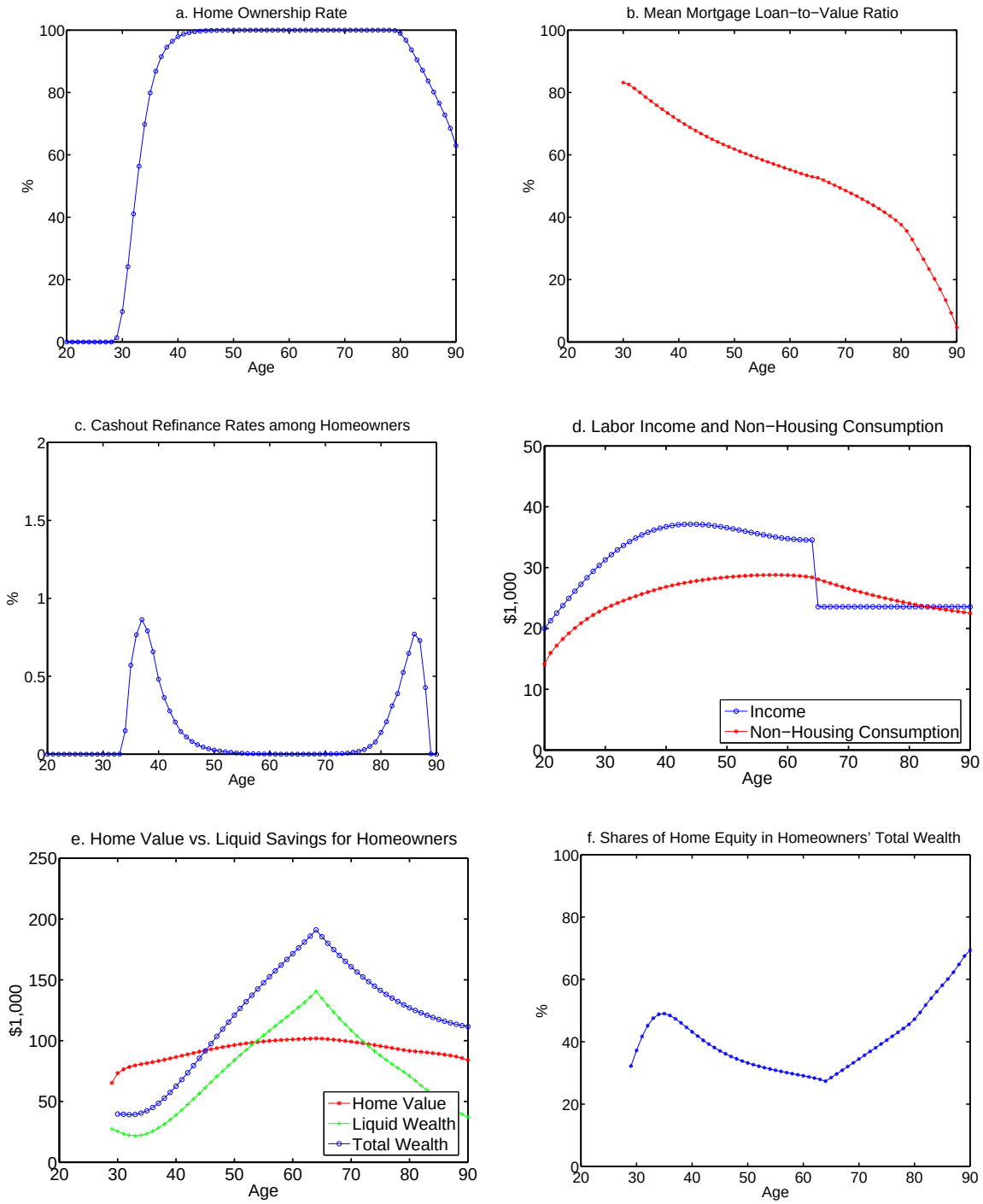


Figure 7. Optimal Life-cycle Housing and Consumption Decisions—Baseline Case

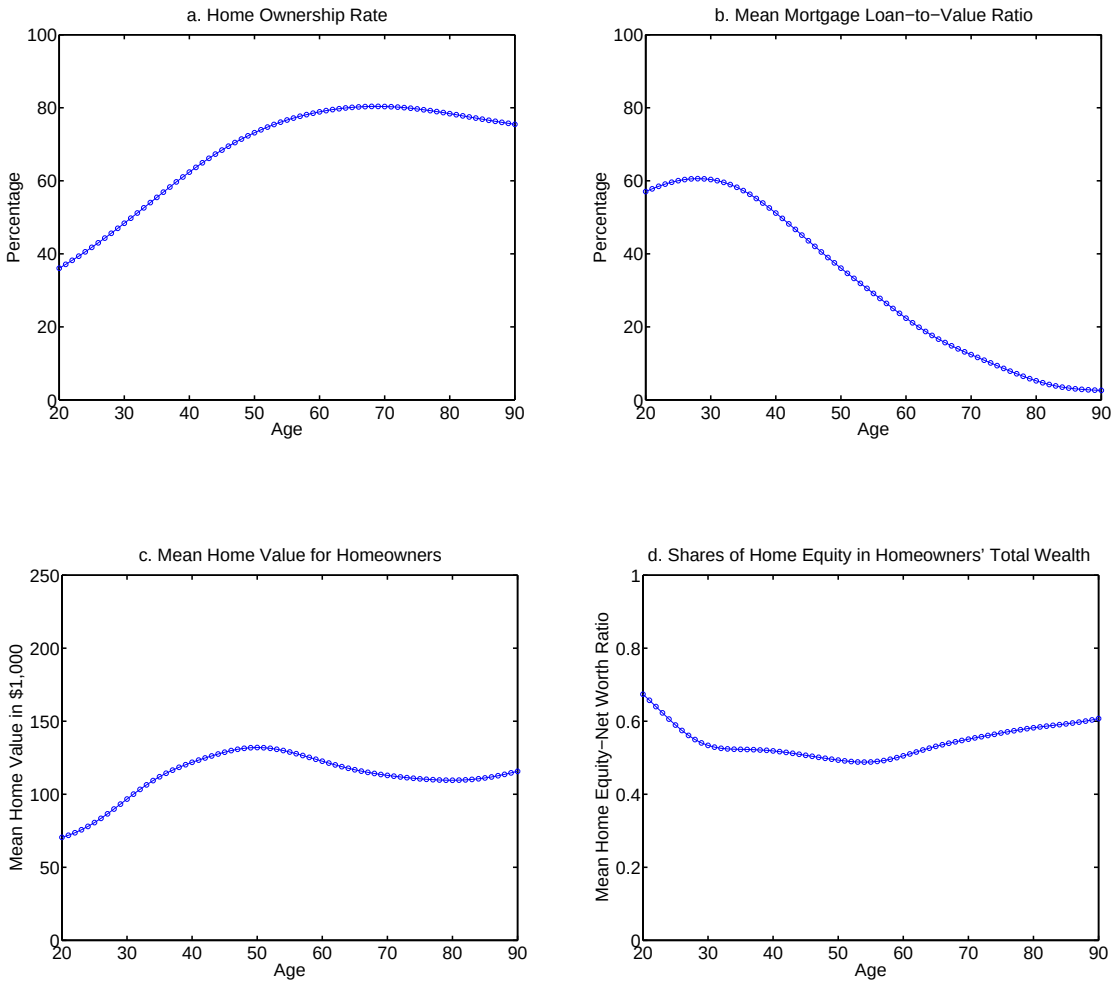


Figure 8. Empirical Life-Cycle Housing and Mortgage Choices Based on SCF Data from 1992 to 2001

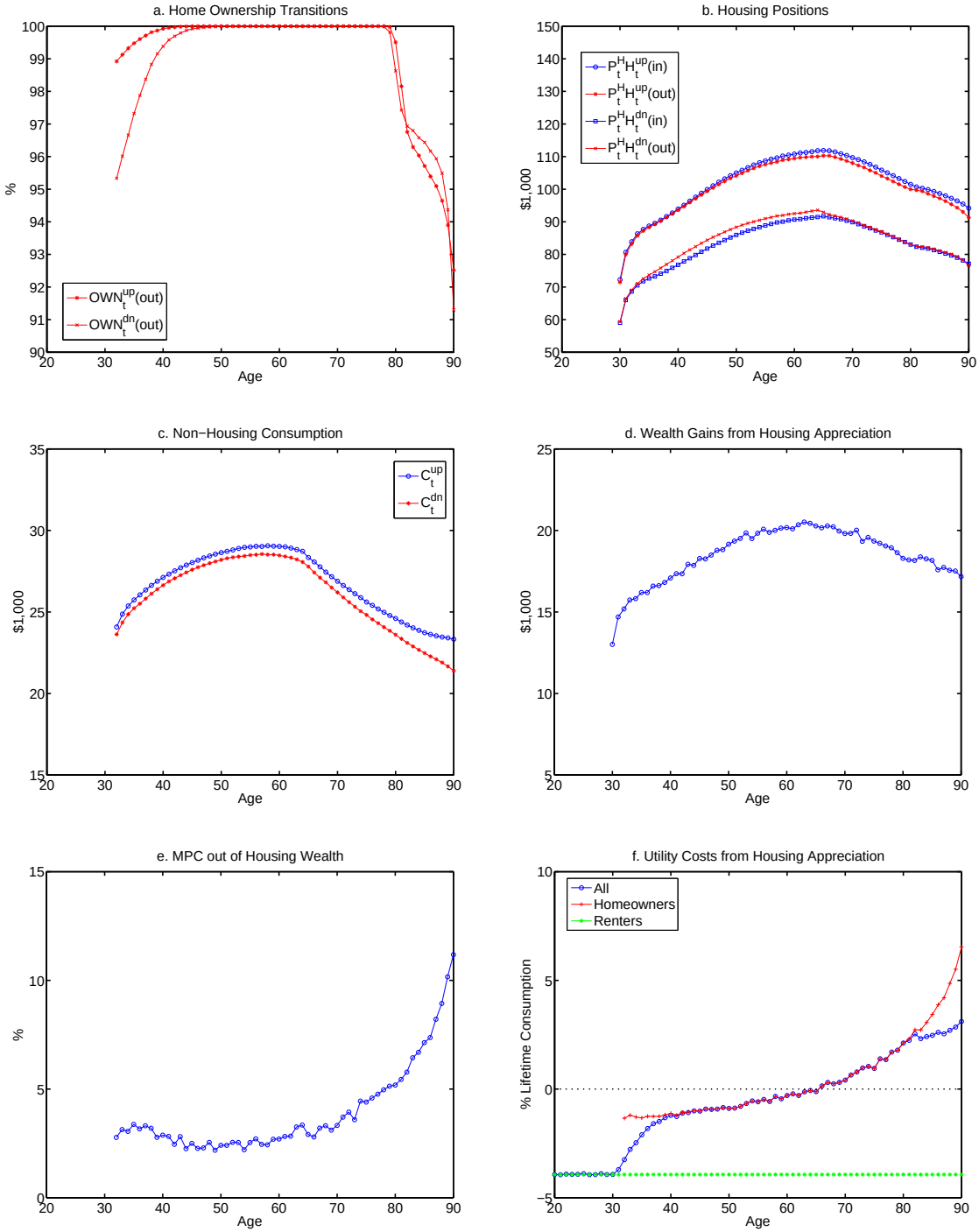


Figure 9. The Consumption and Welfare Effects of House Price Shocks under Baseline Parameterizations

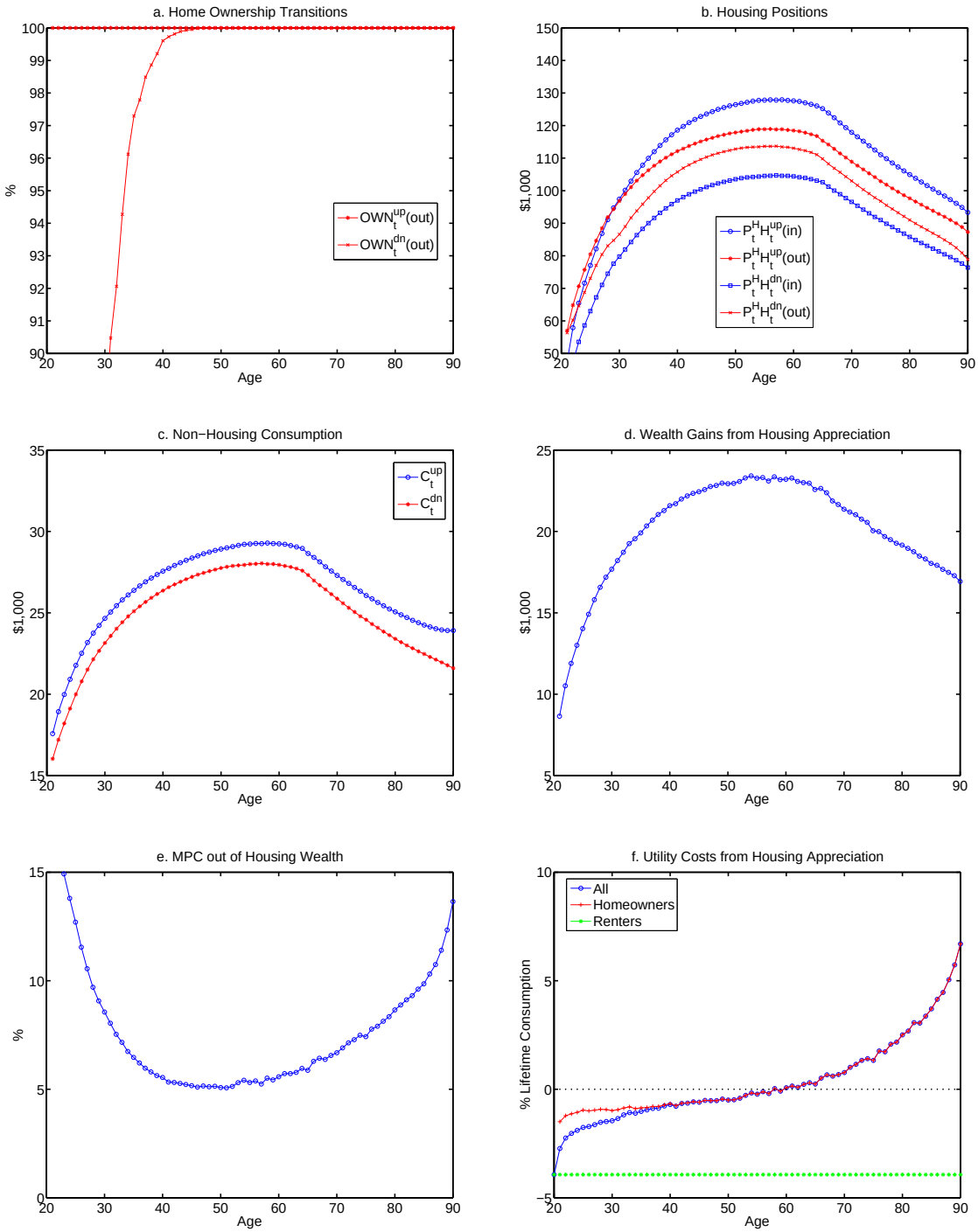


Figure 10. The Consumption and Welfare Effects of House Price Shocks with Zero Adjustment Costs

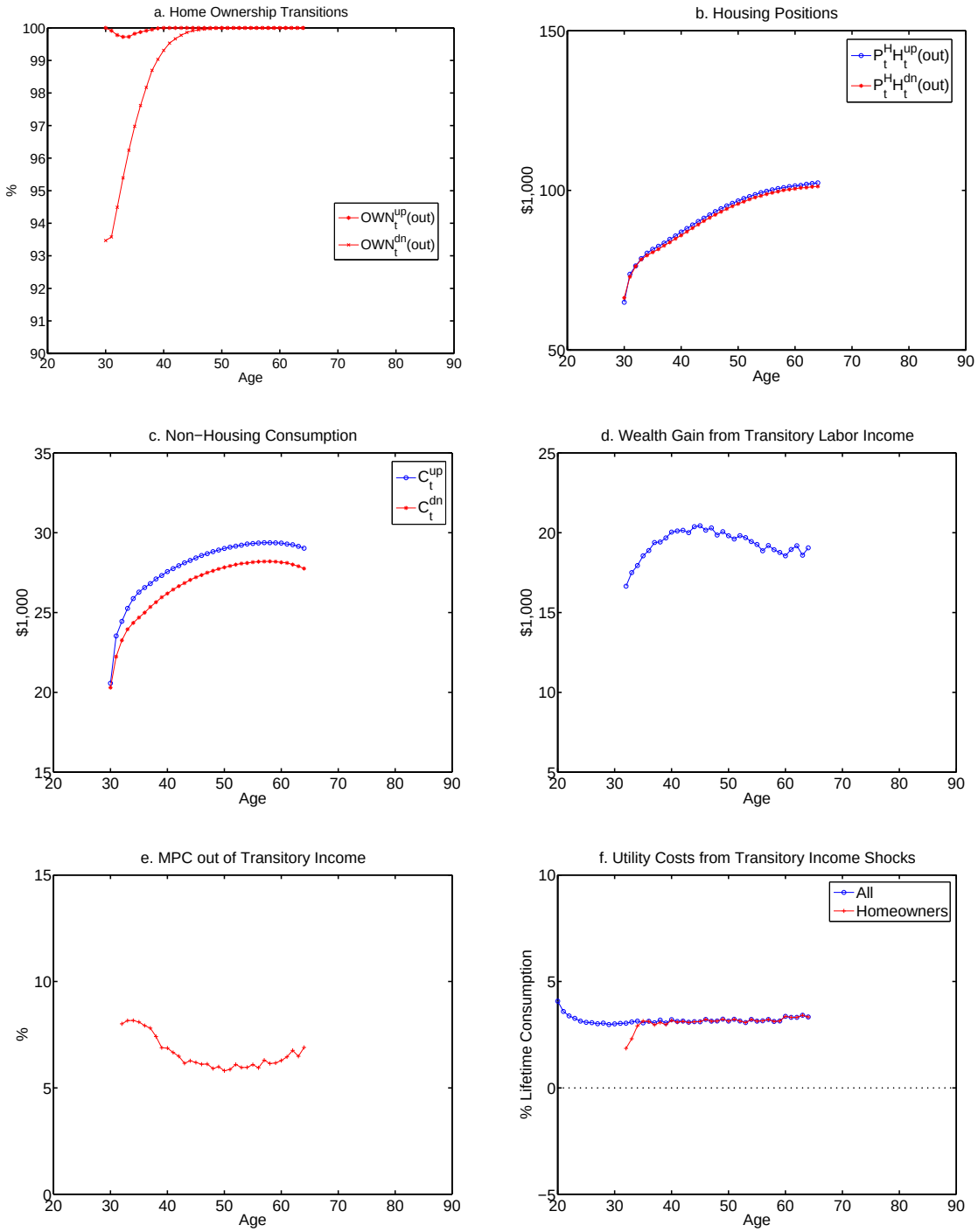


Figure 11. The Consumption and Welfare Effects of Transitory Income Shocks under Baseline Parameterizations

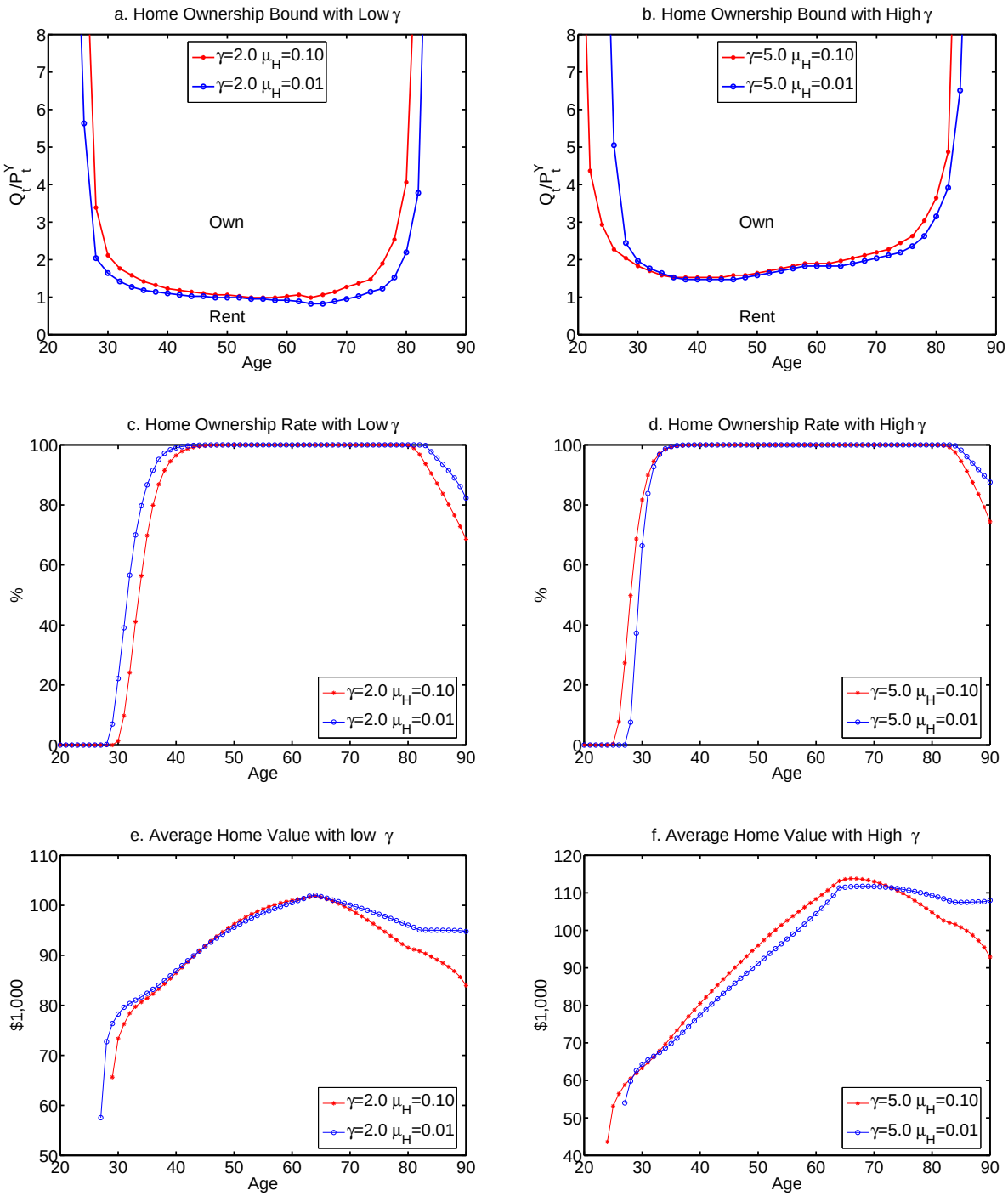


Figure 12. The Effects of House Price Risks on Home Ownership and Housing Expenses