Housing Decisions Under Uncertain Income

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Abstract

How does households' income uncertainty affect housing decisions? Using data from the Panel Study of Income Dynamics and Consumer Expenditure Survey, this paper documents a significant negative effect of income uncertainty on the rate of home ownership, on the ratio of home equity to income, on the ratio of house value to total wealth, and on the ratio of housing to nonhousing consumption. In addition, this paper shows that the negative effect is consistent with a household portfolio choice model which features large housing transaction costs and moderate positive correlation between house price and income.

Keywords: Housing investment; Housing consumption; Income uncertainty; Precautionary saving; House transaction cost; Borrowing constraints; House price risk;

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1 Introduction

It is now well established that households face large idiosyncratic income uncertainty, the degree of which varies across households. How and why does income uncertainty affect housing decisions? In this paper I show empirically that income uncertainty has a significantly negative effect on on the rate of home ownership, on the ratio of house value to income, on the ratio of home equity to total wealth, and on the ratio of house value to nonhousing consumption. In order to understand the rationale behind the negative effect, I solve a life-cycle model in which housing is both a consumption good and an asset. The model is able to generate the negative effect when two features are present: costly housing transactions and positive correlation between house price and income.

These two model features represent two important considerations in portfolio choice literature – illiquidity and risk. The household portfolio choice literature generally suggests that income uncertainty should reduce a household's demand for risky assets and illiquid assets.[1] From this point of view, housing investment should decrease with the degree of income uncertainty due to the portfolio effect. On the other hand, there exists precautionary effect. The literature of precautionary saving establishes both empirically and theoretically that households with greater income uncertainty hold more total wealth, so as to effectively smooth their consumption when income shocks arrive.[2] In addition, Hurst and Stafford (2004) shows empirically that home owners indeed use housing to smooth consumption through refinancing. From this perspective, high degree of income uncertainty should lead to more housing which is the single most important asset for many households. Results of this paper show that portfolio effect dominates precautionary effect.

In my model, transaction costs lead to infrequent housing adjustment (home owners moving to either larger or smaller houses), which is consistent with the (S,s) rule.[3] I find that housing adjustment is mainly caused by income shocks, thus households with greater income uncertainty adjust houses more frequently. Since more frequent transaction means higher user cost of owned housing, households with greater income uncertainty make relative less housing investment in optimality.

Riskiness of housing investment is represented by the volatility of house price and the correlation of house price with income.[4] The latter is found to be much

[1] e.g.,Kimball (1993), Guiso et al. (1996), Viceira (2001), Faig and Shum (2002) and Angerer and Lam (2009)

[2] See Deaton (1991), Carroll (1992) and Carroll and Samwick (1997).

[3] See Grossman and Laroque (1990) and Damgaard et al. (2004).

[4] Correlation of house price with other asset is important. In my model, the only other

more important in explaining the empirical observations. As demonstrated in Han (2008), volatility of house price does not necessarily discourage housing investment, because households planning to move up the housing ladder can use present housing to hedge against future housing cost risk. My paper confirms this point. On the other hand, as I increase the correlation between house price and income in the model, housing investment decreases sharply with the degree of income uncertainty. Intuitively, housing would be a good precautionary wealth against income risks unless its price co-moves with income. This is consistent with Davidoff (2006), which holds income uncertainty constant and proves that households whose income exhibits higher correlation with housing prices own relatively little housing.

Another interesting finding from the model is that high income uncertainty households are more likely to become home owners when house price risks and transaction costs are absent. This is because high income uncertainty households have stronger precautionary motives, save more, and overcome the hurdle of down payment requirement more quickly. In other words, borrowing constraints in the form of down payment requirement is more constraining for low income uncertainty households.

Results in this paper have important implications on portfolio heterogeneity. It remains a huge challenge to explain the considerable cross sectional difference in households' portfolio compositions.[5] My paper establishes that heterogeneity in income uncertainty leads to heterogeneity in housing status, which in turn should leads to heterogeneity in the composition of financial assets. A host of papers have demonstrated that housing status significantly alters optimal allocation of financial assets. Examples include Henderson and Ioannides (1983), Fu (1995), Brueckner (1997), Flavin and Yamashita (2002) Cocco (2004) and Yao and Zhang (2005).

Results in this paper also have implications on the cyclical fluctuation of the macro economy. Storesletten et al. (2004) find strong evidence that income uncertainty increases during recessions. With the increased uncertainty, households reduce their housing investment, which leads to a deeper recession. This prediction is consistent with the empirical findings by Leamer (2007). Bloom et al. (2010) also provide evidence that business cycles might be uncertainty-driven.

A few existing studies also find a negative effect of income uncertainty on home ownership, based on different data sets and measures of income uncer-

asset is risk-free bond whose return has zero correlation with house price by definition.

[5]For a comprehensive review, see Curcuru et al. (2009).

tainty. Haurin (1991) reports evidence from U.S. data and Diaz-Serrano (2005) has similar findings for Spain and Germany. Robst et al. (1999) employs three measures of income uncertainty. With each of measure, income uncertainty lowers the probability of home ownership. On the intensive margin, Haurin and Gill (1987) studies a sample of military personnel families and find that income uncertainty reduces housing consumption. They assume that spouses' income is more uncertain than that of military personnel, and approximate income risk with the share of spouse income in total. The work therefore suffers from both sample selection and measurement problems. Haurin (1991) measures income uncertainty by the coefficient of variation of income across time and finds the impact of income uncertainty on housing demand to be insignificant. Since even deterministic component of lifetime income can exhibit a high coefficient of variation, the test could be biased by measurement problems. Shore and Sinai (forthcoming) shows that housing transaction cost may cause housing demand to increase with the degree of income uncertainty. This result is based on the assumption that housing is a consumption good only, ignoring the its role as an asset.

The rest of the paper is organized as follows: Section 2 presents the empirical results. Section 3 lays out the theoretical and quantitative explorations. Section 4 discusses the robustness of results in section 3. Section 5 concludes.

2 Empirical Investigation

Given the purpose of this paper, household level income uncertainty is necessary for the empirical analysis. Generally the estimates can be obtained from two sources. The first one is the survey questions regarding the expected variability of future income. For example, Guiso et al. (1996) uses the Bank of Italy Survey of Household Income and Wealth which asks respondents to attribute probability weights to given intervals of nominal income increase one year ahead. Estimates from this source is subjective by nature. The second sources is the panel data such as PSID. Since panel data track households for years, a time series of income is available for each households. One can remove the predictable component from the time series and measure the variability of the residues. The problem lies in how to extract the predictable component of income for each household. In this paper I adopt the method used by Carroll and Samwick (1997) and Robst et al. (1999). Even though the negative effect of income uncertainty on housing tenure choice has been documented in some existing papers, the novelty here is that income uncertainty is decomposed into transitory and permanent components. Nevertheless the major empirical contribution of the my paper is one the intensive margin.

2.1 Data

The paper draws upon two data sets for empirical inference: the Panel Study of Income Dynamics (PSID) and Consumer Expenditure Survey (CEX). The data appendix gives details on sample selection and variable definitions.

I extract the following variables from 1984-1997 family file, freely available at the data center of PSID website[6]: total family income, housing status (renter or owner), value of owned house and a rich set of demographics, including age, race, sex, years of schooling, occupation, industry, marital status of househeads, number of children, spouse's years of schooling (if married), as well as region and location of households. Prior to 1997 PSID data were collected annually, and biannually after that. I choose 1997 as the ending year because it is not clear how to adjust for this shift for the purpose of studying income uncertainty. I use the Wealth Supplement Files (1984) to draw information on total wealth, home equity, whether owning business and whether owning stock. I obtain current interest rate on mortgage loan from the 1996 wave of survey[7]. For each household I estimate its degree of income uncertainty based on its realized income during 1984-1997. I assume that a household rationally predicts the degree of uncertainty of its future income, and makes decisions on housing and other financial wealth accordingly.

A major drawback of the PSID data is its lack of detailed information on consumption expenditure. Therefore I turn to CEX for housing-nonhousing consumption ratio. CEX carries high quality information on consumption expenditure, house value and demographics. However CEX is not a panel, thus it is impossible to evaluate the degree of income uncertainty for individual households within CEX. I transport the measure of income risk obtained from PSID to CEX using the two-sample two-stage least square (TS2SLS) technique[8]. The TS2SLS is readily implementable in this case because PSID and CEX can be regarded as two samples independently drawn from the same population. In addition both surveys contain rich information on demographics. Classifications of occupation and industry are slightly different between the two samples. Appendix A.1 provides details on how the occupation and industry types are re-grouped so that they are comparable between the two samples.

[6] http://psidonline.isr.umich.edu/data/

[7] No mortgage rate information is available from PSID prior to 1996

[8] See Angrist et al. (1999) and Inoue and Solon (2008).

2.2 Measuring Income Uncertainty from PSID Data

To obtain the predictable component of income, I run the following regression on the pooled data of the N individual households's 1984-1997 time series.

$$y_{i,t} = Z_{i,t}\beta + u_{i,t}$$

where $y_{i,t}$ is the logarithm of income for household i at time t and $Z_{i,t}$ is the set of demographics that households use to predict their future income paths. Included in the Z are age, age-squared, race, dummies of marital status, education, occupation, industry of employment of househeads and the interaction of age with these dummies. In view of the ever-increasing importance of spouses' contribution to family income, Z also includes dummies of spouse's educational attainment. It's recognized that owning stock or business may have huge impact on the degree of income uncertainty, which is again taken care of by dummies.

Household i has a time series of residue income $\{u_{i,t}\}_{t=1984}^{1997}$. This is not observed by the household at t=1984, but is used by the econometricians to infer the degree of income uncertainty for this particular household. In the simplest case, one can assume that the $u_{i,t}$'s are iid and that $\hat{\sigma}^2_{u,i}$, the sample variance of $\{u_{i,t}\}_{t=1984}^{1997}$, is an unbiased estimator the true variance $\sigma^2_{u,i}$. Even if the residuals are serially correlated, $\hat{\sigma}^2_{u,i}$ is still a valid measure of income uncertainty. To see this, let $u_{i,t} = \rho u_{i,t-1} + \xi_{i,t}$, where ρ measures the persistence of the random shock ξ_t, then $\sigma^2_{u,i} = \frac{\sigma^2_{\xi,i}}{1-\rho^2}$. In this case $\hat{\sigma}^2_{u,i}$ is merely a rescaled version of $\hat{\sigma}^2_{\xi,i}$, the estimate of variance of iid random shock ξ. It is also possible to allow for more general specification of the structure of residual income. Carroll and Samwick (1997) assumes the residual income to be the sum of permanent income plus transitory shock.

$$u_{i,t} = p_{i,t} + \epsilon_{i,t} \tag{1}$$

while the permanent income is assumed to follow a random walk.

$$p_{i,t} = p_{i,t-1} + \eta_{i,t} \tag{2}$$

Both the transitory shock and persistent shock are assumed to follow normal distributions, and the degree of income uncertainty is measured by the variances of the shocks, $\sigma^2_{\eta,i}$ and $\sigma^2_{\epsilon,i}$. This specification is appealing for several reasons. Various pieces of evidence show that income shocks do have a very persistent, near random walk component[9]. Also when implemented in a computational model, this structure can greatly reduce the computational task because all

[9] See MaCurdy (1982), and Abowd and Card (1989). Guvenen (2007) provides a good review of competing views on this issue in the literature.

the state variables can be normalized by the permanent income, reducing the problem by one dimension. More details on this point is given in Appendix A.3. Technical details about estimating $\sigma^2_{\eta,i}$ and $\sigma^2_{\epsilon,i}$ are omitted in this paper, since I follow strictly the methodology in Carroll and Samwick (1997). I examine and report the effects of estimated $\sigma^2_{\eta,i}$ and $\sigma^2_{\epsilon,i}$ on housing decisions.

Table 1 reports the estimated income uncertainty(denoted $\hat{\sigma}^2_{\eta,i}$ and $\hat{\sigma}^2_{\epsilon,i}$ for some subsamples. Apparently, degree of income uncertainty is closely related to househead's years of schooling, occupation and industry of employment. Since $\hat{\sigma}^2_{\eta,i}$ and $\hat{\sigma}^2_{\epsilon,i}$ are to be included in regression as explanatory variables in the empirical investigation, they need to be instrumented to avoid error-in-variable problem. The instruments I use are education attainment, occupation and industry of employment.

Extracting the predictable component of income by using income equation involves a strong assumption, that the individual-specific growth rate of income is completely explained by observable personal characteristics. It also assumes that changes in demographics, such as marital status, are predictable. Although this is a commonly used methodology, there might still be concerns regarding these assumptions. For robustness, I employ another way of extracting the predictable component of income, Hodrick-Prescott Filtering. Put simply, for each household, the time series of realized incomes is detrended by a smooth curve, which is assumed to be predictable. This is a widely used way to recover aggregate shocks in the business cycle literature. Reassuringly, the empirical results from this methodology are qualitatively the same as those from using the income equation approach.

Table 1: Income uncertainty by education, occupation and industry

	var.permanent shock		var.transitory shock	
years of school ≤ 12	0.0158	(0.0054)	0.053	(0.0076)
years of school > 12	0.0076	(0.0014)	0.0486	(0.0042)
operator/fabricator/laborer	0.0177	(0.0043)	0.0412	(0.0058)
professional/managerial worker	0.0086	(0.0018)	0.043	(0.005)
financial sector	0.0148	(0.012)	0.0148	(0.012)
public administration	0.0044	(0.002)	0.033	(0.0052)

The table reports degree of income uncertainty by years of schooling, occupation and industry of employment. In parenthesis are bootstrapped standard errors.

2.3 Empirical Results

The goal is to evaluate the effects of income uncertainty on the housing decision. I regress four dimensions of housing decision, home ownership status, ratio of house value to predicted income, ratio of house value to total wealth and housing-consumption ratio respectively, on estimated income uncertainty and a set of control variables including, age, marital status, number of children, race and gender of househead, stock ownership status and mortgage rate. Measure of income uncertainty, $\hat{\sigma}^2_{\eta,i}$ and $\hat{\sigma}^2_{\epsilon,i}$, are instrumented by househead's education attainment, occupation and industry of employment. Table 2 reports the results.

Column (1) of the table reports the results of a probit model of housing tenure choice. The variance of both the permanent and transitory shocks exert negative effects on the probability of owning residential houses. In addition, permanent shocks have a much stronger effect that transitory shocks. These results are consistent with Robst et. al. (1999) who also tests a probit model based on PSID data. But there income uncertainty is not decomposed.

One might conjecture that the income uncertainty effects on tenure choice are caused by credit constraint. PSID 1996 wave of survey asked respondents whether they had an application for a loan on the current property turned down since January 1991. Of the households in my sample, only 0.38% answered yes[10]. So credit constraint should have very limited influence in this case. Diaz-Serrano (2005) uses Italian data and has similar results. Presumably households with greater income uncertainty choose not to own or become an owner later, either to avoid huge transaction cost or to reduce the variability in income and wealth.

Column (2), (3) and (4) reports results on the intensive margin along two dimensions: (1) ratio of house value to predicted income (2)ratio of house value to total wealth. Notice that only the subsample of homeowners are used hereafter. I take logarithm of each of the three ratio before running the regression. Both $\hat{\sigma}^2_{\eta,i}$ and $\hat{\sigma}^2_{\epsilon,i}$ have significantly negative effects on these ratios. Not surprisingly, the impact of variance of permanent shocks is much stronger than transitory shocks.

Intuitively, if mortgage lenders have information about the riskiness of the borrowers' income, they should price the it and vary the rate accordingly. This should result in correlation correlations between mortgage rate and housing investment. Table 2 shows that mortgage rate has no significant correlation with both housing-income ratio and housing-wealth ratio.

[10]About 50% answered inapplicable because (1) no morgtage on home, (2)not a home-owner,(3) got a mortgage prior to 1991.

Table 2: Effects of income uncertainty on housing and wealth

	ownership prob.	$\frac{housing}{income}$	$\frac{housing}{wealth}$	$\frac{housing}{consumption}$	$\frac{wealth}{income}$
	(1)	(2)	(3)	(4)	(5)
constant	0.785	-1.476	0.846	1.418	-2.661
	(0.278)	(-3.224)	(0.568)	(9.886)	(-4.197)
var. of permanent shocks	-18.773	-0.824	-1.845	-4.678	1.383
	(-1.987**)	(-1.289*)	(-1.759**)	(-2.762***)	(1.709**)
var. of transitory shocks	-9.913	-0.551	-0.998	-0.496	1.017
	(-4.277***)	(-2.847***)	(-3.428***)	(-1.144)	(3.348***)
age	-0.002	-0.022	0.0498	0.006	0.095
	(-0.037)	(-0.989)	(1.3544*)	(0.850)	(2.971***)
age^2	0.0003	1E-04	3E-04	-7E-04	-0.001
	(0.387)	(0.412)	(-1.443*)	(-0.290)	(-1.825**)
married	0.653	-0.269	0.2665	-0.147	0.052
	(3.106***)	(-2.952***)	(1.7614**)	(-4.204***)	(0.356)
with child	0.175	0.107	0.0303	-0.161	-0.023
	(1.217)	(2.012**)	(0.368)	(-5.651***)	(-0.282)
female house head	0.501	0.369	0.088	0.135	0.172
	(1.693**)	(2.852***)	(0.418)	(2.180**)	(0.897)
white house head	-0.103	0.037	0.0908	0.057	0.535
	(-0.664)	(0.587)	(0.924)	(1.507*)	(5.785***)
stock owner	-0.153	-0.051	-0.178	0.012	0.298
	(-1.080)	(-1.126)	(-2.4601***)	(0.482)	(4.308***)
metropolitan area (pop$\geq$1m)	-0.056	0.125	0.2743		-0.028
	(-0.356)	(2.655***)	(3.486***)		(-0.366)
predicted income	-0.884		-0.2812	0.001	
	(-2.583***)		(-1.6704**)	(0.775)	
wealth	0.886	0.264		0.000	
	(13.670***)	(11.484***)		(-0.999)	
Mortgage rate		-0.004	0.0256		
		(-0.295)	(1.273)		

This tables reports the effects of income uncertainty on housing decision and total wealth accumulation, controlling for a set of demographic variables.

Column (5) reports the coefficients of regressing wealth-income ratio on income uncertainty. Precautionary effect is evident here. Income uncertainty is significantly positively correlated with wealth-income ratio. Clearly, higher income uncertainty households hold more total wealth. But much of the wealth is in the form of financial wealth as shown in column (2) and (3). which reflects strong portfolio effect.

Analyzing the impact of income uncertainty on the housing-nonhousing ratio involves two data sets. Household level income uncertainty is measured in PSID, but PSID does not have sufficient information on nonhousing consumption. CEX has high quality consumption expenditure data, but it tracks a household for at most five quarters, which makes the measurement of income risk virtually impossible. To deal with the problem, I use two-sample two-stage least square regression. In the first step, the measures of income uncertainty from PSID, $\hat{\sigma}^2_{\eta,i}$ and $\hat{\sigma}^2_{\epsilon,i}$, are predicted by education, occupation and industry of househeads. The regression coefficients are transported to CEX to predict $\sigma^2_{\eta,i}$ and $\sigma^2_{\epsilon,i}$ for households in CEX sample. The predicted $\sigma^2_{\eta,i}$ and $\sigma^2_{\epsilon,i}$ are then used in the second stage regression, where housing-consumption ratio is regressed on $\sigma^2_{\eta,i}$ and $\sigma^2_{\epsilon,i}$. Column (4) shows that both permanent and transitory income shocks are negative correlated with the ratio, and the effect of permanent shocks is statistically significant.

Figure 1 plot the lifecycle profiles of housing-consumption ratio by education attainments. The profiles are obtained from CEX by constructing synthetic panels. Clearly the low income uncertainty group exhibits a higher ratio, but the gap diminishes with age. I also construct the lifecycle profile for two occupation groups, managerial and professional versus laborers and operators, with the former known to have less exposure to income risks. Figure 2 again displays a higher ratio for low income uncertainty groups.

2.4 Discussion: Mortgage Rates

If mortgage lenders know and price the degree of income uncertainty of borrowers, then differentiated mortgage rates might be the most direct driving force behind the negative correlation between income uncertainty and housing investment. To check this possibility, I use the survey question asked in PSID 1996 regarding interest rate on mortgage. I calculate the correlation of mortgage rate with degree of income uncertainty, income and financial wealth.[11]. The results are reported in table 3

The table shows that income uncertainty is only slightly correlated with

[11]No information on wealth is available in PSID 1996. I use financial wealth in PSID 1994

Table 3: Correlation between mortgage rate and some variables

	correlation	bootstrapped s.e.
var. of permanent shock	0.0734	(0.0405)
var.of transitory shock	-0.0016	(0.0406)
income	-0.2299	(0.0409)
predicted income	-0.2511	(0.0418)
financial asset	-0.0861	(0.0289)

mortgage rate. Apparently, only limited degree of uncertainty is priced in mortgage rate. On the other hand, households with higher income are charged with much lower mortgage rate. Households with more financial asset are also faced with slightly lower mortgage rate. In practice, lenders usually check the credit history and income level of borrowers. However, the major US mortgage guarantors, Fannie Mae and Freddie Mac do not ask about the variance of borrower's incomes. The correlations seem to be evidence that degree of income risk at individual level does not effectively enter the calculation of mortgage rate. In Summary, mortgage rate does not seem to be an important driving force behind the negative correlations documented in this paper.

3 Theory

In this section I present a lifecycle model of household portfolio choice. A household receive exogenous stochastic labor income, and chooses consumption, riskfree bond and housing to optimize lifetime utility. Housing is both a consumption good and an asset. I start with computing and comparing models that have different features, including adjustment costs, house price risks, and borrowing constraints. This way the roles played by these features are highlighted. Next I study how well the model match the data quantitatively.

3.1 General Model

A household enters the labor market with zero asset, and stays on the labor market for 40 years before retirement. After retirement, it lives another 20 years before death. When on the labor market, the household receives stochastic income. Let $y_{i,t}$ denote the logarithm of income for household i with t years of age, the income process before retirement is specified below.

$$y_{i,t} = p_{i,t} + \epsilon_{i,t} \tag{3}$$

$$p_{i,t} = G_t + p_{i,t-1} + \eta_{i,t} \tag{4}$$

where G_t is the deterministic income that captures the hump-shaped lifetime income profile; $\epsilon_{i,t}$ and $\eta_{i,t}$ are random income shocks, with the former being transitory and the latter permanent. $p_{i,t}$ is the permanent income with the initial value $p_{i,0} = 0$.

After retirement, a household receives fixed income that equals $\pi e^{p_{i,40}}$, where π is the income replacement ratio, and $p_{i,40}$ is the permanent income of household i before retirement.

Households are differentiated into types based on the variances of transitory and permanent income shocks. Each type has a unit measure of households. The effect of income uncertainty on housing decisions is assessed by comparing among types the average lifetime profiles of the housing demand. The deterministic income profile $\{G_t\}_{t=1}^{40}$ is assumed to be the same across households, to ensure that the between-type differences are not caused by the difference in income levels or the timing of income flows over the lifecycle.

The permanent shocks $\eta_{i,t}$ follow a normal distribution with mean μ_η and variance σ_η^2. I assume $\mu_\eta = -\frac{\sigma_\eta^2}{2}$ to ensure that higher variance types do not have greater mean values of income[12]. Similarly, the transitory shocks follow a normal distribution with mean $-\frac{\sigma_\epsilon^2}{2}$ and variance σ_ϵ^2. Notice that the distributions of income shocks are type-specific, but the realizations of shocks are household-specific. In the text that follows, the subscript i in income and income shocks are omitted for simplicity. The subscript t is also omitted whenever this causes no confusion.

A household acquires housing services through either renting or owning. Renters own no housing stock while owners consume all the housing stocks they own[13]. The stochastic process for house price Q_t is modeled in a standard way.

$$Q_t = Q_{t-1}(1 + \mu_h)R_{h,t} \tag{5}$$

This is to say the logarithm of house prices follow a random walk with drift. μ_h is the deterministic growth rate of house price and $R_{h,t}$ is the stochastic component which is assume to be lognormal, with mean zero and variance σ_ξ^2.

The rent of a house with stock H and price Q is ωHQ. Thus rents and house prices move perfectly together[14].

[12]Recall that the actual income, e^{y_t} follows a lognormal distribution with mean $e^{\mu+\frac{\sigma^2}{2}}$.

[13]This strengthens the assumptions in Henderson and Ioannides (1983).

[14]If the rent-income correlation differs from correlation between house prices and income, some of the results regarding housing tenure choices in this paper may be affected. Ortalo-Magne and Rady (2002) discusses the effect of rent-income correlation on housing tenure choice.

A household maximizes the lifetime utility by choosing nonhousing consumption (C), housing stock (H), and riskfree asset (A) which accrues at an annual rate of r. In the beginning of each period, a renter decides whether to become an owner given the state vector (y, A, Q). The value function of a renter of age t is

$$v_t(y, A, Q) = max\{v_t^{rent}(y, A, Q), v_t^{own}(y, A, Q)\} \tag{6}$$

where $v_t^{rent}(y, A, Q)$ is the value function of the renter if he decides to keep renting, and $v_t^{own}(y, A, Q)$ is the value function if he decides to become an owner. In that case, he needs to pay down d percent of the house value, and the remaining is financed through mortgage with annual mortgage rate r_m. As a buyer, he also pays ϕ fraction of the house value as the transaction cost.

The optimization problem of an owner has one more state variable – housing stock (H). In the beginning of each period, a homeowner decides whether to sell the house and become a renter. If he keeps owning, he also chooses whether to adjust the current housing stock by selling the existing house and buying another one. Let $w_t(y, A, Q, H)$ denote the value function of a homeowner, then

$$w_t(y, A, Q, H) = max\{w_t^{rent}, w_t^{move}, w_t^{stay}\} \tag{7}$$

where w_t^{rent}, w_t^{move} and w_t^{stay} are the value functions if the owner chooses to rent, to move, and to stay, respectively. Each of these functions depends on the state vector (y, a, Q, H). An owner also spends δ fraction of the house value as the "maintenance cost" which corresponds to property tax, fee charged by homeowner's association, maintenance costs and others in the real world. If an owner decides to sell his house, he pays the selling cost which is λ times the house value.

Now I am ready to define v_t^{rent} v_t^{own} for renters and w_t^{rent}, w_t^{move}, w_t^{stay} for owners recursively. Let $u(C, S)$ be the momentary utility function, where S stands for housing services that come either from renting or owning. Equation (8) to (13) lay out the recursive formulation of the value functions.

The value function of a renter who chooses to keep renting:

$$v_t^{rent}(y, A, Q) = max_{A', S}\, u(C, S) + \beta E_t[v_{t+1}(y', A', Q')] \tag{8}$$

$$\text{s.t. } A' = y + (1 + r)A - \omega QS - C$$
$$A' \geq 0$$

The value function of a renter who choose to become an owner:

$$v_t^{own}(y, A, Q) = max_{A', H'}\, u(C, S) + \beta E_t[w_{t+1}(y', A', Q', H')] \tag{9}$$

$$\text{s.t.} \quad \text{S=H'}$$
$$A' = y + (1+r)A - (\phi + \delta)QH' - C$$
$$A' \geq -(1-d)QH'$$

The value function of an owner who chooses to become a renter:

$$w_t^{rent}(y, A, Q, H) = max_{A',S} u(C, S) + \beta E_t[v_{t+1}(y', A', Q')] \tag{10}$$

$$\text{s.t. } A' = y + (1+r)A + (1-\lambda)QH - \omega QS - C$$
$$A' \geq 0$$

The value function of an owner who chooses to adjust the housing stock:

$$w_t^{move}(y, A, Q, H) = max_{A',H'} u(C, S) + \beta E_t[w_{t+1}(y', A', Q', H')] \tag{11}$$

$$\text{s.t. } S = H'$$
$$A' = y + (1+r)A + (1-\lambda)QH - (\phi + \delta)QH' - C$$
$$A' \geq -(1-d)QH'$$

The value function of an owner who chooses not to adjust the housing stock:

$$w_t^{stay}(y, A, Q, H) = max_{A'} u(C, S) + \beta E_t[w_{t+1}(y', A', Q', H')] \tag{12}$$

$$\text{s.t. s=H=H'}$$
$$A' = y + (1+r)A - \delta QH - C$$
$$A' \geq -(1-d)QH'$$

In period T, the last period of life, the household's future value V_{T+1} depends on the bequest wealth W_{T+1}. Following Yao and Zhang (2005), I assume the following bequest value.

$$V_{T+1}(W_{T+1}) = L^{\gamma} \frac{[W_{T+1}(\theta/\omega Q_{T+1})^{\theta}(1-\theta)^{1-\theta}]^{1-\gamma}}{1-\gamma} \tag{13}$$

This is the solution to the static optimization problem of beneficiaries. L governs the strength of bequest motives. The bequest wealth is the value of house plus the riskfree bond: $W_{T+1} = H_T Q_{T+1} + (1+r)A_T$.

The one-period utility function takes the following form:

$$u(C_t, S_t) = \frac{\left(C_t^{1-\theta} S_t^{\theta}\right)^{1-\gamma}}{1-\gamma}$$

with $S_t = H_t$ for owners and $S_t = \psi H_t$ for renters. Here ψ is the utility discount from being a renter. This modeling strategy, following Kiyotaki et al. (2008), allow for the possibility that renter enjoy less utility from the same owned house. It turns out that model results are quite sensitive to this parameter. The

Table 4: Parameter Values

Parameter	Symbol	value
Discount factor	β	0.96
Coefficient of relative risk aversion	γ	4
renter's utility discount	ψ	0.95
Housing share in utility	θ	0.26
Bequest strength	L	4
Income replacement ratio	π	0.6
Riskfree bond rate	r	0.02
Mean growth rate of house price	μ	0
Standard deviation of house price	σ_ξ	0.1
Downpayment requirement	d	0.1
Closing cost	ϕ	0.02
Selling cost	λ	0.08
Maintenance cost	δ	0.02
House rental price	ω	0.06
Correlation between shocks to house price and permanent income	$\rho_{\xi,\eta}$	0.3
Correlation between shocks to house price and transitory income	$\rho_{\xi,\epsilon}$	0.3

Cobb-Douglas preference is chosen over the more general constant elasticity of substitution preference for computational reasons[15]. The utility function exhibits constant relative risk aversion, and the coefficient γ determines the degree of risk aversion. It is also clear from the recursive formulation above that the elasticity of intertemporal substitution is assumed to be $\frac{1}{\gamma}$ in the model.

Table 4 presents the parameter values used in model computation. The principle here for model calibration is to use the standard values for the parameters whenever possible. For most of the parameters, similar values have been used in Cocco (2004), Yao and Zhang (2005), Li and Yao (2006), Yang (2008) and other papers. Yao and Zhang (2005) sets $\mu = 0$ based on the empirical findings by Goetzmann and Spiegel (2000). The correlation between income shocks and house price shocks are assumed to be 0.3. The proportional rental price of house (ω) is assumed to be 6%. When house price is fixed, owner's user cost is the sum of interest rate ($r = 0.02$), maintenance cost ($\delta = 0.03$) and the amortized value of transaction cost ($\lambda = 0.06$ and $\phi = 0.02$). Therefore the rental price should be above 5%, taking house price risks into account, the 6% rental rate should be considered as a lower bound. Housing share in utility is choose so that the average ratio of rental expenditure to other consumption expenditure equals 0.35 which is calculated from the 1984 wave of CEX data.

The deterministic income profile, $\{G_t\}_{t=1}^{40}$, is estimated from the PSID sam-

[15]See Appendix A.3 for details.

ple used in the empirical study in this paper. It is the average profile for all the households in the sample, hence the same for each household. In the quantitative results that follow, the between-type difference is only attributable to the ex-ante difference in the degree of income uncertainty.

3.2 The Baseline Model

The baseline version of the model assumes a frictionless world in which borrowing constraints and housing transaction cost do not exist. House price is normalized to one and dropped out of the state space.

Define housing-nonhousing consumption ratio as $\frac{H_t}{C_t}$. It is easy to show that in the baseline model, housing-nonhousing consumption ratio is independent of the degree of income uncertainty. This result holds under less restrictive assumptions, which is presented in the theorem that follows. Proof of the theorem is given in appendix A.2.

Theorem. *The housing-nonhousing consumption ratio is independent of the degree of income uncertainty if the following conditions hold.*

- *there exists no borrowing constraints and transaction cost of assets.*
- *the stochastic component of the growth rate of house price can be replicated by a portfolio comprised of human capital (represented by the stochastic income) and financial assets held by the household.*
- *the preference over housing and nonhousing consumptions is homogeneous.*

An important implication arise from the theorem: the dual roles of owner-occupied house, as formalized in Henderson and Ioannides (1983), is disentangled under the aforementioned assumptions. For investment purpose, housing is perfectly substituted by the replicating portfolio. Therefore a household needs only to consider the consumption demand when choosing the housing stock. This results in a housing consumption path with the identical shape as that of the nonhousing consumption which is steeper for household with greater income uncertainty.

Households with greater income uncertainty consume less housing when young, but save more for precautionary purposes. This leads to a lower housing shares in total wealth. Figure **??** demonstrates the lifecycle profile of asset holding, housing-income ratio, housing-wealth ratio and housing-consumption ratio for two types of households. The upper-left panel displays the higher demand for riskfree bonds by households with greater income uncertainty, illustrating their much stronger precautionary motives. The lower-right panel illustrate the constant housing-nonhousing consumption ratio when house price is fixed. It should be noted that if house price has a deterministic trend, this ratio will not be constant, but will remain independent of the degree of income uncertainty. In the upper-right panel, households with greater income uncertainty consume less housing when young, but more when old. This is because that housing consumption demand is not restricted by the investment demand, so housing consumption has exactly the same pattern as non-housing consumption. The lower-left panel shows the lower housing share in total wealth for households with greater income uncertainty.

One valuable insight is gained from the baseline model: the observation that households with low income uncertainty have larger share of housing in total wealth and more housing stock may have nothing to do with house price uncertainty and market frictions such as borrowing constraints and transactions costs. It can at least partially be explained by the differences in precautionary motives and consumption demands among different types of households. In the computational exercises that follow, these results in the baseline model serve as a benchmark for testing the roles played by illiquidity of housing, house price uncertainty and borrowing constraints.

3.3 Illiquidity and price uncertainty

Transaction cost induces an inaction region in the housing decision rule. In a continuous-time infinite horizon setup, using Cobb-Doglous preference over durable and nondurable goods, Damgaard et al. (2004) proves that the boundaries of inaction regions are defined by the ratio of total wealth over the value of durables. Such a nice property is not available in the finite horizon model in the present paper. It is not even clear how the boundaries depend on the degree of income uncertainty. Under the premise of insensitivity of the boundaries to degree of income uncertainty, households with greater income uncertainty should demand less housing due to higher expected user cost. The user cost as a proportion of the value of a house that is kept for τ years is $r + \delta + \bar{\lambda} + \bar{\phi}$. The amortized selling cost ($\bar{\lambda}$) and buying cost ($\bar{\phi}$) are from the following two equations,

$$\bar{\lambda} + \frac{\bar{\lambda}}{1+r} + \frac{\bar{\lambda}}{(1+r)^2} + ... + \frac{\bar{\lambda}}{(1+r)^{\tau-1}} = \frac{\lambda}{(1+r)^{\tau}}$$

$$\bar{\phi} + \frac{\bar{\phi}}{1+r} + \frac{\bar{\phi}}{(1+r)^2} + ... + \frac{\bar{\phi}}{(1+r)^{\tau-1}} = \phi$$

Solving the two equations yields:

$$\bar{\lambda} = \frac{r}{(1+r)^{\tau+1} - 1}\lambda$$

$$\bar{\phi} = \frac{1 - 1/(1+r)}{1 - 1/(1+r)^{\tau+1}}\phi$$

Both $\bar{\lambda}$ and $\bar{\phi}$ decreases with τ. Intuitively, the longer a house is kept, the less is the annual amortization of the transaction cost. If different types of households have similar inaction regions regarding housing decisions, those with higher income uncertainty are more likely to be knocked out of the boundaries. This is confirmed quantitatively. Figure 6 plots the fractions of movers and stayers for two types of households. The figure is generated from the version of the model in which house price is fixed, but transaction costs exit. Households with greater income uncertainty clearly move more frequently than those with relatively stable income. Furthermore,no household moves after retirement, since income shocks no longer occur.

Households with greater income uncertainty move more frequently, resulting in a lower value of τ and higher user cost in expectation. User cost of owned house is essentially the price of housing services, thus higher user cost shall lead to lower housing-nonhousing consumption ratio and housing share in total wealth.

The upper panels of figure 4 shows the change of housing-income ratio when transaction costs are introduced into the model. The ratio becomes non-decreasing, and high income uncertainty households clearly have higher ratio on average (the cross of the two lines occurs much later).

The upper panels of figure 5 shows the change of housing-consumption ratio. With transaction costs, The ratio now increases with age, which is consistent with evidence from various data sources[16]. More importantly, the model replicates the negative effect of income uncertainty on housing-nonhousing consumption ratio, which confirms the above user cost argument. Transaction cost also strengthens the negative effect of income uncertainty on housing share in total wealth.

Next, I consider a model in which house price is uncertain, but is uncorrelated with income shocks. The lower-left panels of figure 4 and figure 5. Compared with the upper-right panels, it becomes clear that the introduction of house price risk encourages high income uncertainty households to become home owners earlier, and have higher housing-income ratio and housing-consumption ratio.

[16]Figure 1 and Figure 2 in this paper relies on data from the Consumer Expenditure Survey. Yang (2008) combines the Consumer Expenditure Survey and Survey of Consumer Finance by constructing synthetic cohorts.

Namely, degree of income uncertainty becomes positively correlated with these two ratios. Why do high income uncertainty households like risky housing? The answers is, these households like to lock in house price earlier by becoming home owners, thus reduce overall exposure to risks. Han (2008) provides an clear argument on the hedging effect of early home ownership in the face of risky house prices.

In reality, house prices move together with income at the aggregate level. Cocco (2004) estimates the correlation between house price and the aggregate component of household income uncertainty to be more than 53%. In light of this, the zero correlation assumption seems unrealistic. The lower-right panels of figure 4 and figure 5 display the housing-income ratio and housing-consumption ratio when correlation between income shocks and house price is assume to be 0.3 for both types of income shocks. Now both ratios decrease with the degree of income uncertainty. The reason is very intuitive. High income uncertainty households stronger precautionary motives. Given the positive correlation between house price and income, housing is a very poor precautionary asset. For example, when a homeowner receives a huge negative income shock and become unemployed, she might consider downsize her housing to support non-housing expenditure. A positive correlation between price and income means that house price is like to be low at a time when the house needs to be sold. Therefore it should be optimal for her to invest a larger fraction of wealth in nonhousing asset.

3.4 Borrowing constraints

I follow the common assumption that (1) no borrowing is allowed except mortgage debt and (2) house purchase entails an upfront downpayment. Hence the borrowing constraints have a weak form in which collateral borrowing is allowed. The roles played by the borrowing constraints are best understood from the viewpoint of the tension between the housing consumption motives and housing investment motives, as demonstrated in Henderson and Ioannides (1983) and Fu (1995). For young households, retirement is decades away, so they need limited saving only for precautionary purpose. Therefore acquiring housing service from owning entails over-saving. When borrowing is allowed, households can balance out the over-saving by hold negative financial assets. With borrowing constraints imposed, the conflict between housing consumption motives and investment motives rises. Households with greater income uncertainty have stronger precautionary motives, hence suffer less from the over-saving and have a high probability of owning, especially when young.

The computational results show that such a conflict indeed causes higher homeownership rate for households with greater income uncertainty, provided that house prices are uncorrelated with income. This is shown in Figure 7. The upper panel is generated from the model without house price risks, and the lower panel with house price risks, but house price is assumed to be uncorrelated with income. The squared lines plots the increase of homeownership rate with the degree of income uncertainty. In contrast, absent borrowing constraints, homeownership rate exhibit little change in response to income uncertainty, which is shown by the starred lines.

It should be noted that borrowing constraints do not increase homeownership rate, but lower homeownership rate to greater extent for households with more stable income, causing the homeownership rate to increase with income uncertainty. When house prices and income are assumed to be positively correlated, the correspondence between income uncertainty and homeownership rate is no longer monotone, because risk-avoidance consideration begins to gain strength. When both $\rho_{\xi,\eta}$ and $\rho_{\xi,\epsilon}$ reach 20%, homeownership rate decreases monotonically with income uncertainty. Furthermore, in this case the correspondence between homeownership rate and income uncertainty is virtually the same as in the absence of borrowing constraints. This indicates the home buyers are little bound by borrowing constraints, but choose not to borrow to reduce the risk exposure.

My results are consistent with those in Diaz-Serrano (2005). Using Italian data, Diaz-Serrano (2005) finds that borrowing constraints exerts a significant negative effect on the probability of homeownership, but the negative relationship between income uncertainty and homeownership is driven by households' risk aversion.

Another interesting question regarding borrowing constrains is: do the borrowing constraints help explain the negative effect of income uncertainty on housing decisions on the intensive margin? To answer this question, I set the correlation between both $\rho_{\xi,\eta}$ and $\rho_{\xi,\epsilon}$ to 20%, and compare the quantitative results from the model with borrowing constraint to those from the model without borrowing constraint. I find little difference, which again shows that households are little bound by the borrowing constraints when risk-avoidance consideration dominates housing decisions.

3.5 Results from the fully-specified model

Figure 8 displays housing decisions in the fully-specified model, the version with borrowing constraints, housing transaction cost and house price which is uncertain and positively correlated with income. The model is able to generate the negative correlation between degree of income uncertainty and housing investment on each of the four dimensions.

In order to examine how well the model matches the data quantitatively, I search through different value of β, γ and ψ so that the model results can match 8 moments in the data as much as possible. Table 5 shows the moments from the data, as well as from the model. The model does a quite decent job in matching the mean values of the four measures of housing investment. Regarding the magnitude of the negative effect, the model does not perform well with home ownership rate and housing-wealth ratio. In the model, the negative effect of income uncertainty is too strong on housing-wealth ratio, but too week on the probability of ownership. The model performs quite well in matching other moments.

Table 5: Matching model with data

parameters	β	γ	ψ
	0.965	3.7	0.94
		data	model
mean values	home ownership rate	0.678	0.521
	housing-income ratio	3.337	3.969
	housing-weath ratio	0.317	0.372
	housing-consumption ratio	3.853	5.714
regression coeff of permanent shocks	home ownership rate	-18.773	-8.204
	housing-income ratio	-0.824	-0.774
	housing-weath ratio	-1.845	-18.596
	housing-consumption ratio	-4.678	-4.214
regression coeff of transitory shocks	home ownership rate	-9.913	-5.948
	housing-income ratio	-0.551	-0.290
	housing-weath ratio	-0.998	-1.692
	housing-consumption ratio	-0.496	-0.725

4 Robustness

The computational results presented in the previous section generally do not change qualitatively with reasonable changes in parameter values. Examples include changing γ between 2 to 5, changing down payment requirement from 10% to 20%, and changing the selling cost of houses to from 6% to 8% of the house values. The exception is ψ, the utility discount due to rental status. When ψ is lowered, home ownership becomes more desirable. With a very low ψ, households with greater income uncertainty, who save relatively more, are more likely to become home owners. The relationship between income uncertainty and homeownership rate is the result of the tension between two mechanisms. (i) The conflict between housing consumption and investment demand leads to a positive relationship. (ii) The comovement between income and house prices leads to negative relationship. The sensitivity of homeownership rate to ω shows that the second mechanism dominates the first one only weakly.

Thus far I have assumed free refinancing[17] and the same interest rate for mortgage debt and riskfree bond. In reality these assumptions do not hold. Home buyers typically pay off their mortgage debt according to a mortgage payment schedule which is costly to change via refinancing. These arrangements make housing investment more irreversible. They also intensify the conflict between housing consumption demand and investment demand, because costly refinancing implies more stringent borrowing constraints. With these considerations in mind, I solve a model in which home buyers are required to pay off the mortgage debt in 15 years, mortgage rate is assumed to be 4%, and refinancing cost is 0.5% of the house value. This computational exercise reveals: (i) The results in the previous section still hold qualitatively; (ii) The relationship between income uncertainty and homeownership rate becomes even more sensitive to the rental price of houses ω.

5 Concluding remarks

This paper studies the effect of income uncertainty on housing decision. It uses four variables to measure housing demand: homeownership rate, ratio of house value to income, ratio of home equity to total wealth, and ratio of house value to nonhousing consumption. The paper presents empirical evidence that all these variables are negatively correlated with the degree of income uncertainty.

On the theoretical side, the paper demonstrates that the empirical observations are consistent with a optimal portfolio choice model featuring costly housing transaction and positive correlation between house price and income. Housing transaction cost are critical in explaining the data facts because it leads to higher expected cost for households with greater income uncertainty. When house price is uncorrelated with income shocks, price risks lead to more earlier home ownership by households with greater income uncertainty. A positive

[17] Here I am equating refinancing with loans backed by home equity.

correlation between house price and income leads to the significant decrease of housing demand with income uncertainty. Borrowing constraints discourage housing demand of households with greater income uncertainty to a less extent, because they suffer less from the conflict between the consumption and investment demand of housing relative to those with more stable income.

These findings necessitate a reassessment of a class of portfolio choice models that abstracts from housing but uses income uncertainty to explain the reluctance of households to hold stocks in spite of the high equity premium. Since income uncertainty depresses housing investment, and the depressed housing investment in turn leads to more investment in other risky assets, this class of models overstates the impact of income uncertainty on portfolio choice. Therefore a profitable direction of future research is to evaluate the impact of income uncertainty on portfolio choice in the presence of housing.

Findings in this paper also provide a channel to resolve the lifetime consumption inequality puzzle. Zhu (2008) uses data from Consumer Expenditure Survey and documents an almost flat lifetime profile of housing consumption inequality. This is puzzling because a standard lifecycle model predicts that within-cohort housing consumption inequality should rise with age of the cohort due to the persistent idiosyncratic income shocks. Since the negative effect of income uncertainty on housing demand diminishes with age, the housing consumption gap between households with greater income uncertainty and those with less income uncertainty is high when they are young, then decreases with age. This generates a tendency for within-cohort housing consumption inequality to decrease over lifetime, which can potentially counteract the increasing tendency caused by the arrival of persistent income shocks.

Another direction of future research is to incorporate the negative effect of income uncertainty on housing demand into the study of cyclical fluctuations in the housing market. Storesletten et al. (2004) shows the dramatic increase of household level income uncertainty during recessions, which further reduces housing demand during recessions. This channel may potentially explain the excessive volatility of residential investment and house trading volume observed in the data.

Appendices

A.1. Data Appendix

Income and consumption data used in the paper are from the Panel Study of Income Dynamics (PSID). Since Survey of Economic Opportunity subsample includes low-income families only, it does not represent the general population, and is excluded in this study.

From the family files of PSID surveys 1984-1997, I take the total family income (variable V11022, V12371, V13623,V14670, V16144, V17533,V18875, V20175, V21481, V23322 ER12079) of 1066 households. Total family income is defined as the sum of total taxable income and transfers of all family members. Information on a household's total wealth, house value, home equity value, whether owning stock and whether owning business are obtained from Wealth Supplement Files for year 1984 and year 1994. PSID interviewers started to ask about interest rates on mortgage loans since 1996. This study uses the mortgage rate on the first loan (asked in survey year 1996) in the empirical analysis. A household is included in the sample if all of the following selection criteria are satisfied: (1) The househead should age between 20-60 in 1984 and live in urban area and (2) It should have non-zero income in each year from 1984-1997. (3) It should report valid information on househead's marital status, number of children, occupation and industry of employment, and region of residence from 1984-1993 (not available for the other years). (4) It should have valid code for location of residence in 1985-1993 (not available for the other years). (5) In 1984 survey, it should have valid information on age, sex, race, years of schooling of househead, and years of schooling of the spouse if present. (6) If it is an homeowner, it should report valid information on mortgage rate in 1996.

Consumer Expenditure Survey data are available from NBER website[18]. In the family files, total expenditure is defined as the sum of expenditures on food, tobacco, alcohol, nightclub; nonfood, clothing, personal care, household operations, business service, life insurance, transportation, recreation, education, charity, medical expenditure and housing service. My measure of nonhousing consumption is the total expenditure minus housing service which is the actual or imputed rent paid by the household. I exclude in the sample the households that (1) are not homeowners, (2) reported head age that is less than 20, (3) reported zero nonhousing consumption, (4) lived rural area, (5) do not report valid information on age, sex, race, years of schooling, and head's occupation

[18] http://www.nber.org/data/*ces_cbo*.html.

and industry of employment.

Definitions of occupations and industries are slightly different in PSID and CEX. To reconcile the two samples, I define six categories of occupation and nine categories of industry. The table below lists the corresponding PSID and CEX codes.

Occupation Category	PSID 3-digit (H-E) code	CEX occupation code
Not working or retired	0	09, 10
Professional, and managerial workers	1-195, 201-245	01
Technical and administrative workers	260-285, 301-395,401-600	02, 05
Operator,fabricator and laborers	601-695-701-715,740-785	06
Farmer, farm manager and worker	801-802, 821-824	04
Service workers	901-965, 980-984	03
Industry Category	**PSID 3-digit (H-E) code**	**CEX industry code**
Agriculture, forestry, fisheries and mining	17-28, 47-57	01
Construction	67-77	02
Manufacturing	107-398	03
Public Utilities	407-479	04
Whole and retail trade	507-698	05
Finance, insurance and real estate	707-718	06
Business, personal and recreational services	727-759, 769-798, 807-809	08
Professional services	828-897	07
Public administration	907-937	09

A.2. Proof of the Theorem

A household solves the following problem

$$max_{C_t,H_t,A_t} \ u(C_t,H_t)+\beta E_t[V(W_{t+1})]$$
$$\text{s.t.}$$
$$C_t=(1+\mu_p)\tilde{R}_{p,t}A_{t-1}-A_t+Q_tH_{t-1}-Q_t(1+\delta)H_t$$
$$W_{t+1}=(1+\mu_p)\tilde{R}_{p,t+1}A_t+Q_{t+1}H_t$$

where A_t is the value of a portfolio of nonhousing financial assets and the stochastic labor income (human capital). $1+\mu_p$ is its mean return and $\tilde{R}_{p,t}$ is the stochastic component of the portfolio return. W_{t+1} is the total wealth in the beginning of period t+1. As in the main text, Q_t is the house price and H_t is the housing stock. The expectation E_t integrates the value function, $V(W_{t+1})$, over the probability space Ω.

In a frictionless world the value function is differentiable and it is easy to derive the following first order conditions.

$$(1+\delta)Q_t\frac{\partial u(C_t,H_t)}{\partial C_t}=\frac{\partial u(C_t,H_t)}{\partial H_t}+\beta E_t\left[Q_{t+1}\frac{dV(W_{t+1})}{dW_{t+1}}\right] \tag{A.2.1}$$

$$\frac{\partial u(C_t,H_t)}{\partial C_t}=(1+\mu_p)\beta E_t\left[\tilde{R}_{p,t+1}\frac{dV(W_{t+1})}{dW_{t+1}}\right] \tag{A.2.2}$$

Divide both sides of (A.2.1) by Q_t and recall $\frac{Q_{t+1}}{Q_t}=(1+\mu_h)R_{h,t}$, then

$$(1+\delta)\frac{\partial u(C_t,H_t)}{\partial C_t}=\frac{1}{Q_t}\frac{\partial u(C_t,H_t)}{\partial H_t}+\beta(1+\mu_h)E_t\left[R_{h,t}\frac{dV(W_{t+1})}{dW_{t+1}}\right] \tag{A.2.3}$$

By assumption (2), $R_{h,t}$ can be replicated, say by A_t for ease of exposition. In other words, $\tilde{R}_{p,t}(\omega) = R_{h,t}(\omega)$, $\forall \omega \in \Omega$. Therefore (A.2.3) can be rewritten as

$$(1+\delta)\frac{\partial u(C_t, H_t)}{\partial C_t} = \frac{1}{Q_t}\frac{\partial u(C_t, H_t)}{\partial H_t} + \beta(1+\mu_h)E_t\left[\tilde{R}_{h,t}\frac{dV(W_{t+1})}{dW_{t+1}}\right] \tag{A.2.4}$$

Combining (A.2.2) and (A.2.4) and rearranging terms yields

$$\left(1-\delta-\frac{1+\mu_h}{1+\mu_p}\right)\frac{\partial u(C_t, H_t)}{\partial C_t} = \frac{1}{Q_t}\frac{\partial u(C_t, H_t)}{\partial H_t} \tag{A.2.5}$$

By assumption (3), let $u(C_t, H_t) = [(1-\theta)C_t^{\alpha} + \theta H_t^{\alpha}]^{\alpha_1}$, then from (A.2.5),

$$\frac{H_t}{C_t} = \left\{1/\left[Q_t\left(1-\delta-\frac{1+\mu_h}{1+\mu_p}\right)\frac{1-\theta}{\theta}\right]\right\}^{1/(1-\alpha)} \tag{A.2.6}$$

Note that the expectation operator does not appear in the (A.2.6). The housing-nonhousing consumption is independent of degree of income uncertainty.

For investment purpose, housing is an redundant asset under assumption (1) and (2). But households own houses due to the consumption demand. In the case of fixed house price, the "stochastic" component of house price is replicated by riskfree bond. Hence the housing-nonhousing consumption ratio is also independent of income uncertainty.

A.3. Model Computation

First, I show that the model can simplified by rescaling. Let $P_t = e^{p_t}$ and $Y_t = e^{y_t}$, from equation (3), (4) and (5), one can get

$$\frac{P_t}{P_{t-1}} = e^{G_t \eta_t} \tag{A.3.1}$$

$$\frac{Y_t}{P_t} = e^{\epsilon_t} \tag{A.3.2}$$

$$\frac{Q_t}{Q_{t-1}} = (1+\mu_h)R_{h,t} \tag{A.3.3}$$

Consider the value of an owner in the last period of life who decides to adjust the housing stock.

$$w_t(y_T, A_{T-1}, Q_T, H_{T-1}) = max_{A_T, H_T} u(C_T, H_T) + \beta E_T[V_T(W_{T+1})] \tag{A.3.4}$$

s.t.

$$\begin{aligned} Y_T &= \pi P_T \\ C_T &= (1+r)A_{T-1} + (1-\lambda)H_{T-1}Q_T - A_T - (1+\phi)H_T Q_T \\ W_{T+1} &= (1+r)A_T + (1-\lambda)H_T Q_{T+1} \end{aligned}$$

Define $a_T = \frac{A_T}{p_T}$, $h_T = \frac{H_T Q_T}{p_T}$ and $c_T = \frac{C_T}{p_T}$. Dividing both sides of (A.3.4) by $(P_T/Q_T^{\theta})^{1-\gamma}$ yields

$$\frac{w_t(y_T, A_{T-1}, Q_T, H_{T-1})}{(P_T/Q_T^{\theta})^{1-\gamma}} = max_{a_T, h_T} u(c_T, h_T) + \beta E_T[v_T(w_{T+1})] \tag{A.3.5}$$

where

$$v_T(w_{T+1}) = \frac{V_T(W_{T+1})}{(P_T/Q_T^{\theta})^{1-\gamma}} = \frac{L^{\gamma}}{1-\gamma}\left(\frac{1}{(1+\mu_h)R_{h,T+1}}\right)^{\theta(1-\gamma)}\left[w_{T+1}(\theta/\omega)^{\theta}(1-\theta)^{1-\theta}\right]^{1-\gamma}$$

and

$$w_{T+1} = (1+r)a_T + (1-\lambda)h_t(1+\mu_h)R_{h,T+1}$$

Dividing both sides of the budget constraints by P_T yields

$$x_T = \pi$$
$$c_T = (1+r)a_{T-1}\frac{p_{T-1}}{p_T} + (1-\lambda)h_{T-1}\frac{Q_T p_{T-1}}{Q_{T-1}p_T} - a_T - (1+\phi)h_T$$
$$w_{T+1} = (1+r)a_T + (1-\lambda)h_t(1+\mu_h)R_{h,T+1}$$

where $x_T = Y_T/P_T$. Note that the new budget constraints can be further simplified by substituting (A.3.1) and (A.3.3) in.

Therefore the last period problem is rewritten as equation (A.3.5) and the new budget constraints. It turns out that the value function in each period can be normalized by $(P_t/Q_t^\theta)^{1-\gamma}$; and the budget constraint in each period can be normalized by P_t. Thus the whole optimization problem can be normalized, and P_t, Q_t are dropped out of the state space. This greatly reduces the computational load of the problem.

The Cobb-Douglas preference is needed for such a simplification, since the equality

$$\frac{u(C_t,H_t)}{(P_t/Q_t^\theta)^{1-\gamma}} = u(c_t,h_t)$$

does not hold for more general constant elasticity of substitution preference. Also, the random walk specification of y_t and Q_t leads to (A.3.1) and (A.3.3), which is also necessary for the simplification.

I approximate both riskfree bond and housing asset by 150 equally-spaced grid points. Realization of income and house price shocks are approximated by two states using Gaussian quadrature (Tauchen and Hussey (1991)). In the model with costly refinancing, it is necessary to keep track of years to maturity of the mortgage loan. If house prices are fixed, mortgage balance can be calculated from years to maturity. In case of risky house prices, I use two states to approximate the ratio of current house price to the purchase price to infer mortgage balance. In case of 15-year mortgage, the state variables of the model are represented by a high-dimensional grid of $150 \times 150 \times 15 \times 2 \times 2 \times 2$. Given the high-dimensionality of the problem, it is hardly feasible to solve it on a personal computer. The numerical solutions in the paper are obtained by running Fortran-MPI programs on a cluster.

For each type of households, in each state, policy functions for bond holding, housing stock, nonhousing consumption are solved by grid search. For homeowners, there is an additional policy function that states whether they should refinance. To obtain the lifecycle profile of housing stock, home equity share, housing-nonhousing consumption ratio and homeownership rate for a particular type, I compute the measure of households on each grid point, then integrate the policy functions over these grid points. In the first period, all the households start with zero housing stock and riskfree bond, hence the measure is initially distributed based on the realizations of income shocks and house prices shocks. As the policy functions link each grid point in the first period to a grid point in the next period, it brings these measure to the next period and the periods that follows.

The computational results are more intuitive if they are on the original scale. For that purpose, I compute the weighted average level of permanent income on each grid point, and multiple the policy function with that.

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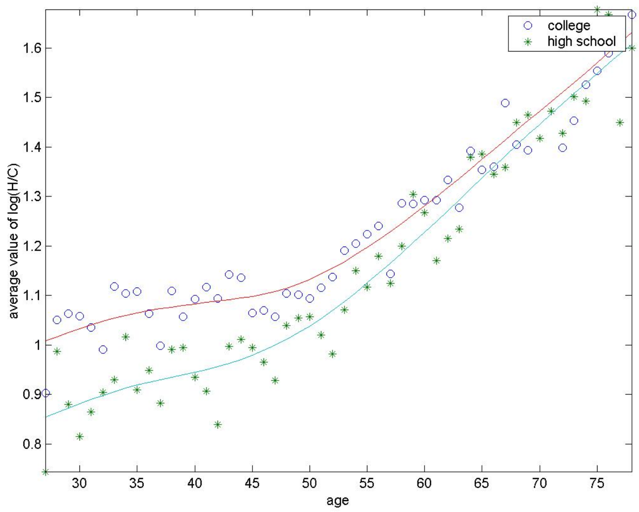

Figure 1: Housing-nonhousing ration by education.

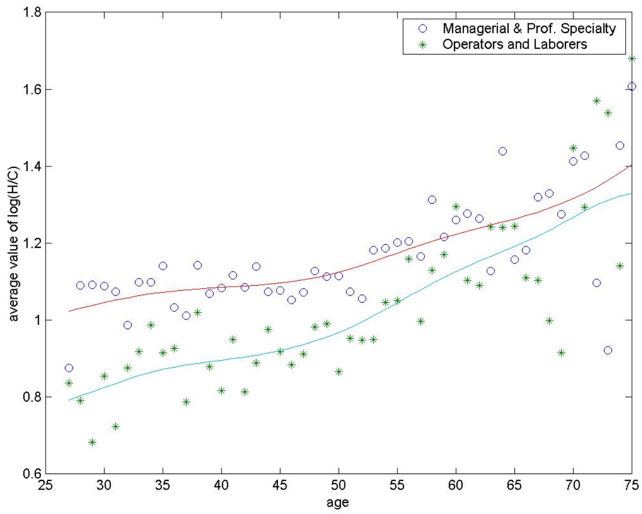

Figure 2: Housing-nonhousing ration by occupation.

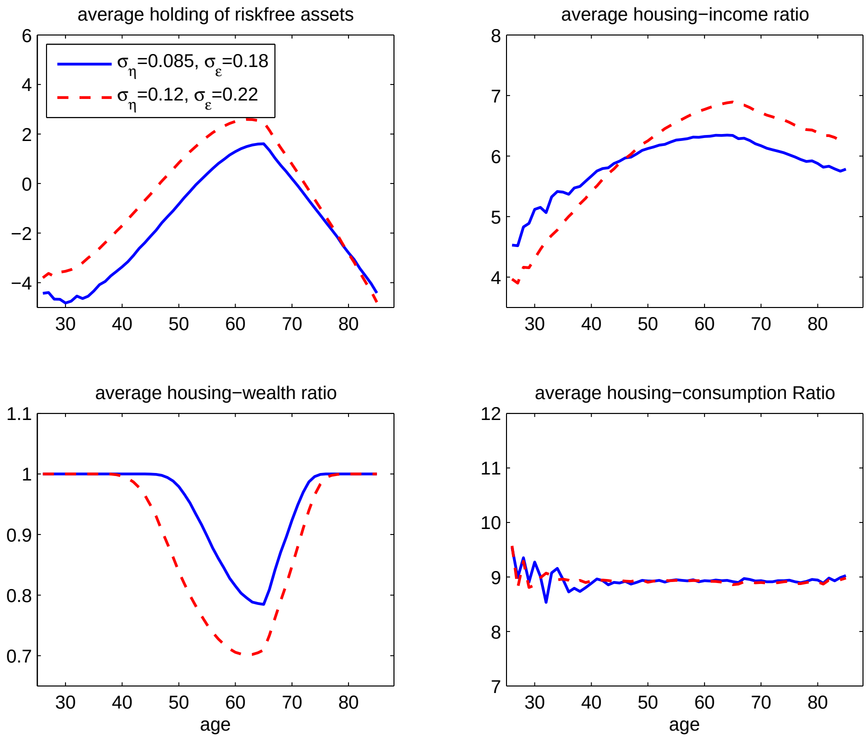

Figure 3: Housing decisions in the baseline model in which borrowing constraints and housing transaction cost is absent. House price is fixed at 1.

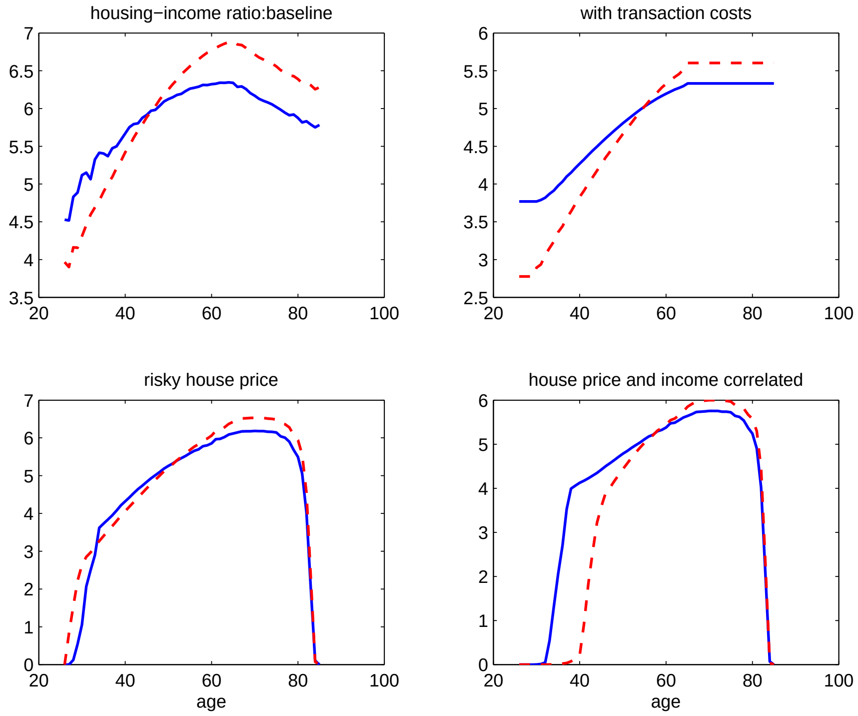

Figure 4: Housing-income ratios in various versions of the model.

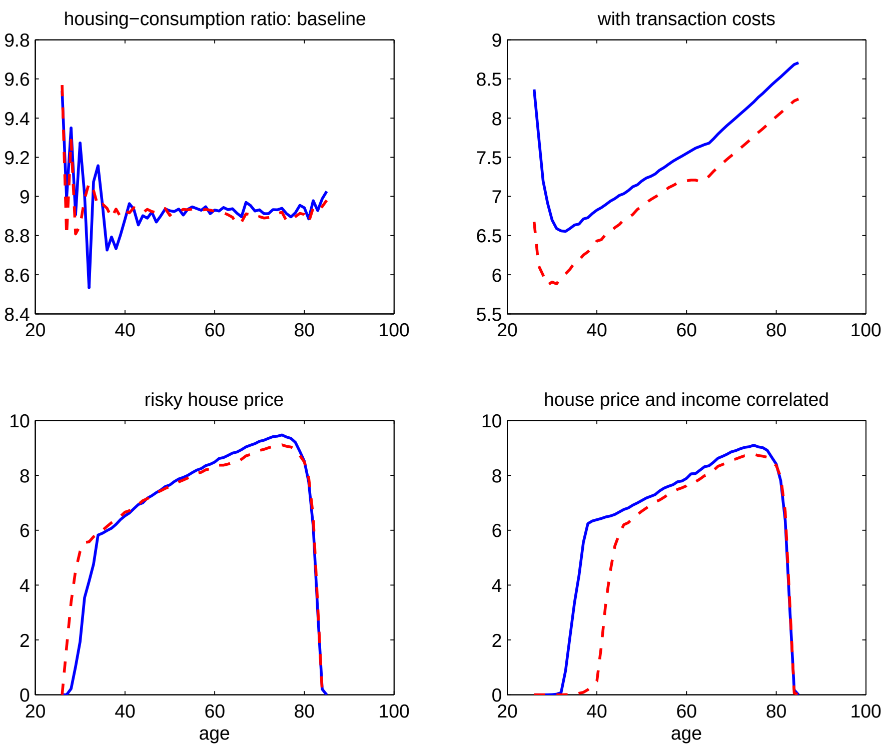

Figure 5: Housing-consumption ratios in various versions of the model.

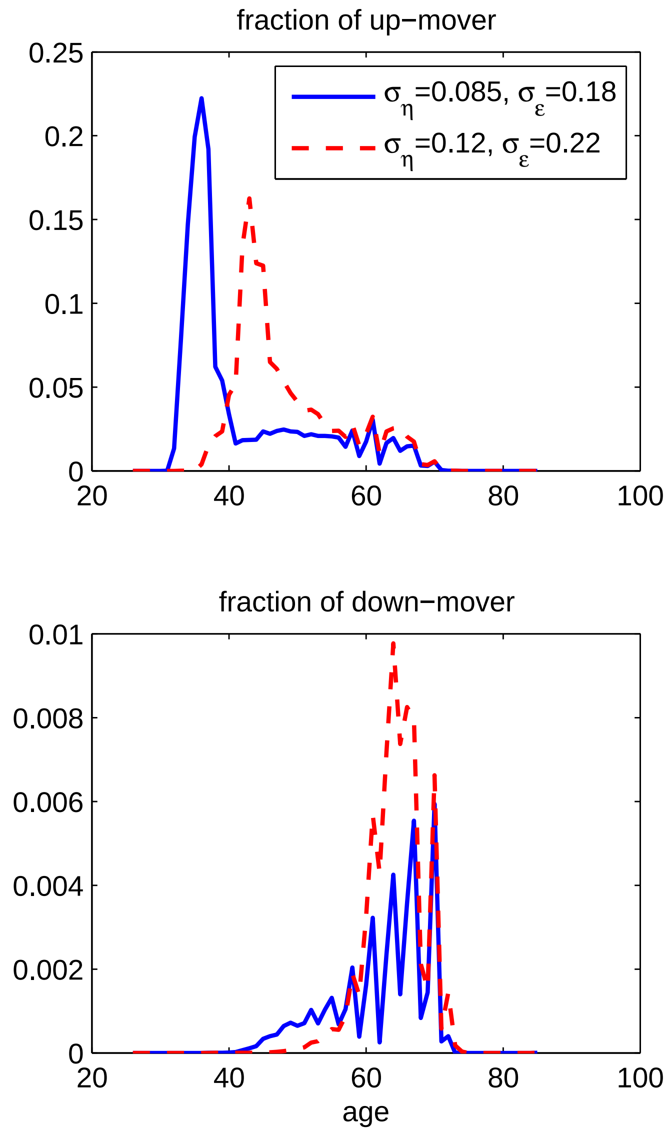

Figure 6: Fractions of movers and stayers, calculated from the model without house price risks.

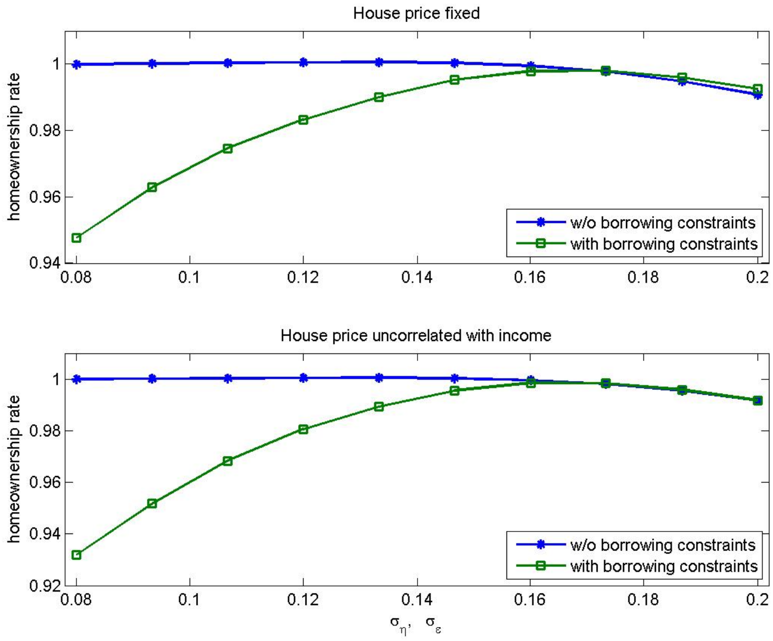

Figure 7: Homeownership rate as a function of standard deviations of income shocks. The upper panel is for the situation without house price uncertainty, the lower panel assumes house prices are uncertain but uncorrelated with income.

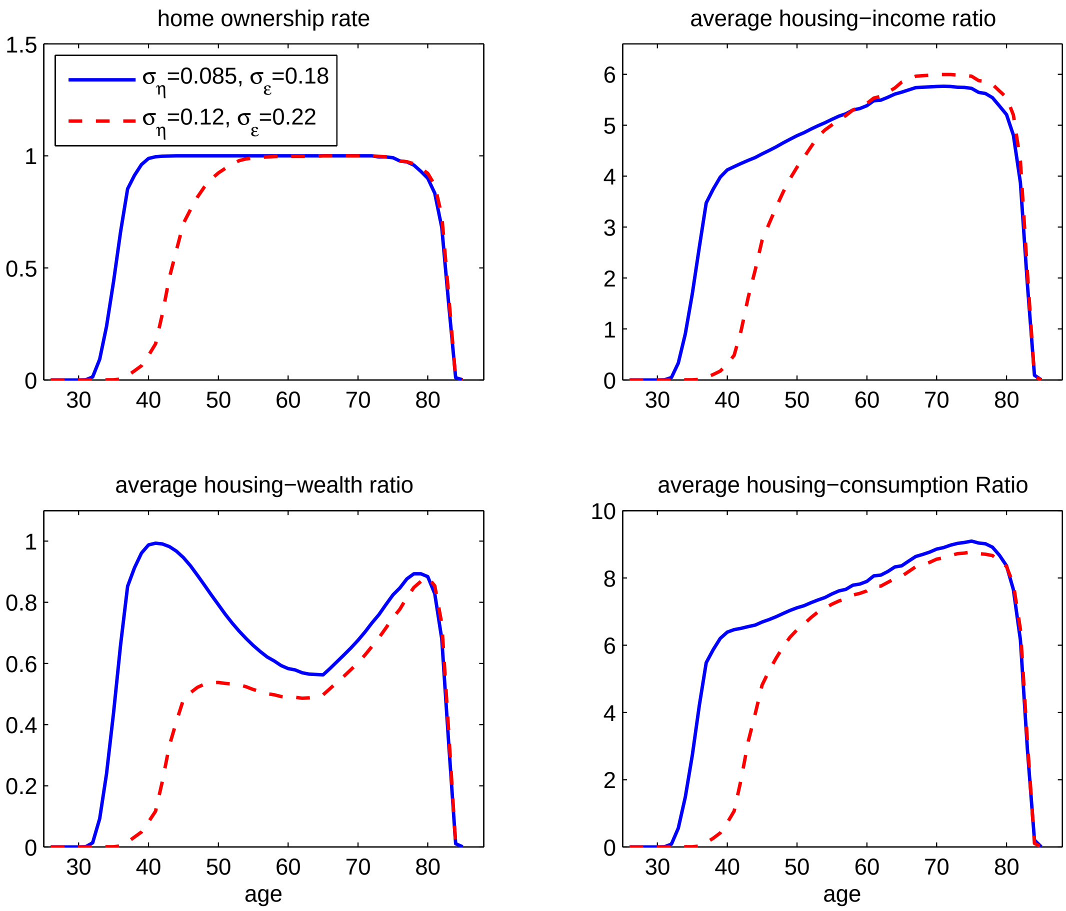

Figure 8: A comparison of housing decisions in the fully-specified model.