Abstract

What determines the evolution of housing price and quantity in the long term? This paper investigates the contribution of the Baby Boom and Bust, the limitation of land development, general productivity growth and the gap in productivity growth rates between construction and the other sectors in accounting for the evolution of the housing market in the United States. Using a life cycle model of a closed economy with housing, I find that the limitation of land development and general productivity growth play a major role in the long term. In contrast, the Baby Boom and Bust has a limited impact on the housing price, after taking into account its impact on the real interest rate.

Keywords: housing price, housing quantity, land, structure, real estate, life cycle, demographic structure, medium term, long term
1 Introduction

Housing constitutes a large fraction of the national wealth in the United States, and housing price dynamics have strong macroeconomic implications.\(^1\) The recent boom and bust cycle has attracted much attention to short- and medium-term housing price movements. However, given that the long-term housing price trend is a component of overall housing price movements and that houses are illiquid assets and their investment horizon is typically long, it is important to understand long-term housing price movements.

Data suggests that from 1960 to 2011, the national real housing price in the United States had an upward trend of 1.3\%, interrupted by the recent boom and bust cycle.\(^2\) It is not clear what drove up the housing price or what the future movement will be. Several competing channels have been discussed in the literature. Some studies suggest the importance of the change in demographic structure (Mankiw and Weil, 1989, Abel, 2001, 2003, Martin, 2006). They argue that since the size of the Baby Boom generation is much larger than the generations adjacent to them, their demands for housing services and savings instruments may drive up the housing price in their middle-aged period. When Baby Boomers enter their retirement age, they may sell off their assets, and asset prices, including the housing price, may decline.

On the other hand, as a house consists of a reproducible tangible structure and a non-reproducible plot of land, some studies suggest that the growth of general productivity would lead to increased demand for housing; since land is scarce, the land price would increase and lead to an increase in the housing price (DiPasquale and Wheaton, 1994). Such a long-term upward trend may be further strengthened by rising construction costs, due to slower productivity growth in the construction sector compared to the rest of the economy (Davis and Heathcote, 2003).

Given these competing channels, the purpose of this paper is to investigate the contribution of the Baby Boom and Bust, the limitation of land development, general productivity growth, and rising construct costs to the long-term housing price trend in the United States. I ask two questions: (1) what is the relative importance of these factors? (2) Will the housing price decline in the following decades due to the aging of the Baby Boomers?

---

\(^1\)According to Davis and Heathcote (2007), "The market value of the housing stock in the United States to be $24.1 trillion at the end of 2005. This figure is 1.42 times the combined capitalizations of the NYSE, Nasdaq and Amex exchanges."

\(^2\)From 1980 to 2011, I use the Federal Housing Finance Agency repeated sales housing price index. From 1960 to 1980, the housing price index is constructed by extending Davis and Heathcote (2007). Section 3.1 and the Appendix explain the details.
To study these questions, the main challenge is to determine how easily people can substitute structure for land in producing housing services. If that is easy, strong growths of demand side factors may only drive up the land price but have a weak impact on the housing price growth, because people can still provide housing services in a relatively cheap way by using more structure per unit of land to build houses.

To determine the substitution elasticity between land and structure in producing housing service, however, is challenging. The United States is a big country, and it is unlikely that the substitution elasticity is homogeneous across regions, given that home building regulations vary substantially (Glaeser et al., 2005). Also, taking into account the quality of land, building homes in less desired locations effectively substitutes structure for land. Accounting for huge amount of heterogeneity is challenging.

To solve this issue, instead of developing a model that includes multiple housing markets and households’ location choices, I choose to construct data that is consistent with a model that has one integrated housing market and homogeneous land.

I develop an overlapping generations life cycle model of general goods and housing services production, with the productivity in producing general goods growing and newborn generation size growing and fluctuating over time. Housing services are produced from combining land and structure using a Constant Elasticity of Substitution (CES) technology. Land is developed using general goods, with the productivity of land development declining when more land has been developed; this is referred to as the limitation in land development. Structure is transformed from general goods, with the transformation cost rising over time.

I calibrate the model to the U.S. data from 1960 to 2011. In particular, I construct aggregate price and quantity indices of land and structure which control for quality, and estimate the CES technology based on these indices. My data construction extends the seminal work of Davis and Heathcote (2007).

The calibrated model matches well long-term trends of price and quantity of land and structure, and the housing price trend in the model is similar with the counterpart in the data. The estimated substitution elasticity between land and structure in producing housing services is substantially lower than one. If I choose the substitution elasticity to be close to one and recalibrate the model, the housing price trend in the model is much flatter than the counterpart in the data.

The impacts of the four factors on housing prices are studied through a series of shutdown experiments. When only the Baby Boom and Bust is considered, it drives up the housing price by 0.12% per annum from 1960 to 2010, and leads to a decline of 0.25% per
annum from 2010 to 2040. To give these numbers perspective, according to the Case-Shiller National Price index, the peak-to-trough decline from 2006 to 2012 was around 8% per annum, whereas the previous peak-to-trough decline from 1989 to 1997 was around 1.8% per annum.

After including the limitation in land development, the housing price increases by 0.5% from 1960 to 2020, and declines by 0.2% per annum from 2020 to 2040. Here, an interaction between the limitation in land development drives up the housing price. However, it is not strong enough to prevent the housing price from declining due to the aging of the population between 2020 and 2040.

When further including the general productivity growth, the housing price always rises, with an annual growth of around 1.3% between 1960 and 2010. This shows that an interaction between the limitation of land development and general productivity growth is significantly stronger than the downward pressure of the Baby Boom and Bust on the housing price. This answers the second question.

Further, taking into account rising construction costs, I find that the housing price trajectory remains largely the same even though the aggregate structure value constitutes a large fraction of the aggregate house value, and the construction cost had an upward trend of around 0.6% per annum. The intuition is that a decline in the land price offsets rising construction costs, as rising construction costs reduce future demands for land and the land price is forward looking. The weaker future demands for land come from lower future demands for structure and low substitution elasticity between land and structure in producing housing services.

The sequence of adding the four factors does not affect the conclusion about their relative importance; the limitation in land development and the general productivity growth play the major roles in the housing price dynamics over the long term, whereas rising construction costs and the Baby Boom and Bust have limited effect. Thus, the first question is answered. Similar conclusions hold for the relative importance of these factors' effect on housing quantity as a fraction of GDP, as changes in housing demand manifest themselves through changes in housing price or housing quantity.

**Related literature** My paper belongs to a large literature that studies mechanisms of housing price dynamics,\(^3\) and is especially connected with those studying the impact of demographic structure on the national housing price. An influential paper by Mankiw and

---

Weil (1989) extrapolates a historical relationship between aggregate housing demand and the national real housing price, and predicts that the national real housing price would decline by 47% from 1987 to 2007 due to the aging of the population. While this prediction was later contradicted by the data, few studies examined the reason for the discrepancy quantitatively.\footnote{Several quantitative studies on demographic structure and social security (Attanasio et al. 2007, Krueger and Ludwig 2007 among others) do not take housing prices into account.} Borrowing the mechanisms shown in Abel (2001, 2003) and Geanakoplos et al. (2004), Martin (2006) argues that what is missing in Mankiw and Weil (1989) is an interest rate channel of change in demographic structure. The model in Martin (2006) has an endowment economy and fixed supply of assets, and its calibrated results predict a substantial decline of the housing price after 2010 due to the retirement of the Baby Boomers. The contribution of this paper is to examine the demographic effects on the housing price in a systematic way, by considering the interest rate channel, developing a production economy model and allowing for the housing supply to adjust endogenously.

By quantifying different factors’ effect on the long-term housing price trend, my paper contributes to the literature on the long-term dynamics of the housing market (Mankiw and Weil 1989, Davis and Heathcote, 2005, Glaeser et al., 2005, Shiller, 2005). A closely related paper is Davis and Heathcote (2005), which shows that a limited supply of land and slower productivity growth in the construction sector as opposed to the rest of the economy explain the upward trend of the national real housing price\footnote{They measure the national real housing price based on the Freddie Mac Conventional Mortgage Home Price Index deflated by the NIPA price index for Personal Consumption Expenditure. In addition, they compare the housing price trend in the model with the data only for the period between 1970 and 2001, as the index is not available before that.}. My paper differs from theirs by differentiating the quantitative impacts of the two channels and disciplining the housing supply side of the model to be consistent with the behaviors of constant-quality price and quantity indices of land and structure.

By decomposing housing prices into land and structure prices, my paper is connected with recent studies by Glaeser et al. (2005) and Davis and Heathcote (2007). Davis and Heathcote (2007) construct the first constant-quality price and quantity indices for the aggregate stock of residential land in the United States. In defining structure values, they do not remove the gap between developed land values and raw land values from residential fixed assets. Therefore, their indices effectively measure raw land, rather than developed land. In this paper, I remove the gap from residential fixed assets and make other adjustments accordingly.\footnote{See Section 3.1 and the Appendix for details.} In this way, I construct developed land indices. Given that developed land prices
are the selling prices faced by land developers and developed land quantities measure the output of the land development sector, these indices are crucial to quantify the endogenous land development process as described in my paper.

My paper also contributes to an active literature that examines the interaction between financing constraints and housing in general equilibrium. Favilukis et al. (2012) argue that shocks to financing conditions have significant impacts on the national housing price, while Kiyotaki et al. (2011) argue that financing shocks have a limited impact on the national housing price even though they have a significant effect on the homeownership rate. My paper contributes to this literature by studying the impact of borrowing constraints on the housing price dynamics in the long term. I find that by affecting the life cycle consumption of housing services and savings, borrowing constraints influence the impact of demographic structure on the national housing price but the effects are limited.

The paper is organized as follows: Section 2 describes the model. Section 3 parameterizes the model, which explains the construction of consistent data measures, presents the stylized facts of the housing market in the United States, and describes the calibration strategy. Section 4 documents the main results and sensitivity analysis. Section 5 offers some discussion about the model setting and implications of the model, and Section 6 concludes.

2 The Model

In this section, I describe the model, which includes four factors that affect housing dynamics in the long term. On the demand side, it allows population age structure to change and general productivity to grow over time. On the supply side, it features that land is scarce and productivity in the construction sector grows more slowly than the rest of the economy.

The economy of the model has two types of final goods: general goods and housing services. Housing services are produced by combining structures and developed land. General goods, structure and developed land are produced by separate technologies. Overlapping generations of households live in the economy, who live for a finite life of $T$ periods. In period $t$, households of population size $n_t^1$ are born in the economy, and $n_t^1$ changes over time.

2.1 Households

Households receive endowments of efficient labor units $\{e^a\}_{a=1}^T$ in a life cycle pattern: before a retirement age $T_R$, $e^a > 0$, and afterwards, $e^a = 0$. The superscript $a$ indicates the age of
the household.

Households consume both general goods and housing services. For a household aged \( a \) in period \( t \), the period utility function \( u(C^a_t, H^a_t) \) is represented by

\[
u(C^a_t, H^a_t) = \frac{(C^a_t)^\alpha (H^a_t)^{1-\alpha})^{1-\rho}}{1-\rho}, \tag{1}
\]

where \( C^a_t \) is the general goods and \( H^a_t \) is the housing services consumed by the household in period \( t \).

The flow of fund constraint of the household in period \( t \) is

\[
C^a_t + d_t H^a_t + B^a_t = w_t e^a + R_t B^a_{t-1},
\]

where \( d_t \) is the rental rate, \( B^a_t \) is the household’s investment in financial and real assets, and \( w_t \) is the wage rate in period \( t \). \( R_t \) is the gross return to asset in period \( t \). As I will focus on the perfect foresight equilibrium, all assets earn the same return.

Households cannot borrow and

\[
B^a_t \geq 0.
\]

I assume that housing services can be acquired only through rental contracts. This assumption recognizes the fact that in the real world, households can acquire housing services through a rental market, and is similar to the assumption used in Kiyotaki and Moore (1997), in which agents buy assets while their borrowing is limited by the present value of the remaining value of the assets – thus agents only need to finance the user cost of the assets from their net worth.

### 2.2 The General Goods Production Sector

Competitive firms produce general goods by combining capital \( K \) and labor \( N \), using a Cobb-Douglass production technology:

\[
\max_{\{K_t, N_t\}} \{(K_t)^\gamma (Z_t N_t)^{1-\gamma} - r_t K_t - w_t N_t\}, \tag{2}
\]

where \( Z_t \) is the labor productivity and \( r_t \) is the rental rate of capital.

Capital is transformed from general goods and depreciates at a rate \( \delta^K \). It is owned by households, and as the gross return to capital in period \( t \) is \( R_t \),

\[
r_t = R_t - (1 - \delta^K).
\]
The optimal choice of general goods producers is to equate the marginal value productivity of factors to their costs:

\[ \gamma \left( \frac{K_t}{Z_t N_t} \right)^{\gamma-1} = r_t, \]  
\[ (1 - \gamma) \left( \frac{K_t}{Z_t N_t} \right)^{1-\gamma} = w_t. \]  

(3) \hspace{1cm} (4)

2.3 The Construction Sector

Competitive firms in the construction sector transform general goods into structure and produce one unit of structure using \( p^S_t \) units of general goods in period \( t \).\(^7\) Structure depreciates at a rate \( \delta^S \).

2.4 The Land Development Sector

Measure one of identical firms develop land using the following technology:

\[ F^L(C^L_t; L_{t-1}) = A^L(L_{t-1})^\epsilon(C^L_t)^b, \]

where \( A^L \) is a constant controlling the productivity of land development, \( L_{t-1} \) is the aggregate developed land in period \( t - 1 \), \( C^L_t \) is the general goods used to developed land.

I assume \( \epsilon < 0 \) to capture the idea that land is scarce; with easier-to-develop and higher quality land being developed first, it becomes increasingly more costly to develop new land. Implicitly, I assume land is developed from developable/raw land and general goods using the following technology:

\[ F^L(C^L_t; L_{t-1}) = A^L(\bar{L} - L_{t-1})^\chi(C^L_t)^b, \]

where \( \bar{L} \) is the total developable land in the economy, and \( \chi > 0 \). \( \bar{L} - L_{t-1} \) captures the quantity of developable land left in the economy.

I assume a decreasing return to scale land development technology, with \( b < 1 \). This is consistent with the idea that the land supply in the short run is inelastic\(^8\) and implies that there is a profit for land development in a given period. In the background, I assume there

\^ An equivalent assumption is that competitive firms produce structure using a Cobb-Douglas production function \( (K_t^S)^\gamma (Z_t^S N_t^S)^{1-\gamma} \). Under this assumption, \( p^S_t = \frac{Z_t^S}{Z_t^S} \).

\^ If \( b = 1 \), the land price will be determined purely by land development productivity, which declines with the expansion of the developed land stock. This feature is inconsistent with the data: in some periods, the land stock continued to expand but the land price declined.
is a "span-of-control" model in the spirit of Lucas (1978), i.e., land development requires expertise, which has a limited supply, and the profit is the rent for such expertise. I do not model these for simplicity.

Individual land developers do not internalize the negative externality of today’s land development for future land development and maximizes their current profit:

$$\pi_t^L = \max_{\{C_t^L\}} \{p_t^L A^L (L_{t-1})^s (C_t^L)^b - C_t^L\}. \tag{5}$$

where $p_t^L$ is the land price.

The optimal input of general goods can be derived from the first order condition of (5) as

$$C_{t,s}^L = (bA_t^L) T^{-1} (p_t^L)^{-1} (L_{t-1})^r T^{-r} , \tag{6}$$

which suggests that the amount of land developed by the firm in a given period positively reacts to the land price and decreases with more land having been developed in the past.

Developed land does not depreciate and the aggregate quantity of developed land follows the following dynamics:

$$L_t - L_{t-1} = A^L (L_{t-1})^s (C_{t,s}^L)^b. \tag{7}$$

Land development firms are owned by households. I assume households own the firms through mutual funds, which also do not internalize the externality of land development. The total value of the land development firms is

$$V_t^L = \sum_{s=0}^{\infty} \frac{1}{\prod_{i=0} R_{t+i}} \pi_{t+s}^L,$$

where

$$\pi_{t+s}^L = (1-b)p_{t+s}^L A^L (L_{t+s-1})^s (C_{t+s}^L)^b.$$

### 2.5 The Housing Service Production Sector

A housing service producer buys structure from the construction sector and developed land from the land development sector. It produces housing services by combining aggregate structure $S_t$ and aggregate developed land $L_t$ using a Constant Elasticity of Substitution (CES) technology:

$$F^H(S_t, L_t) = (\phi(S_t)^{-p} + (1-\phi)L_t^{-p})^{-1/p}.$$
The housing service producer is owned by households and maximizes its value:

\[
V_t^H = \max_{\{S_t, L_t\}, s=0} \frac{1}{\prod_{i=0}^{s-1} R_{t+i}} \left\{ \sum_{s=0}^{\infty} \left[ d_{t+s} F_s^H(S_{t+s}, L_{t+s}) - p^L_{t+s}(L_{t+s} - L_{t+s-1}) - p^S_{t+s}(S_{t+s} - (1 - \delta^S)S_{t+s-1}) \right] \right\}.
\]

The first order conditions of (8) yield

\[
p^L_{t+s} - \frac{p^L_{t+s+1}}{R_{t+s}} = d_{t+s} \frac{\partial}{\partial L_{t+s}} F^H(S_{t+s}, L_{t+s}),
\]

\[
p^S_{t+s} - \frac{(1 - \delta^S)p^S_{t+s+1}}{R_{t+s}} = d_{t+s} \frac{\partial}{\partial S_{t+s}} F^H(S_{t+s}, L_{t+s}).
\]

These equations are intuitive: their left hand sides are the user costs of land and structure, which equal their marginal value productivity in the current period.

In the literature, there are two approaches of modeling the production of housing services by differentiating land and structure. The first approach assumes that new (residential) land is created every period, and new houses are produced by combining new land and structure using a Cobb-Douglass technology. Existing houses depreciate and cannot be demolished to reuse their land (Davis and Heathcote (2003) among others). The second approach makes the assumptions that the aggregate supply of land is fixed and can be reused every period; tangible assets are produced by combining land and structure and can be used either as capital to produce general goods or as houses to provide housing services (Kiyotaki et al. (2011)). I use a different set of assumptions such that the model can be calibrated to be consistent with the empirical regularity of the housing market in the United States; I will return to this point later.

### 2.6 Equilibrium

I define the perfect foresight equilibrium of the economy as a collection of prices \(\{R_t, w_t, p^L_t, p^S_t\}_{t=0}^\infty\), allocations \(\{(C^a_t, H^a_t, B^a_t)_{a=1,\ldots,T, t=0,\ldots,\infty}, (K_t, N_t, S_t, L_t, C^L_t, C^S_t)_{t=0,\ldots,\infty}\}\), and initial conditions \(\{R_0B^a_0, K_0, S_0, L_0\}\) such that:

1. \((C^a_{t+a-1}, H^a_{t+a-1}, B^a_{t+a-1})^T_{a=1}\) solves the optimal decision problem of a household born in period \(t\).
2. \((K_t, N_t)\) satisfy (3) and (4).
3. \(C^L_t\) satisfies (6).
(4) \((S_{t+s}, L_{t+s})_{s=0}^\infty\) satisfy (9) and (10).

(5) The following markets clear:

\[
\begin{align*}
\sum n_t^a C_t^a + C_t^L + C_t^S &= (K_t)^\gamma (Z_t N_t)^{1-\gamma} - (K_t - (1 - \delta^K) K_{t-1}) \text{ (general goods)}, \\
S_t - (1 - \delta^S)S_{t-1} &= \frac{C_t^S}{p_t^S} \text{ (structure),} \\
L_t - L_{t-1} &= A^L (L_{t-1})^\rho (C_t^L)^{b} \text{ (developed land),} \\
\sum a n_t^a H_t^a &= (\phi(S_t)^{-\rho} + (1 - \phi) L_t^{-\rho})^{-1/\rho} \text{ (housing services),} \\
\sum a n_t^a B_t^a &= K_{t+1} + V_t^L + V_t^H \text{ (fund),} \\
\sum a n_t^a e^a &= N_t \text{ (labor).}
\end{align*}
\]

(6) The population dynamics is internally consistent:

\[n_t^a = n_{t-a+1}^1.\]

**2.7 Thought Experiment**

I let the economy of the model receive two types of exogenous disturbances: demographic structure and productivity growth rates. Induced by these changes, the economy experiences a transition dynamics and after all the changes are completed, gradually settles to a steady state.

The existence of a steady state in the economy causes an issue. When the substitution elasticity between land and structure in producing housing services is not one, the economy has a steady state only if the general productivity growth rate takes a special value, taking other parameters of the economy as given.\(^9\) In this case, I choose the productivity growth rate of the economy to switch to the special value and stay constant afterwards such that the economy can gradually reach a steady state. Moreover, the time when the productivity growth rate switches is sufficiently far away from the period of interest such that my results are not sensitive to the time of the switch. The Appendix provides the detailed analysis about this issue.

I start computing the model from a chosen initial state in 1960. I assume that people become active in the economy at age 20, and choose the population size of people aged 20 to be consistent with the U.S. Census Bureau’s estimates from 1960 to 2010 and its projections

---

\(^9\)This is because a steady state can exist in these economies only if the land and structure prices have the same growth rates.
after 2010. The productivity growth rate of the economy stays constant from 1960 to 2260 and is equal to the average of its counterpart in the data between 1960 and 2010, and switches to a special value\textsuperscript{10} consistent with the existence of a steady state after 2260. The economy reaches a steady state in 2460.

The Appendix contains the detailed characterization of the transition dynamics.

3 Parameterization

To parameterize the model, I first align the data to their model counterparts, following the methodology of Cooley and Prescott (1995). To be consistent with the assumption in the model that land and structure are homogeneous, I construct constant-quality price and quantity indices of land and structure by extending the seminal work of Davis and Heathcote (2007). In this section, I first describe the data construction, whose details, as well as a comparison between my indices and those constructed by Davis and Heathcote (2007), can be found in the Appendix. Then, I show the empirical regularity of the constructed housing indices and describe the strategy to calibrate the model, part of which is based on these indices.

3.1 Defining Consistent Measurements

Consistent with the methodology of Cooley and Prescott (1995), I define capital as the sum of private non-residential fixed assets, inventories, consumer durable goods and the government non-defense capital. The general goods include non-durable consumption goods, services and imputed service flows from durable goods and government non-defense capital. Both are constructed from the National Income and Product Account (NIPA) of the United States for the period between 1960 and 2011.

I construct consistent measures in the housing sectors as follows: I define the constant-quality structure price index as the RS Means historical construction cost index from 1960 to 2011. As a construction cost information provider, RS Means develops the index by estimating the sum of labor costs and material costs for the construction of a hypothetical building.\textsuperscript{11} The constant-quality structure quantity index is defined as aggregate structure value divided by the constant-quality structure price index.

\textsuperscript{10}The value is 0.3\% in my baseline calibration.

\textsuperscript{11}Davis and Heathcote (2007) define the structure price using the price index of gross investment in new residential structure determined by the Bureau of Economic Analysis. I do not use this index because it is an weighted average of the developed land price and the construction cost. See the Appendix for details.
Aggregate structure value is defined as the replacement cost of residential fixed assets excluding broker fees and land development costs from the Fixed Asset Tables (FAT) as determined by the Bureau of Economic Analysis (BEA) for the period between 1960 and 2011. I exclude broker fees from residential fixed assets, following Davis and Heathcote (2007). As argued by them, including broker fees in residential fixed assets is a conceptual flaw, and the structure value of a house does not change with the house being sold several times. Land development costs are defined as the gap between developed land values and raw land values, which are counted as part of the residential fixed assets by the BEA.

The challenge for removing land development costs from residential fixed assets comes from the fact that in compiling the FAT, the BEA does not provide a breakdown of residential fixed assets which can be used to directly identify land development costs. I exploit the idea that including the land development cost (which does not depreciate over time) into the structure value leads the overall depreciation rate to be lower than the structure depreciation rate, with the gap between the two depreciation rates reflecting the land development cost as a fraction of the residential fixed asset. I can solve an equation system using available data to remove land development costs from residential fixed assets. The Appendix provides the details.

To define the constant-quality land price index, I follow the procedure of Davis and Heathcote (2007). Note that for a Laspeyres-type housing price index, the following relationship holds

\[
\frac{p_{t+1}^{\text{Laspeyres}}}{p_{t}^{\text{Laspeyres}}} = \theta_t^{L} \frac{p_{t+1}^{L}}{p_{t}^{L}} + (1 - \theta_t^{L}) \frac{p_{t+1}^{S}}{p_{t}^{S}},
\]

where \( \theta_t^{L} \) is the land share, \( p_t^{L} \) is the land price index, and \( p_t^{S} \) is the structure price index in period \( t \). Then, \( \{p_t^{L}\}_t \) can be backed out from \( \{p_t^{\text{Laspeyres}}, p_t^{S}, \theta_t^{L}\}_t \).

For the period after 1975, following Davis and Heathcote (2007), the Laspeyres index \( \{p_t^{\text{Laspeyres}}\}_t \) is defined as the Federal Housing Finance Agency (FHFA) repeated sales index. As argued by Davis and Heathcote, for the houses whose values form the basis of the FHFA index, the renovation and the depreciation of their structures largely cancelled each other and hence the FHFA index is a good proxy of the Laspeyres index. The structure price index \( p_t^{S} \) is previously defined. The land share \( \theta_t^{L} \) is defined as one minus the aggregate structure value as a fraction of the aggregate house value in period \( t \). Aggregate house values are defined below.

For the period before 1975, because the FHFA index is not available, I use a second procedure to construct the land price index. The idea comes from Davis and Heathcote (2007).
By assuming a parametric form of \( \{p_t^{\text{Laspeyres}}\} \), aggregate house values can be represented as functions of the unknown coefficients of the parametric form. The coefficients can be solved by equating those aggregate house values in census years to the aggregate house values constructed based on the Decennial Census of Housing and the Residential Finance Survey. The Appendix provides the details.

The constant-quality land quantity index is defined as aggregate land value divided by the constant-quality land price index. Aggregate land value is defined as aggregate housing value minus aggregate structure value.

To define aggregate housing values, I follow Davis and Heathchote (2007), who construct them in Census years based on the Decennial Census of Housing and the Residential Finance Survey and in other years using a perpetual inventory method. They argue that such a construction is better than using aggregate housing values from the Flow of Funds, whose method of construction is not consistent over time.

The constant-quality housing price index is measured by the Federal Housing Finance Agency’s repeated housing price index between 1975 and 2011, and before 1975, by the Laspeyres-type index whose construction was previously explained. The constant-quality housing quantity index is defined as aggregate housing value divided by the constant-quality housing price index.

### 3.2 Stylized Facts of the United States Housing Markets

In this section, I demonstrate the dynamics of the constant-quality price and quantity indices of housing, land and structure. I also show how demographic structure and general productivity change in the data. Moreover, I document that housing consumption expenditures as a fraction of total expenditures were quite stable historically.

Figure 1 plots the constant-quality price and quantity indices of housing, land, and structure from 1960 to 2011 in the United States. The dotted line in Figure 1(A) describes the real housing price index. We observe an upward trend of about 1.32% in annual growth, which was interrupted by a boom and bust cycle starting in 2000. The dashed line in Figure 1(A) describes the constant-quality structure price index. We observe that the index rose on average by 1.01% per annum from 1960 to 2011, perhaps due to a gap in the productivity growth rate between the construction sector and other sectors.\(^{12}\) The solid line in Figure

\(^{12}\)Davis and Heathcote (2003) calculate that the construction sector’s total factor productivity growth rate was slightly negative between 1950 and 2000, while the total factor productivity of the rest of the economy grew at around 1.64%.
1(A) is the constant-quality land price index, which has an even steeper upward trend of 1.71% average annual growth rate. Together, the long-term price trends have the following relationship:

\[ 0 < \text{trend}_{\text{structure price}} < \text{trend}_{\text{housing price}} < \text{trend}_{\text{land price}}. \]

The dotted line of Figure 1(B) describes the quantity indices of housing, land and structure as fractions of real GDP. The three indices lag the real GDP and the long-term quantity trends have the following relationship:

\[ \text{trend}_{\text{land stock}} < \text{trend}_{\text{housing stock}} < \text{trend}_{\text{structure stock}} < \text{trend}_{\text{real GDP}}. \]

As the growth rate of asset value equals the sum of the growth rates of asset quantity and price, the long-term value trends have the following relationship:

\[ \text{trend}_{\text{real GDP}} < \text{trend}_{\text{structure value}} < \text{trend}_{\text{housing value}} < \text{trend}_{\text{land value}}. \]

Consistent with the relationship of the value trends, Figure 2(A) shows that the aggregate values of housing, structure, and land as fractions of the real GDP all increased from 1960 to 2011. Aggregate housing value was around 106% of real GDP in 1960 and 136% in 2011. From 1960 to 2011, the aggregate structure value as a fraction of real GDP increased from 72.2% to 89.8%, and the aggregate land value as a fraction of real GDP increased from 34.3% to 46.8%. Figure 2(B) shows that the land share rose before the recent crash. The land share was 32.2% in 1960, climbed to more than 53.0% in the recent decade and crashed to 34.3% in 2011. Figure 2(C) suggests that on average, houses become increasingly structure intensive, as the ratio of aggregate structure quantity to aggregate land quantity increases over time.

Figure 3 shows some stylized facts about the demand side of the housing markets in the United States. Figure 3(A) shows a strong boom and bust cycle of the population of people aged 20.\(^{13}\) It is easy to identify the hump as the Baby Boom generation born between 1945 and 1964, who entered into their 20s in the period between 1965 and 1984. Figure 3(B) plots the total factor productivity with the utilizations of capital and labor adjusted, constructed from the data created by Fernald and Natsuki (2012). It shows that productivity

\(^{13}\)I choose to plot population of people aged 20, because in the model, households enter the economy at age 20.
growth in the United States was relatively slow between 1975 and 1995 and accelerated after 1995 until a slowdown during the recent recession. Finally, Figure 3(C) shows that the housing consumption expenditures as a fraction of total consumption expenditures has been quite stable over time. This supports my choice of the Cobb-Douglass utility function for general goods and housing services. It suggests that with general productivity growth, people demand more housing services.

3.3 Calibration

I calibrate the parameters of the model by choosing one period to be five years. For parameters calibrated inside the model, I match first moments in the transition dynamics of the economy of the model to their counterparts in the data.\textsuperscript{14}

3.3.1 Land Development Technology

To determine the land development technology

\[ F^L(C^L_t, L_{t-1}) = A^L(L_{t-1})^\epsilon(C^L_t)^b, \]

I need to calibrate \( A^L \), \( \epsilon \) and \( b \).

From the land developer’s first order conditions (6) and (7),

\[ \ln(L_t - L_{t-1}) = \ln(b^{\frac{b}{1-b}}N^L(A^L)^{\frac{1}{1-b}}) + \frac{b}{1-b}\ln(p^L_t) + \frac{\epsilon}{1-b}\ln(L_{t-1}). \quad (11) \]

One way to estimate \( b \) and \( \epsilon \) is to regress \( \ln(L_t - L_{t-1}) \) on \( \ln(p^L_t) \) and \( \ln(L_{t-1}) \). However, the multicollinearity does not allow me to do so, as the coefficient of correlation between \( \ln(p^L_t) \) and \( \ln(L_{t-1}) \) is as high as 0.8498. As an alternative, if the value of \( b \) is known, one can estimate \( \epsilon \) through the regression of \( \ln(L_t - L_{t-1}) - \frac{b}{1-b}\ln(p^L_t) \) on \( \ln(L_{t-1}) \). Unfortunately, there is no data source to specifically determine \( b \).

To deal with this issue, I determine a range of \( b \) based on surveys done by the National Association of Home Builders (NAHB). Then, I choose a value of \( b \) in this range as my baseline calibration and perform robustness tests for other possible values of \( b \) later.

\textsuperscript{14}As will be seen soon, the calibrated value of the substitution elasticity between land and structure in producing housing services is not one, which implies that the economy of the model does not have a steady state except that the general productivity growth rate and the population growth rate have a special relationship. It turns out that the relationship does not hold for the average population growth rate or the average productivity growth rate from 1960 and 2011. Therefore, it is not possible to calibrate the parameters using a steady state.
The lower bound of $b$ is set to be 0.299, based on a survey done in 2004 by NAHB for home builders about the breakdown of land development cost. This value is consistent with the ratio of the total value of the cost categories that should be treated as general goods as a fraction of the developed land value.\footnote{These categories include site preparation, site improvement, water/electric hook-up, tree preservation and planting, and wetland preservation and planting.}

The upper bound of $b$ is set to be 0.564, based on the idea that as a part of the developed land value, raw land value should not be counted as the land development input of general goods. According to the National Association of Home Builders (NAHB), the developed land value as a fraction of new home sales value was stable at about 23.4% since 1969. A memorandum of the United States Census suggests that the raw land value as a fraction of new home sales value is 10.4%.\footnote{This is an unpublished memorandum sent from Dennis Duke to Paul Hsen in 2000. It is cited as supportive evidence for data construction in Davis and Heathcote (2007).} Therefore, $b$ should be smaller than $1 - \frac{10.4\%}{23.4\%} = 0.564$.

Then, I choose $b = 0.564$ in my baseline calibration. To estimate $\epsilon$, I regress $\ln(L_t - L_{t-1}) - \frac{b}{1-b} \ln(p^L_t)$ on $\ln(L_{t-1})$. If the equation (11) holds exactly in the data, this regression should give the coefficient exactly as $\frac{\epsilon}{1-b}$. However, this should not be true, because agents have perfect foresight about future states in the economy of the model, whereas in the data, both the land and structure prices may be affected by unexpected shocks.\footnote{As an example of this discrepancy, the user costs of land should always be positive in an economy with perfect foresight. However, the user costs of land in the period between 1974 and 1979 in the data were negative due to a strong appreciation of housing prices. Topel and Rosen (1984) discuss the negative implicit rent in this period.} As a consequence, the estimates may be biased due to measurement errors caused by unexpected shocks.

To reduce measurement errors due to unexpected shocks, I estimate (11) using the trend components of the variables and obtain the trend components using the Hodrick-Prescott (HP) filter with the multiplier $\lambda$ equal to 1600. If the measurement errors of the trend components are orthogonal to the trend components and each other, they lead to downward biases of the estimates. I assume these hold in my data and run two regressions with the dependent variable and the independent variable switched. In this way, I can get a range which bounds $\frac{\epsilon}{1-b}$. The corresponding range of $\epsilon$ is $[-0.750, -0.743]$\footnote{I find that the range of $\epsilon$ is not sensitive to whether I use the trend components of the variables or the variables themselves. As both the land price and quantity grow over time, the relationship between $\ln(L_t - L_{t-1}) - \frac{b}{1-b} \ln(p^L_t)$ and $\ln(L_{t-1})$ is not far from being linear.}. I choose $\epsilon = -0.750$ as my baseline calibration, and find that the results are not sensitive to choosing other values of $\epsilon$ in the range.

For $A^L$, I choose its value such that the land quantity growth from 1960 to 2010 in the transition dynamics matches its data counterpart.
3.3.2 Housing Service Production Technology

To determine the housing service production technology

\[ F^H(S_t, L_t) = (\phi(S_t)^{-\rho} + (1 - \phi)L_t^{-\rho})^{-1/\rho}, \]

I need to calibrate two parameters: \( \phi \) and \( \rho \).

I exploit the housing service producer’s first order conditions (9) and (10), which imply

\[
\ln\left( \frac{p_t^L - \frac{p_{t+1}^L}{R_t}}{p_t^S - \frac{1}{(1-\delta)p_{t+1}^S}} \right) = \ln\left( \frac{1 - \phi}{\phi} \right) + (1 + \rho) \ln\left( \frac{S_t}{L_t} \right). \tag{12}
\]

By regressing \( \ln\left( \frac{p_t^L - \frac{p_{t+1}^L}{R_t}}{p_t^S - \frac{1}{(1-\delta)p_{t+1}^S}} \right) \) on \( \ln\left( \frac{S_t}{L_t} \right) \), I can get the intercept as \( \ln\left( \frac{1 - \phi}{\phi} \right) \) and the coefficient as \( 1 + \rho \). Similar to the estimation of the land development technology, to reduce measurement errors due to unexpected shocks, I estimate (12) using the trend components of the variables and obtain the trend components using the Hodrick-Prescott (HP) filter with the multiplier \( \lambda \) equal to 1600. By assuming that the measurement errors of the trend components are orthogonal to the trend components and each other, they lead to downward biases of the estimates. I run two regressions with the dependent variable and the independent variable switched. In this way, I can get a range which bounds \( \rho \).

The estimation yields the range that bounds \( \rho \) as [3.54, 3.77],\(^\text{19}\) and \( \phi \) can be calculated from the corresponding intercept. I choose \( \rho = 3.54 \) and \( \phi = 0.799 \) as my baseline calibration, and try other values of \((\rho, \phi)\) as robustness tests.

3.3.3 Transformation Costs

I calibrate transformation costs \( \{p_t^S\} \) such that they match the long-term trend of the RS Means historical construction cost index. Figure 6 shows the construction cost index and its long-term trend.

3.3.4 Other Parameters

I choose the capital share in general goods production as 0.290 to match the share of capital income in GDP excluding housing services. The standard parameter in the literature is

\(^{19}\)I find that the range of \( \rho \) is sensitive to whether I use the trend components of the variables or the variables themselves. If I use the variables themselves, I will estimate the range of \( \rho \) as [8.0, 72], with the upper bound being implausibly large.
between 0.3 and 0.4. My value is smaller as I separate the housing stock from capital. Kiyotaki et al. (2011) use 0.258 based on their assumption that durable goods are part of the housing stock, whereas I treat durable goods as part of capital.

I choose the depreciation rate of capital as 0.0717 to be consistent with the ratio of the consumption of fixed capital to capital. The depreciation rate of structure is set to be 0.0167, which is obtained in the process of removing the land development cost from residential fixed asset. The details can be found in the Appendix. Davis and Heathcote (2003) use 0.014. The difference may come from the fact that their definition of structure includes the land development cost, which does not depreciate over time and the inclusion of which leads to lower overall depreciation rate.

For household preferences, I calibrate the share of housing services in the utility function such that the average ratio of aggregate housing value to GDP from 1960 to 2010 matches its data counterpart. This gives the value as 0.085, which is lower than values used in other studies. Li and Yao (2007) use 0.2 based on the average share of housing expenditure found in the 2001 consumption expenditure survey. Jeske et al. (2012) choose 0.141 to match the share of housing in total consumption expenditures in the NIPA data. As I use a broader definition of consumption, which includes the government consumption and services flow from the government asset, the share of housing in total consumption expenditures is 0.112. As a robustness test, I set the share of housing services in the utility at this value, recalibrate the model and find that with the exception that the ratio of the aggregate housing value to GDP becomes higher than the data, the results remain largely unchanged.

I choose the discount rate $\beta$ such that the average return to capital from 1960 to 2011 matches its data counterpart. This gives the value of 0.758, which amounts to an annual discount rate of 0.946. I choose the risk-aversion coefficient $\sigma = 1$, and the results are not sensitive to choosing $\sigma$ to be other values.

Households’ life cycle endowments of efficient labor units are interpolated from the values reported by Hansen (1992). For simplicity, I use average efficient labor units of men and women, without taking into account the difference in their labor market participation rates. Figure 6 plots the life cycle labor endowments of efficient labor units. In an economy in which the population size is constant across age groups, this life cycle pattern implies that the ratio of mean income of 41- to 60-year-olds to the mean income of 21- to 40-year-olds to be 1.18, which is slightly lower than the value 1.3 used by Kiyotaki et al. (2011), which is based on the evidence from the Panel Study of Income Dynamics. I find that the model results are insensitive to a change of this ratio. As a summary, Table 1 lists the values for
4 Results

4.1 Model Performances

Model outputs are compared to the stylized facts presented in Section 3. I define housing price and quantity in a manner consistent with the data construction. Aggregate housing value is defined as the sum of the aggregate land value and the aggregate structure value. The housing price is defined through a Laspeyres index. Let $p_{t}^{H}$ be the housing price in period $t$, and I choose an arbitrary period $t_0$ to set $p_{t_0}^{H} = 1$. Change in housing prices from period $t$ to period $t + 1$ is defined as:

$$\frac{p_{t+1}^{H}}{p_{t}^{H}} = \frac{\theta_{t}^{L} p_{t+1}^{L}}{p_{t}^{L}} + (1 - \theta_{t}^{L}) \frac{p_{t+1}^{S}}{p_{t}^{S}},$$

where $\theta_{t}^{L}$ is the ratio of the aggregate land value to the aggregate housing value, $p_{t}^{L}$ is the land price, and $p_{t}^{S}$ is the structure price in period $t$. The aggregate housing quantity is defined as the aggregate housing value divided by the housing price.

The model output of prices and quantities of housing, land and structure, land share, the ratio of structure quantity to land quantity, and aggregate values of housing, land and structure relative to GDP are compared to the data. Figure 6(A1) shows that the housing price generated by the model has an upward trend, which traces its data counterpart well. Suppose that the housing price was exactly on the trend implied by the model in year 1960, it deviated from the trend significantly after the housing price boom in the late 1970s, and slowly came back to the trend in 2000. The recent boom and bust cycle was significantly above the trend. After the recent crash, the housing price in 2010 was close to the trend, and the trend will reach the recent peak of the housing price only three decades later.

Figure 6(A2) suggests that the model generates a decline in the ratio of housing quantity to real GDP consistent with the data. The two agree with each other particularly well in recent decades. Figure 6(A3) shows that the aggregate house value relative to GDP increases from 1960 to 2010 in the economy of the model, which is close to its data counterpart. The average ratio of aggregate house value to GDP is the same with its data counterpart, due to the calibration of the share of housing services in utility function.

Figure 6(B1) and (B2) suggest that the model generates land prices and quantities similar to the data counterparts. Figure 6(B3) shows that aggregate land value increases
significantly faster than the GDP in the economy of the model, in a way consistent with what we observe in the data.  

Finally, Figure 6(C1) to (C3) compare prices, quantities and values of structures with the data, and show that their movements are broadly consistent with the data counterparts.

Figure 7 compares the land shares and the ratios of structure quantities to land quantities in the model to their data counterparts, which suggests that the model captures the upward trends of both. Overall, Figure 6 and 7 suggest that the model is broadly consistent with the secular trends of the housing market.

The performances of the model in matching the joint dynamics of prices and quantities of housing, land and structure in the long term are crucially dependent on the substitution elasticity between land and structure in producing housing services, which is substantially lower than one. In the sensitivity analysis, I find that the model performance deteriorates when the substitution elasticity approaches one.

By calibrating the substitution elasticity between land and structure in producing housing services directly from the data, I extend the existing approaches of modeling the housing services production by differentiating land and structure decomposition (Davis and Heathcote, 2003 and Kiyotaki et al., 2011). The existing approaches tend to have this parameter implied by other assumptions. The implied value then may not be consistent with the data. For example, Davis and Heathcote (2003) assume that existing houses cannot be demolished and new houses are produced by combining raw land and structure using a Cobb-Douglass production function, where the land share is around 10%. Then, such a low land share implies too large a substitution elasticity between land and structure in producing housing services. I find that if I take Davis and Heathcote’s assumptions in my model, the trends of the housing price and the ratio of housing quantity to GDP are both flatter than the data counterparts.

4.2 Quantifying the Drivers of the Long-Term Trends in the Housing Market

I study the relative importance of the four factors in affecting long-term trends in the housing market: land scarcity, slower productivity growth of the construction sector relative to the

---

20 I choose the initial state in 1960 such that the land share in 1960 is the same as the counterpart in the data. The Appendix explains the choice of the initial state.

21 This assumption helps avoid the real option problem of re-using existing land.

22 They choose 10.6% to match the average raw land share in house value, according to a memorandum of the United States Census. See footnote 16 for details.
rest of the economy (the construction cost channel hereafter), general productivity growth and the Baby Boom and Bust cycle.

I carry out a series of experiments in which I first shut down all four factors and then add them back one by one. To shut down land scarcity, I set $\epsilon = 0$. I set the productivity of the construction sector equal to the rest of the economy to shut down the construction cost channel. By setting general productivity to be constant over time, the general productivity growth is shut down. Finally, I assume the population size of people aged 20 grows at a constant rate between 1960 and 2010 (Figure 8), so that the effects of the Baby Boom and Bust are eliminated.

The first experiment is designed to study the prediction by Mankiw and Weil (1989) that the housing price would experience a substantial decline from 1987 to 2007. They argue that the entry of the Baby Boom generation into their prime home-buying years caused the housing price to increase in the 1970s, which would reverse with the the Baby Bust generation being active in the economy. I set the interest rate of the economy of the model be fixed at 6.43%, i.e., making the economy a small open economy. I first shut down all four factors and then add the Baby Boom and Bust.

The solid line in Figure 9(A) describes the housing price path if all four factors are shut down, and the dashed line in Figure 9(A) represents the housing price trajectory if the Baby Boom and Bust is present in the economy with the other three factors being shut down. Their gap measures the impact of the Baby Boom and Bust on the housing price. We observe that due to the Baby Boom and Bust, the housing price increases from 1960 to 1980 and reverses afterwards. While the timing of the housing price changes is broadly consistent with Mankiw and Weil (1989)’s prediction, their magnitude is tiny. From 1980 to 2040, the decline is smooth and around 0.07% per annum.

In the second experiment, I study Martin (2006)’s critique on Mankiw and Weil (1989). As the savings demands of the Baby Boomers can push up housing prices in their middle age, referred to as the savings channel of the Baby Boom and Bust, Martin argues that this channel may explain why Mankiw and Weil (1989)’s prediction is inconsistent with the data, as the housing price actually increased between 1987 and 2007. Using a representative agent framework, Martin (2006) does not account for the interaction between population age

---

23 After I shut down the four factors, the housing price path may not be flat as the population grows slowly; the weak fluctuation is attributed to the demographic structure change, as I calibrate the population age structure in the initial state to be consistent with the 1960 census.

24 The "Baby Boom" refer to Americans born between 1945 and 1964. If one defines the middle-aged period as ages between 40 and 60, the middle-aged period of people who were born in 1955 is between 1995 and 2015.
structure and the life cycle savings, which is critical to quantify the timing and magnitude of the savings channel of the Baby Boom and Bust. In contrast, my model considers such interaction. To study Martin’s critique, I let the economy of the model be a closed economy and study the effect of the Baby Boom and Bust on the housing price.

The gap between the solid and dashed lines in Figure 9 (B) measures the impact of the Baby Boom and Bust on the housing price in the closed economy of the model; that impact amounts to 0.12% increase per annum from 1960 to 2010. The gap between the solid and dashed lines in Figure 9 (D) measures the impact of the Baby Boom and Bust on the interest rate in the closed economy, and we observe that the Baby Boom and Bust drives up the interest rate before 2000 and reduces it afterwards.

These patterns support Martin (2006)’s critique. However, even considering this channel, the impact of the Baby Boom and Bust on the housing price is still quite limited, with the decline from 2010 to 2040 being around 0.25% per annum.\footnote{Note that the housing price and interest rate cycles are asynchronous, with the peak of the housing price being around 2000 and the bottom of the interest rate being close to 2020. This comes from the fact that the housing price is forward looking and factors into the anticipated reversal of the interest rate. See Geanakoplos et al. (2004) for a discussion on this point. They show that due to this mechanism, the Baby Boom and Bust also affects the term structure, with the short-term rate being higher than the long-term rate in the declining phase of the short-term rate, and the opposite in the ascending phase of the short-term rate.}

In the third experiment, I add land scarcity into the economy. The solid line in Figure 10 (A) describes the housing price path in the case in which only the Baby Boom and Bust is present, and the dashed line in Figure 10 (A) represents the housing price trajectory if both the Baby Boom and Bust and the land scarcity are present, with the other two factors being shut down. Figure 10 (C) shows the corresponding paths of the land price. It can be observed that when the land scarcity is present, there are long-term upward trends of housing and land prices. However, there are still slow declines of both between 2020 and
2040, which is around 0.2% per annum.

In the fourth experiment, I further add general productivity growth into the economy. The solid line of Figure 10 (B) describes the housing price path if only the Baby Boom and Bust and land scarcity are present, and the dashed line of Figure 10 (B) represents the housing price trajectory if the general productivity growth is also present. Figure 10 (D) shows the corresponding paths of land price. The dashed line suggests that an interaction between land scarcity and general productivity growth dominate the Baby Boom and Bust, as the housing price continues to rise over time. Such an interaction strongly influences the land price, as shown in Figure 10 (D), and with the presence of the general productivity growth, the increase of the land price from 1960 to 2010 rises from around 80% to around 250%.

In the fifth experiment, I add rising construction costs to the economy. The solid and dashed lines in Figure 11 (A) describe the housing price paths with the rising construction cost channel shut down and being present. It can be observed that the construction cost has little impact on the housing price. This is counter-intuitive as the structure value constitutes more than half of the housing value, and the construction cost had an upward trend of 0.6% from 1960 to 2010. This can happen only if there is a decline in land share or a slowdown in the land price appreciation rate simultaneously. Because the housing price appreciation rate is the weighted average of the appreciation rates of the land price and the construction cost and the land price appreciates faster than the construction cost, either may offset rising construction costs’ impact on the housing price.

Figure 11 (B) and (C) suggest that the decline in land share plays the major role in offsetting rising construction costs’ impact on the housing price. The solid and dashed lines of Figure 11 (B) describe the land shares with and without the rising construction cost. It is observed that the gap between them is around 10%. As the gap between the growth of the land price and the construction cost from 1960 to 2010 is around 200%, a 10% decline in the land share drives down the housing price increase by 20%, which is close to the positive impact of the rising construction cost on the housing price. Figure 11 (C) shows the land price paths with and without the rising construction cost, from which we observe that the land price appreciation rate is not sensitive to whether the construction cost is rising.

The decline in the land share comes from the low substitution elasticity between land and structure in producing housing services, which implies that future demands for land will decline when the rising construction cost drives down future demand for structures. As the land price is forward looking, the current land price drops and as a consequence, the land
share declines.

From these experiments, we learn that general productivity growth and land scarcity play the major roles in housing price movements in the long term. In contrast, the Baby Boom and Bust and rising construction costs have limited impacts. I find that this conclusion does not depend on the sequence of adding the four factors.

As changes in the demand for housing services manifest them through either changes in housing price or housing quantity, we expect that land scarcity and general productivity growth have stronger impacts on housing quantity than the other two factors. To study this, I run four experiments in which each factor is shut down separately, and Figure 12 describes the dynamics of the ratio of the housing quantity to GDP in these experiments. The patterns in Figure 12 suggest that without land scarcity, the decline in housing quantity relative to GDP from 1960 to 2010 would have been around half of what we observe in the data; without the general productivity growth, the housing quantity barely declines relative to GDP; without the Baby Boom and Bust or rising construction costs, the decline of the ratio of the housing quantity to GDP would have been similar to the data.

4.3 Sensitivity Analysis

As the available data can only determine ranges for the parameters of the land development and housing service production technologies, I study whether my results are sensitive to these parameter values.

I first analyze whether the model performances are sensitive to the output elasticity of general goods in developing land. Recall that the land development technology takes the form

\[ F^L(C_t^L; L_{t-1}) = A^L(L_{t-1})^\epsilon(C_t^L)^b. \]

In the calibration, I determine that the output elasticity of general goods in developing land \( b \) should fall into the range of \([0.299, 0.564]\).

To do the sensitivity analysis, I choose the values of \( b \) ranged from 0.1 to 0.6 with the increment being 0.1, and recalibrate other parameters based on the calibration strategy.\(^{26}\) I find that in the recalibration, the absolute value of \( \epsilon \) declines and other parameter values do not change when \( b \) increases. Table 2 lists the combinations of \((b, \epsilon)\).

Figure 13 shows the performance of the model in matching the stylized facts in Figure 1 and 2 for different values of \( b \). We observe that the model performance is quite insensitive to

\(^{26}\)I choose \( \epsilon \) as the middle of the estimated range. The estimated ranges of \( \epsilon \) are narrow, and the results are similar if I choose the left end of the range of \( \epsilon \).
different \((b, \epsilon)\) combinations. This pattern comes from the following interaction between land scarcity and the decreasing return to scale land development technology. Suppose a growth in aggregate demand for housing services drives up aggregate land quantity. Land scarcity then drives down the land development productivity. As a consequence, a larger amount of input is needed to develop land to meet the growing demand for land, which further drives down the marginal productivity of general goods in land development, due to the decreasing return to scale. Therefore, either a strong land scarcity represented by a large absolute value of \(\epsilon\), or a strong decreasing return to scale represented by a small \(b\), may have the same quantitative effects of driving up land development costs when there is a growth in demand for housing services.

I also find that the relative importance of the four factors are insensitive to the values of \(b\), and the intuition is the same as above: because the role of the land scarcity in driving up the land price comes from an interaction between land scarcity and the decreasing return to scale technology, this interaction can be quantitatively similar for different combinations of \((b, \epsilon)\).

I also study whether the model performance is sensitive to the substitution elasticity of land and structure in producing housing services. Recall that I determine the range of the elasticity \(\rho\) as \([3.54, 3.77]\). To do the sensitivity analysis, I recalibrate the model by changing the value of \(\rho\) from 1 to 5.

Figure ?? plots the model performance in matching the stylized facts in Figure 1 and 2 for different values of \(\rho\). It shows the quantitative results are not sensitive to values of \(\rho\) in the range of \([3.54, 3.77]\). However, when \(\rho\) is close to 0, the performance deteriorates. For example, Figure ?? (A1) shows that the housing price trend is significantly below the data counterpart, and Figure ?? (C2) suggests that structure quantity as a fraction of GDP declines less than the data. I also find that the relative importance of the four factors is not sensitive to the value of \(\rho\) in the range of \([3.54, 3.77]\).

5 Discussion

Demographic structure in the United States is also affected by a long-term decline in mortality risk. I add this feature into the model to study its implications on the housing market dynamics. Several studies explore the implications of borrowing constraints and land shares for housing price dynamics (Kiyotaki et al. (2011), among others). Connected with them, I discuss how the level of borrowing constraint may affect long-term housing price movements.
in the economy of the model. In addition, I discuss the driving force behind the upward trend of land shares (Figure 7).

5.1 Declining Mortality Risk

Figure 15 plots the age-dependent mortality risk in 1960 and 2010 and its projected values in 2050. The mortality risk at age \( a \) is defined as 1 minus the probability of survival at age \( a + 1 \) conditional on being alive at age \( a \). The Figure suggests that the mortality risk declines substantially from 1960 to 2010 and is projected to further decline in the following four decades. When people live longer, the lower mortality risk encourages them to save more for old age, which may have an impact on long-term housing price trends. To understand the role of declining mortality risk on housing trends, I extend the model by changing the assumption about household preferences.

In the extended model, households face time varying mortality risk \( \pi_t^a \), and if a household aged \( a \) in period \( t \) dies in the end of the period, he has a positive utility from leaving bequests to other households:

\[
\eta \left( \frac{(M_{t+1}1_{\{M_{t+1} > 0\}})^{1-\rho}}{1-\rho} \right).
\]

The government transfers the bequests of households who die in the previous period to all surviving and newly born households equally in a lump sum.

Then, the households’ decision problem can be written recursively as:

\[
V_t(W_t^a, a) = \max_{(C_t^a, H_t^a, B_t^a)} \{ u(C_t^a, H_t^a) + \beta[(1-\pi_{t+1}^a)V_{t+1}(W_{t+1}^a, a+1) + \pi_{t+1}^a \eta \left( \frac{(M_{t+1}1_{\{M_{t+1} > 0\}})^{1-\rho}}{1-\rho} \right)] \}
\]

s.t. \( C_t^a + d_t H_t^a + B_t^a = W_t^a \),

\( W_{t+1}^a = w_{t+1}e^{a+1} + R_{t+1}B_t^a + Tr_{t+1} \),

\( M_{t+1} = R_{t+1}B_t^a \),

\( B_t^a \geq 0 \),

where the transfer \( Tr_t \) is determined by

\[
Tr_t = \frac{1}{\sum_{a=1}^{T} n_t^a} \sum_{a=1}^{T} n_t^a R_{t-1}B_{t-1}^a \pi_{t-1}^a.
\]

Adding mortality risk introduces additional parameter \( \eta \) to determine. I choose \( \eta \) such
that the ratio of the average net worth of people older than 70 to the average net worth of people below the age of 35 matches the data counterpart from the Survey of Consumer Finance 1995. Since the incentive of people to save is sensitive to their bequest motive, $\eta$ can be precisely pinned down as 3.3. I find that housing price movements are quite insensitive to whether a long-term decline in the mortality risk is included in the model.

5.2 Borrowing Constraints

Several studies explore the impact of financial shocks on housing price movements. Kiyotaki et al.(2011) find that changes in borrowing constraints have a strong impact on the homeownership rates but little impact on the housing price. Favilukis et al.(2011) show that in a model in which households face both aggregate and idiosyncratic risk, a sudden decline of mortgage down payments from 20% to 0%, together with a decline in the trading cost of houses, may lead to an increase in housing price to rent ratio of a similar magnitude as what happened in the recent housing boom episode in the United States.

Nevertheless, little is known about how borrowing constraints affect long-term housing price dynamics, especially in the presence of change in demographic structure. As the borrowing constraint affects the life cycle consumption of housing services and savings, the impact of demographic structure on the housing price may depend on the level of the borrowing constraint.

To study this question, I assume that households can acquire housing services only through ownership and can borrow up to a certain fraction of the housing value. To introduce homeownership, I assume that the fraction of aggregate housing service consumed by a household is equal to the fraction of the total shares of the housing service producer he owns. Households cannot lease housing to each other. Moreover, households can borrow from each other using their shares of the housing service producer as collateral. Specifically, the household’s recursive problem is defined as follows:

$$V_t(W^a_t, a) = \max_{(C^a_t, H^a_t, B^a_t)} \{ u(C^a_t, H^a_t) + \beta V_{t+1}(W^a_{t+1}, a + 1) \}$$

s.t. \( C^a_t + p_t H^a_t + B^a_t = W^a_t \),
\[ W^a_{t+1} = w_{t+1} e^a_{t+1} + R_t B^a_t + p_{t+1} L^a_t + p_{t+1}^B H^a_t, \]
\[ B^a_t \geq -\theta p_t H^a_t. \]

27
Moreover,
\[
\sum_a n^a_t H^a_t = H_t,
\]
\[
\begin{align*}
   p_t H_t &= p^L_t L_t + p^S_t S_t, \\
   p^B_{t+1} H_t &= p^L_{t+1} L_t + p^S_{t+1} (1 - \delta^S) S_t.
\end{align*}
\]

I assume that the amount of shares of the housing service producer is adjusted to equal the amount of housing services produced in each period; \(p^B_t\) is the share price before and \(p_t\) after the adjustment. Other assumptions of the model are the same as before.

The computation of such a model with ownership is more difficult than the previous model where households can acquire housing services only through rental contracts. To make the computation efficient, I use an endogenous grid method (Carroll (2006)) and prove its applicability in this setting. More details can be found in the Appendix.

Using such a model, I study how the housing price trajectory changes when I vary the borrowing limit \(\theta\) and find that the housing price path is quite insensitive to \(\theta\).

At first glance, looser borrowing constraints increase young Baby Boomers’ consumption for housing services, which should push up the housing price. However, such effects are weakened by two channels: first, looser borrowing constraints increase the demand for borrowing and hence increases the interest rate, which dampens the increase in the housing price. Second, looser borrowing constraints lead young households to save less, and makes them able to afford less housing in the later stage of life. As the housing price is forward looking, the reduced future demand for housing services limits the housing price increase in the current period.

5.3 Rising Land Shares

Several studies suggest that land share is important for understanding housing price dynamics. Davis and Heathcote (2007) show that MSAs with higher land shares had stronger appreciation in the housing price from 1980 to 2005. Kiyotaki et al. (2011) argue that the housing price in an economy with higher land shares is more sensitive to shocks in interest rates and general productivity growth rates. Glaeser et al. (2005) and Davis and Heathcote (2007) both find that land shares were significantly lower in the 1950s than in the recent decades in the United States. Glaeser et al. (2005) attribute the increase in land shares to tighter regulatory constraints in building new homes in the recent decades, especially in coastal areas, which drive home values significantly beyond the replacement cost of struc-
Connected with these studies, the model shows that there is an upward trend in land share (Figure 7), which is caused by two factors: the low substitution elasticity between land and structure in producing housing services, and limitation in land development. Due to the limitation in land development, houses are built with increasingly more structure per unit of land. Therefore, the marginal productivity of structure relative to land declines. Due to the low substitution elasticity, this decline is severe, and the structure share in housing value declines.

To see this point, land share can be derived based on the housing service producer’s first order conditions (9) and (10):

\[
\theta_t^L = \frac{p_t^L L_t}{p_t^L L_t + p_t^S S_t} \tag{14}
\]

\[
= \left[ 1 + \sum_{s=0}^{\infty} \frac{1}{\prod_{j=0}^{s} R_{t+j}} \frac{(1-\delta^S) (p_{t+s}^L - (1-\delta^S) p_{t+s+1}^S R_{t+s})}{1 - \phi \left( \frac{L_t}{S_t} \right)^{\rho}} \right]^{-1}.
\]

Consider a benchmark case in which the production function is Cobb-Douglass. Define the growth rate of the user cost of land and structure as

\[
\begin{align*}
\kappa_t^{UL} &= \frac{p_t^L - \frac{p_{t+1}^L}{R_t}}{p_{t-1}^L - \frac{p_{t-1}^L}{R_{t-1}}}, \\
\kappa_t^{US} &= \frac{p_t^S - (1-\delta^S) \frac{p_{t+1}^S}{R_t}}{p_{t-1}^S - (1-\delta^S) \frac{p_{t-1}^S}{R_{t-1}}}.
\end{align*}
\]

the land share for a Cobb-Douglass production function is

\[
\theta_t^L = \left[ 1 + \phi \sum_{s=0}^{\infty} \frac{1}{\prod_{j=0}^{s} R_{t+j}} \frac{(1-\delta^S) g_{t+1}^{UL}}{g_{t+1}^{UL} R_{t+j}} \right]^{-1}.
\tag{15}
\]

**Lemma 1 (Land share of a Cobb-Douglass production function)**

In a steady state with \(\frac{g_{t+1}^{UL}}{R_{t+j}}\) and \(\frac{g_{t+1}^{US}}{R_{t+j}}\) being constant, \(\theta_t^L\) is a constant, increases with \(\frac{g_{t+1}^{UL}}{R_{t+j}}\) and declines with \(\frac{g_{t+1}^{US}}{R_{t+j}}\).
In the steady state with a Cobb-Douglass production function, the decline of the marginal productivity of structure relative to land is proportional to the expansion of the structure quantity relative to land quantity, implying a constant land share. Then, if the substitution elasticity is lower than one, the decline in the marginal productivity of structure relative to land will be more severe, driving down the structure value relative to the land value. Reflected in (14), the term \((\frac{L}{St})^\rho\) declines with a rising \(\frac{St}{Lt}\) when \(\rho > 0\).

Figure 16 shows that with higher substitution elasticity between land and structure in producing housing services, the upward trend of land share becomes increasingly flatter.

Rising land shares imply that policies which may affect the land price in the medium and long term can have more significant effects on the housing price. One example is the immigration policy. Based on the projections of the U.S. Census in 1999, the population growth rate of the United States would be zero after 2050, without immigration. In contrast, the annual population growth will be around 0.5% under a scenario of a medium influx of international immigrants. These suggest that the immigration policy has a significant impact on long-term housing price trends.

6 Concluding Remarks

This paper develops a quantitative model to study the dynamics of the housing market in the long term, with a particular focus on understanding the impacts of the Baby Boom and Bust, the limitation of land development, general productivity growth and the gap in productivity growth rates between the construction sector and the rest of the economy.

The calibration of the model uses constant-quality price and quantity indices of land and structure, which are constructed by extending the seminal work of Davis and Heathcote (2007). Through decomposition, the model shows that the majority of the trends of housing price and quantity are attributable to a declining productivity of land development due to an interaction between the limitation of land development and general productivity growth. In contrast, the impact of the Baby Boom and Bust is limited, and rising construction costs also have little impact on housing price and quantity.

This paper revisits Martin’s 2006 critique of Mankiw and Weil (1989) by showing that due to an interaction between the Baby Boom and Bust and life cycle savings, the housing price peak is delayed to around 2010, which helps explain why Mankiw and Weil’s prediction contradicts the data. However, I also show that an interaction between limitation in land development and general productivity growth, which is downplayed in Mankiw and Weil
(1989), dominates the Baby Boom and Bust in impacting the housing price.\footnote{Despite of ignoring the impact of the Baby Boomers’ savings on aggregate housing demand, Mankiw and Weil (1989)’s prediction is based on a strong dependence of the housing price on the change in aggregate housing demand, which is criticized by several other papers published in the Regional Science and Urban Economics (1991). There is also a critique on the wrong hump-shape of the life cycle demands for housing services used in Mankiw and Weil (1989), as they use a cross-sectional relationship between the housing demand and age to forecast individuals’ time-series profile of housing demand.\footnote{Angell and Williams (2005), Bernanke (2005), Himmelberg et al. (2005), Lereah (2005), McCarthy and Peach (2005), Shiller (2005, 2006).}}

This paper is a step towards having a framework that can be used to assess unusual housing price movements in the medium term. According to the Case-Shiller National Index, the housing price appreciation rate was only 0.4\% between 1987 and 2000; it suddenly jumped to 8.4\% between 2000 and 2006, before its recent crash. Such an episode has been widely regarded as a bubble. Before the busting of the bubble, there was a fierce debate\footnote{Angell and Williams (2005), Bernanke (2005), Himmelberg et al. (2005), Lereah (2005), McCarthy and Peach (2005), Shiller (2005, 2006).} about whether the booming housing prices were aligned with fundamental factors. However, few papers assemble fundamental factors to provide a quantitative assessment of the housing price movements. By characterizing the housing price trend as determined by the four fundamental factors, this model could have served as a benchmark model to provide an early warning sign that the strong boom significantly deviated from the housing price trend.

Another implication of the model is that the land share in housing value is rising over time because of the low substitution elasticity between land and structure in producing housing services, and a faster appreciation rate of land price than construction costs. As the housing price is a weighted average of the land price and the construction cost with the weight being the land share, and demand side factors only affect the land price, rising land share suggests that the impacts of the demand side factors are time-variant. Therefore, an assessment concerning demand side factors’ impact on the housing price may need to take that feature into account.

For future research, it would be interesting to use the framework of the model to understand long-term trends of housing price and quantity in other countries. Also, the current model assumes the capital price to be one as there is no adjustment cost in transforming general goods into capital, and hence stock price movements are assumed away. In future research, accounting for stock price movements may improve our understanding about medium-term housing price movements, given that the strong boom in the housing market followed a severe crash in the stock market, which suggests a strong link between the medium-term movements in the two asset markets.
References


Appendix

A. A Constant-Quality Developed Land Price Index

In this section, I detail how I construct the constant-quality developed land price index. I provide a summary of the methodology of Davis and Heathcote (2007) (hereafter DH), describe my construction method and compare the developed land price index with the raw land price index.

A.1 Summary of the Methodology of Davis and Heathcote (2007)

To construct the constant-quality raw land price index, DH rely on three equations

\[ \frac{p_{t+1}^{L}}{p_{t}^{L}} = \theta_{t} \frac{p_{t+1}^{L}}{p_{t}^{L}} + (1 - \theta_{t}) \frac{p_{t+1}^{S}}{p_{t}^{S}}, \]  \hspace{1cm} (16)

\[ V_{t+1}^{S} = V_{t}^{S} \frac{p_{t+1}^{S}}{p_{t}^{S}} (1 - \delta_{t}^{S}) + I_{t+1}^{S}. \]  \hspace{1cm} (17)

\[ V_{t+1}^{L} = V_{t}^{L} \frac{p_{t+1}^{L}}{p_{t}^{L}} + I_{t+1}^{L}. \]  \hspace{1cm} (18)
where the first equation defines a Laspeyres-type housing price index and the other two describe dynamics of aggregate structure and land values based on perpetual inventory methods. In particular, \( p_{t}^{\text{Laspeyres}} \) is a Laspeyres-type housing price index, \( \theta_{t}^{L} \) is the ratio of aggregate land value to aggregate house value, \( p_{t}^{L} \) is the price of land, \( p_{t}^{S} \) is the price of structure, \( V_{t}^{S} \) is the aggregate value of structure, \( \delta_{t}^{S} \) is the depreciation rate of structure, \( I_{t}^{S} \) is the investment in structure, \( V_{t}^{L} \) is the aggregate value of land, \( I_{t}^{L} \) is the investment in land.

DH’s idea is that if one knows \( V_{t_{0}}^{L} \) in a certain year \( t_{0} \) and can construct all the variables in the equation system except for \( \frac{p_{t+1}^{L}}{p_{t}^{L}} \) and \( V_{t}^{L} \), operating the equation system over time can determine \( \frac{p_{t+1}^{L}}{p_{t}^{L}} \) and \( V_{t}^{L} \). For this idea to work, one needs to know \( p_{t+1}^{\text{Laspeyres}} \). For the period after 1975, DH use a repeated sales house price index as the proxy; they use the Federal Housing Finance Agency repeated sales index and the Case-Shiller-Weiss repeated sales house price index. For the period before 1975, as these indices are not available, DH use a second construction method: by assuming that \( p_{t}^{\text{Laspeyres}} \) has a certain parametric form, \( V_{t}^{L} \) can be represented as a function of the unknown parameters of \( p_{t}^{\text{Laspeyres}} \). Then, by letting \( V_{t}^{L} \) in the Census years equal to the imputed aggregate land values obtained in the data, they can determine the values of these parameters. The second method can also be used to construct data from 1975 to 2000.

**A.2 My Construction Method**

To construct the developed land price index, I follow the method used by DH, with three differences: first, I define structure prices \( p_{t}^{S} \) using the historical construction cost index provided by RS Means. DH define structure prices using the price of gross investment in new residential structure determined by the Bureau of Economic Analysis (BEA). I use a different definition because the price of gross investment in new residential structure uses the Census Bureau price index of new single family houses under construction, which includes land development costs.

A limitation of using the RS Means index is that it reflects the building cost for both residential structure and non-residential structure. However, the two have similar trends in the data. Figure 17 plots the RS Means construction cost index, and the price indices of non-residential and residential investment in new structure, as determined by the BEA. I normalize their values in 1960 to be 100. The Figure shows that the three have similar long-term trends. As a robustness check, I define structure prices using the price index of residential investment and get similar results.

Second, I define aggregate structure value \( V_{t}^{S} \) as the aggregate value of residential fixed
assets excluding broker fees and land development costs. In the National Income and Product Account, residential investment includes both land development cost and broker fees. DH argue that this is a conceptual flaw and transactions do not change the structure value of a house. Following the method offered in their on-line appendix, I exclude broker fees from structure value by calculating the stock of broker fees and subtracting it from the aggregate value of residential fixed assets. In section A.4, I will explain how I remove land development costs.

Third, in the second construction method, I assume the Laspeyres-type index is a linear spline while DH use a cubic spline. Assuming that the Laspeyres-type index is a cubic spline introduces more coefficients to be determined. Davis and Heathcote (2007) assume that the first derivative of the index with respect to time is continuous and the index satisfies the not-a-knot endpoint conditions. DH report that their results are very similar between assuming the index follows a linear spline and a cubic spline.

### A.3 Comparison of Land Price Indices

In this section, I compare developed land price indices constructed using the two methods and two raw land price indices constructed by DH. There are two main findings: first, developed land shares are significantly higher than corresponding raw land shares. The average developed land share from 1960 to 2011 is 40.3%, whereas the average raw land share in the same period is 29.04%.

Second, as suggested by Figure 18, the indices constructed based on two different methods do not agree with each other, even in terms of the growths between census years. The difference between the two methods is smaller for developed land price indices, compared with raw land price indices. The raw land price index constructed based on the housing price repeated sales index has an appreciation of 205% from 1980 to 2000, while the index constructed based on the cubic form of the Laspeyres-type housing price index has an appreciation of 305% in the same period. In contrast, the developed land price indices have real appreciations of 183% and 202% respectively in this period, with a smaller difference between the two construction methods.

To demonstrate that the improved consistency is not driven by defining structure prices based on the construction cost index or assuming that the Laspeyres-type index follows a linear spline, I construct my data without removing land development costs but maintaining these two features. Figure 19(A) shows that the index constructed in this way has larger difference between two construction methods, and their long-term patterns are very similar as corresponding raw land price index constructed by DH.\(^{29}\)

\(^{29}\)There are some differences in the medium term. For instance, the increase in land prices between 1975
Figure 20 shows the stylized facts about housing quantity and price constructed using DH’s data, in which all the long-term patterns are qualitatively the same as those documented using my constructed data.

A.4 Removing Land Development Cost from Residential Fixed Assets

In the detailed table of residential fixed assets, the BEA breaks down the residential fixed assets into different subcategories, according to their owner type, number of units and whether the residential investment is the original part\textsuperscript{30}, additions and alterations, or major replacements of the house. I assume that land development costs are included in the original part of the house, but not in additions, alterations, or major replacements. To remove land development costs from the original part of the house value, a challenge exists in that the BEA does not provide a breakdown of such subcategories further into land development costs and other parts. Then, I directly compute the residential fixed assets excluding land development costs and broker fees, referred to as the structure value, based on a perpetual inventory method.

The dynamics of the structure value are determined by

\[ V^S_t = (1 - \delta^S_{t-1}) \frac{p^S_t}{p^S_{t-1}} V^S_{t-1} + I^S_t, \]  

(19)

where \( V^S_t \) is structure values, \( \delta^S_t \) is the structure depreciation rate, \( p^S_t \) is the structure price, and \( I^S_t \) is the new structure investment in period \( t \).

If I have the information of \( \delta^S_{t-1} \), \( p^S_t \) and \( I^S_t \), and an initial value of \( V^S_t \), I can generate the time series of \( \{V^S_t\} \). To do this, first, I assume that \( \delta^S_{t-1} \) is a constant \( \delta^S \), whose determination will be explained soon. Second, I define \( p^S_t \) as the RS Means construction cost index.

Third, for the investment of structure \( I_t \), I define it as residential investment excluding broker fees and land development costs. The BEA provides the total value of broker fees but does not break it down into different subcategories of residential investment. I assume broker fees as a fraction of residential investment is the same across the previously mentioned subcategories of residential investment. To remove land development costs, I utilize information provided by the National Association of Home Builders (NAHB) and a Census Bureau memorandum.\textsuperscript{31} Table 3 lists the breakdown of new home sales value based on surveys done by the NAHB, which suggests that after 1969, the developed land value as a fraction of the

\textsuperscript{30}It is termed as "new" in the table.

\textsuperscript{31}This is sent from Dennis Duke to Paul L. Hsen in Aug, 2000.
new home sales value is quite stable and the average is 23.4\%\,^{32} The Census memorandum suggests that the raw land value as a fraction of new home sales value is 10.5\%. Based on these, I assume that land development costs (which is the gap between the developed land value and the raw land value) as a fraction of new home sales value is 12.9\%. Since the residential investment as a fraction of aggregate new home sales value is 84.2\%,\,^{33} land development costs as a fraction of residential investment is 15.2\%.

Fourth, the initial year is set as 1960, and to obtain \( V_{1960}^S \). I exploit the idea that since land development costs do not depreciate over time, the depreciation comes from broker fees and structures:

\[
\delta_{1960}^R = \frac{V_{1960}^S}{V_{1960}} \delta^S + \frac{V_{1960}^B}{V_{1960}} \delta^B,
\]

where \( \delta_{1960}^R \) is the depreciation rate of residential fixed assets, \( V_{1960}^S \) is the structure value, \( V_{1960} \) is the replacement cost of residential fixed assets, \( V_{1960}^B \) is the broker fee stock and \( \delta^B \) is the depreciation rate of broker fee in 1960. Therefore, \( V_{1960}^S \) can be backed out from the formula if \( \delta_{1960}^R, V_{1960}, \delta^S, V_{1960}^B \) and \( \delta^B \) are known:

\[
V_{1960}^S = \frac{\delta_{1960}^R V_{1960} - \delta^B V_{1960}^B}{\delta^S}.
\]

As \( \delta_{1960}^R, \delta^B, V_{1960}, \) and \( V_{1960}^B \) can be determined using the detailed table of residential fixed assets and the NIPA determined by the BEA, knowing \( \delta^S \) can determine \( V_{1960}^S \).\,^{34}

\( \delta^S \) is determined as follows: as all the information needed to operate (19) is available except for \( \delta^S \), \( V_t^S \) can be obtained as a function of \( \delta^S \). Then, I can calculate \( \delta^S \) by solving the following equation:

\[
\frac{1}{52} \sum_{1960}^{2011} \delta_t^R = \frac{1}{52} \sum_{1960}^{2011} \left( \frac{V_t^S}{V_t} \delta^S + \frac{V_t^B}{V_t} \delta^B \right).
\]  

\(^32\)For the lower fraction of the finished land value as a fraction of the new home value in 1949, a conversation with a previous employee in the National Association of Home Builders suggests two possibilities: first, the 1949 numbers were based on data for Federal Housing Agency (FHA)-financed homes, rather than an NAHB survey, and FHA may have measured lot cost differently, perhaps using only raw land rather than finished lot. Second, there were increases in development standards and fees between 1949 and 1969, and perhaps raw land was much more than half of the finished lot cost in 1949. These points, however, need to be further investigated in future research.

\(^33\)The BEA defines residential investment as the value of structure put in place determined by the Census Bureau, which assumes that it is 84.2\% of new home sales value.

\(^34\)According to Davis and Heathcote (2007)'s online appendix, expenditures on broker fees are treated by the BEA as gross investment in "new 1-4 unit structures," and they calculate the depreciation rate of broker fees as the average depreciation rate of the category of "new 1-4 unit structures". I follow their method.
**B. Transition Dynamics**

In this section, I characterize the transition dynamics by describing the initial state and the exogenous disturbances of the economy.

The initial state has the same wealth distribution across age groups as reported by the 1962 Survey of Financial Characteristics of Consumers. I choose the initial aggregate capital stock such that the interest rate of the model economy in the period between 1960 and 1964 is the same as the average return to capital between 1960 and 1964, which was 6.31%.

The initial aggregate housing stock and $N^L(A^L)^{1/2}$, the parameter of land development technology, are chosen such that the initial land share in house value is the same as the average land share between 1960 and 1964, which was 29.6%, and the land quantity growth from the beginning of the period between 1960 and 1964 to the end of the period between 2005 and 2009 matches the land quantity growth from 1960 to 2010 in the data, which was 234%.

The aggregate labor productivity growth rate is exogenous. It is a constant and equals the average between 1960 and 2010, which was 1.624%, before 2260; it switches to a value which is consistent with the existence of a long-run steady state after 2260.

The demographic process is determined as follows: people enter the economy at age 20 and the population size of people aged 20 is chosen to be consistent with the historical data and the long run projections. Between 1960 and 2000, I use the estimated values from the United States Census Bureau. Between 2000 and 2100, I use the projected numbers released by the United States Census Bureau in 1999. After 2100, I assume the annual growth rate of the population aged 20 will be a constant at 0.54%, which is the average of the projected growth rates of the population aged 20 between 2050 and 2100. In addition, I choose the initial age distribution in 1960 to be consistent with the 1960 decennial census.

**C. The Computational Method**

**Household Problem** To compute households’ optimal choices, I use an endogenous grid method, and the algorithm is adapted from the one used by Krueger and Ludwig (2007). The endogenous grid method is proposed by Carroll (2006), which greatly enhances the computation efficiency in solving a household decision problem, compared with the traditional exogenous grid method. The basic idea is to simplify the time-consuming task of calculating policy functions given an exogenous grid of wealth into a task of backing out the decisionmaker’s wealth from the choices. By specifying an exogenous grid of choice variables, typically households’ savings, households’ wealth can be backed out to form an endogenous grid. Optimal choices are derived by interpolating the grid points.
Algorithm Solving the model where households obtain housing services only through renting houses.

**Step 1.** Choose a grid of savings \( G^S = \{s_1, ..., s_N\} \), with \( s_1 = 0 \) and \( s_i < s_j \) for \( i < j \).

**Step 2.** Choose a grid of cash on hand at age \( T \): \( G^X = \{x_{T}^1, ..., x_{T}^N\} \):

\[
x_{T}^i = \begin{cases} 
    w_T e^T + s_{i-1} & \text{if } i > 2 \\
    \frac{1}{2} s_2 & \text{otherwise}
\end{cases}
\]

**Step 3.** Iterate \( a \) from \( T - 1 \) to 1. Update the grid of cash on hand at age \( a \): \( G^X_a = \{x_{a}^1, ..., x_{a}^N\} \) and \( V_x(x, a) \) for \( x = x_{a}^i \), with \( i = 1, ..., T \).

For \( i \geq 2 \), \( x_{a}^i \) is updated as the cash on hand at age \( a \) such that the optimal saving is \( s_{i-1} \) and is solved by backward induction. Given \( V_x(x, a + 1) \) is already updated for \( x \in G^X_{a+1} \) and \( V_x(\tilde{x}, a + 1) \) for any \( \tilde{x} \) can be interpolated accordingly, \( x_{a}^i \) can be solved from the Euler equations. \( V_x(x_{a}^i, a) \) is updated as the corresponding marginal utility of consumption.

For \( x_{1}^a \), if \( x_{2}^a > w_a e^a \),

\[
x_{1}^a = w_a e^a, \quad V_x(x_{1}^a, a) = u_C,
\]

where \( u_C \) is the corresponding marginal utility of consumption.

Otherwise, \( x_{1}^a \) is set to an arbitrary value smaller than \( x_{2}^a \), and

\[
V_x(x_{1}^a, a) = 0.
\]

**Perfect Foresight Equilibrium** I solve the perfect foresight equilibrium by searching for interest rates \( \{R_t\}_{t=1}^{\infty} \) and the ratios of structure quantity to land quantity \( \{\frac{S_t}{L_t}\}_{t=1}^{\infty} \), such that the markets for funds and developed land clear in every period of the transition dynamics.

The idea is to represent all the prices \( \{d_t, R_t, p_t^L, p_t^S\}_{t=1}^{\infty} \) as functions of \( \{R_t, \frac{S_t}{L_t}\}_{t=1}^{\infty} \), such that individual households’ choices can be computed based on the algorithm described above given these prices; therefore, aggregation of individual households’ choices lead to market clearing conditions, which are equations of \( \{R_t, \frac{S_t}{L_t}\}_{t=1}^{\infty} \). \( \{R_t, \frac{S_t}{L_t}\}_{t=1}^{\infty} \) are solved accordingly.

To represent \( \{d_t, R_t, p_t^L, p_t^S\}_{t=1}^{\infty} \) as functions of \( \{R_t, \frac{S_t}{L_t}\}_{t=1}^{\infty} \), note that \( \{p_t^S\}_{t=1}^{\infty} \) are already known, and hence I only need to represent \( \{d_t, p_t^L\}_{t=1}^{\infty} \) as functions of \( \{R_t, \frac{S_t}{L_t}\}_{t=1}^{\infty} \).

For the rents \( \{d_t\}_{t=1}^{\infty} \), they are determined as:

\[
d_t = \left(p_t^S - \frac{(1 - \delta^S)p_t^S}{R_t}\right)\phi\left(\frac{S_t}{L_t} \times \left(\frac{H_t}{L_t}\right)^{-1}\right).
\]
where, by definition of the housing service production technology, the ratio of aggregate housing services to aggregate land \( \frac{H_t}{L_t} \) satisfies

\[
\frac{H_t}{L_t} = (\phi\left(\frac{S_t}{L_t}\right)^{-\rho} + 1 - \phi)^{-\frac{1}{\rho}}.
\]

For the land prices \( \{p_t^L\}_{t=1}^\infty \), recall the first order conditions of the housing service producer:

\[
\frac{p_t^L - \frac{p_{t+1}^L}{R_t}}{\frac{1}{\phi} \left(\frac{S_t}{L_t}\right)^{1+\rho} - \frac{1}{\phi} \left(\frac{S_{t+1}}{L_t}\right)^{1+\rho}} = \frac{1 - \phi \left(\frac{S_t}{L_t}\right)^{1+\rho}}{\phi \left(\frac{S_t}{L_t}\right)^{1+\rho}}.
\]

Given \( \{p_t^S, R_t, \frac{S_t}{L_t}\}_{t=1}^\infty \), \( \{p_t^L\}_{t=1}^\infty \) can be determined by solving the difference function forward as:

\[
p_t^L = \sum_{s=0}^{\infty} \frac{1}{R_t} \prod_{j=0}^{s-1} \frac{1 - \phi \left(\frac{S_{t+j}}{L_{t+j}}\right)^{1+\rho}}{\phi \left(\frac{S_{t+j}}{L_{t+j}}\right)^{1+\rho}} (p_{t+j}^S - \frac{1 - \delta^S}{\phi} p_{t+j+1}^S).
\]

To solve the equation system of \( \{R_t, \frac{S_t}{L_t}\}_{t=1}^\infty \), I use the Broyden’s method. When computing the model where housing services can be obtained only through the rental market, the Broyden’s method is always sufficient to reach a desired precision of computation. In contrast, when computing the model where housing services can be obtained only through owning houses, the Broyden’s method sometimes cannot converge. In these cases, similar with the computational algorithm outlined in the Appendix of Buera and Shin (2012), I solve market clearing conditions one by one, penalize the adjustment, and repeat these steps until desired convergence is achieved.

**The Model with Homeownership** In the model in which households acquire housing services only through owning houses and they can borrow up to a fraction of their housing value, the computation becomes more challenging, because the endogenous grid method may not be readily applicable. A necessary condition of implementing the endogenous grid method is that the mapping from the decision maker’s saving choice to his wealth is one-to-one.\(^{35}\) I prove that the following regularity condition can guarantee the uniqueness of the mapping from savings to wealth in such a model:

\[
p_t - \theta R_{t-1} p_{t-1} > 0 \text{ for all } t.
\]

\(^{35}\) The algorithm designed by Kruger and Ludwig (2007) bypasses this issue in computing a model with zero borrowing limits. The idea is that when households’ wealth is sufficiently low, they have a binding borrowing constraint and choose zero savings. Hence there is a cutoff line of wealth, below which savings are zero. In addition, saving are strictly monotonic in wealth above this cutoff. Then, we can apply the endogenous grid method only for the wealth above this cutoff. The previous described algorithm effectively implements this idea. However, when borrowing limits are linked to house values, this idea does not work.
I verify that the condition holds under my model parameters, which enables me to use the endogenous grid method for the model with richer borrowing constraints. The proof for the uniqueness of the mapping is available upon request.
Table 1: Model parameters. Note: This table lists all the parameters of the baseline model. I calculate technology parameters from the data and calibrate household preference parameters inside the model by matching certain data targets.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Housing services production</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\rho$</td>
<td>(Substitution elasticity)$^{-1} - 1$</td>
<td>3.54</td>
</tr>
<tr>
<td>$\phi$</td>
<td>Structure share</td>
<td>0.799</td>
</tr>
<tr>
<td>$\delta^S$</td>
<td>Depreciation rate of structure</td>
<td>0.0167</td>
</tr>
<tr>
<td>Land development</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$b$</td>
<td>Output elasticity of general consumption goods</td>
<td>0.564</td>
</tr>
<tr>
<td>$\epsilon$</td>
<td>Negative externality of land</td>
<td>-0.75</td>
</tr>
<tr>
<td>General goods production</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\gamma$</td>
<td>Output elasticity of capital</td>
<td>0.290</td>
</tr>
<tr>
<td>$\delta^K$</td>
<td>Depreciation rate of capital</td>
<td>0.0717</td>
</tr>
<tr>
<td>Household Preference</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\alpha$</td>
<td>Consumption share in utility</td>
<td>0.912</td>
</tr>
<tr>
<td>$\beta$</td>
<td>Discount rate</td>
<td>0.758</td>
</tr>
<tr>
<td>$\sigma$</td>
<td>Risk aversion coefficient</td>
<td>1</td>
</tr>
<tr>
<td>$\eta$</td>
<td>Bequeath intensity</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 2: Parameters of robustness tests.

<table>
<thead>
<tr>
<th></th>
<th>$b$</th>
<th>$\epsilon$</th>
<th>$\rho$</th>
<th>$\phi$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change substitution elasticity</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0.564</td>
<td>-0.75</td>
<td>1.0</td>
<td>0.761</td>
</tr>
<tr>
<td>2</td>
<td>0.564</td>
<td>-0.75</td>
<td>2.0</td>
<td>0.776</td>
</tr>
<tr>
<td>3</td>
<td>0.564</td>
<td>-0.75</td>
<td>3.0</td>
<td>0.791</td>
</tr>
<tr>
<td>4</td>
<td>0.564</td>
<td>-0.75</td>
<td>4.0</td>
<td>0.805</td>
</tr>
<tr>
<td>5</td>
<td>0.564</td>
<td>-0.75</td>
<td>5.0</td>
<td>0.819</td>
</tr>
<tr>
<td>Change output elasticity</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0.1</td>
<td>-0.159</td>
<td>3.54</td>
<td>0.799</td>
</tr>
<tr>
<td>7</td>
<td>0.2</td>
<td>-0.285</td>
<td>3.54</td>
<td>0.799</td>
</tr>
<tr>
<td>8</td>
<td>0.3</td>
<td>-0.410</td>
<td>3.54</td>
<td>0.799</td>
</tr>
<tr>
<td>9</td>
<td>0.4</td>
<td>-0.536</td>
<td>3.54</td>
<td>0.799</td>
</tr>
<tr>
<td>10</td>
<td>0.5</td>
<td>-0.662</td>
<td>3.54</td>
<td>0.799</td>
</tr>
<tr>
<td>11</td>
<td>0.6</td>
<td>-0.788</td>
<td>3.54</td>
<td>0.799</td>
</tr>
</tbody>
</table>
Table 3: Single family home sales price breakdown. This table shows that after 1969, the ratio of finished lot cost to home sales price was stable over time. Source: National Association of Home Builders.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Finished lot cost</td>
<td>11.0</td>
<td>21.0</td>
<td>24.0</td>
<td>24.4</td>
<td>23.6</td>
<td>23.5</td>
<td>26.0</td>
<td>24.5</td>
<td>20.3</td>
<td>21.7</td>
</tr>
<tr>
<td>Total construction cost</td>
<td>69.0</td>
<td>55.0</td>
<td>45.0</td>
<td>53.3</td>
<td>54.8</td>
<td>50.8</td>
<td>51.7</td>
<td>48.1</td>
<td>58.9</td>
<td>59.3</td>
</tr>
<tr>
<td>Financing cost</td>
<td>5.00</td>
<td>7.00</td>
<td>15.0</td>
<td>2.00</td>
<td>1.90</td>
<td>2.13</td>
<td>1.80</td>
<td>2.40</td>
<td>1.70</td>
<td>2.10</td>
</tr>
<tr>
<td>Other costs</td>
<td>15.0</td>
<td>17.0</td>
<td>16.0</td>
<td>20.4</td>
<td>19.7</td>
<td>23.6</td>
<td>19.1</td>
<td>25.0</td>
<td>19.1</td>
<td>16.8</td>
</tr>
<tr>
<td>- Overhead and general expenses</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>5.80</td>
<td>5.70</td>
<td>5.53</td>
<td>5.40</td>
<td>7.00</td>
<td>5.40</td>
<td>5.20</td>
</tr>
<tr>
<td>- Marketing cost</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2.20</td>
<td>1.40</td>
<td>2.39</td>
<td>1.40</td>
<td>2.50</td>
<td>1.40</td>
<td>1.50</td>
</tr>
<tr>
<td>- Sales commission</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3.30</td>
<td>3.40</td>
<td>3.67</td>
<td>3.40</td>
<td>4.30</td>
<td>3.40</td>
<td>3.30</td>
</tr>
<tr>
<td>- Profit</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>9.10</td>
<td>9.20</td>
<td>12.0</td>
<td>8.90</td>
<td>11.2</td>
<td>8.90</td>
<td>6.80</td>
</tr>
</tbody>
</table>

Figure 1: Constant-quality Price and Quantity Indices of Housing, Land and Structure
This figure describes secular trends in the housing market between 1960 and 2011 in the United States. (A) documents housing price, and (B) ratio of housing quantity to GDP. The indices are constructed in the procedure of creating developed land price and quantity indices, and the details can be found in the Appendix. Source: Davis and Heathcote (2007), BEA, Author’s Calculations.
Figure 2: Stylized Facts of United States Housing Markets (1960 - 2011) This figure describes the temporal variation of housing values, land shares and structure quantity to land quantity ratios between 1960 and 2011 in the United States. Panel (A) documents ratio of aggregate value of housing, land, and structure to GDP, panel (B) describes land share, and panel (C) plots ratio of structure quantity to land quantity. The indices are constructed in the procedure of creating developed land price and quantity indices, and the details can be found in the Appendix. Source: Davis and Heathcote (2007), BEA, Author’s Calculations.
Figure 3: Demand-Side Features of the United States Housing Markets in This figure describes demand-side features of the housing market between 1960 and 2011 in the United States. (A) documents the population of people aged 20, (B) total factor productivity, and (C) ratios of housing services to consumption expenditures. Source: U.S. Census Bureau, BEA, Author’s calculations.
Figure 4: **RS Means Construction Cost Index** This figure shows the trend of the construction cost index which is obtained from regressing the log of the index over a time trend. Source: RS Means.

![RS Means Construction Cost Index](image)

Figure 5: **Life Cycle Labor Endowments** This figure plots life-cycle endowments of efficient labor units. Source: Hansen (1992), Author’s interpolation.

![Life Cycle Labor Endowments](image)
Figure 6: Model Performances in Matching Prices, Quantities and Values This figure compares model outputs with their data counterparts. (A1) to (A3) document housing price, housing quantity to GDP and housing value to GDP, (B1) to (B3) land price, land quantity to GDP and land value to GDP, and (C1) to (C3) structure price, structure quantity to GDP, and structure value to GDP. Sources: Davis and Heathcote (2007), BEA, Author’s calculations.
Figure 7: Model performance in matching land shares and structure quantities relative to land quantities. This figure compares model outputs with their counterpart in the data. (A) documents land share, and (B) describes the ratio of structure quantity to land quantity. Source: Davis and Heathcote (2007), BEA, Author’s calculations.

Figure 8: Population size of people aged 20. This figure shows the population of people aged 20 in the data and when the Baby Boom is shut down. Sources: United States Census Bureau, Authors’ Calculations.
Figure 9: **Comparisons of housing prices in different experiments.** In this figure, panels (A) and (C) plot housing prices and the interest rates with all channels being shut down and with only the Baby Boom in the small open economy defined in Section 4.2. Panels (B) and (D) plot the housing prices and interest rates with all channels being shut down and with only the Baby Boom in the closed economy in Section 4.2.
Figure 10: **Comparisons of housing prices in different experiments (cont’d).** In this figure, panels (A) and (C) compare the housing prices and the land prices with only the Baby Boom and with both the Baby Boom and the limitation in land development. Panels (B) and (D) compare the housing prices and the land prices with both the Baby Boom and the limitation in land development and with only rising construction costs being shut down.
Figure 11: **Comparisons of housing prices in different experiments (cont’d).** In this figure, panels (A), (B), and (C) compare the housing prices, the land shares, and the land prices with only the rising construction costs being shut down and with all channels present.
Figure 12: Comparisons of housing quantities relative to GDP in different experiments. In this figure, panels (A), (B), (C) and (D) compare the housing quantities to GDP ratio with the limitation in land development, the general productivity growth, rising construction costs and the Baby Boom and Bust being shut down respectively.
Figure 13: **Model performances for different output elasticities to general consumption goods**

This figure compares model outputs of different output elasticities to general consumption goods. (A1) to (A3) document housing price, ratio of housing quantity to GDP, and ratio of housing value to GDP. (B1) to (B3) document land price, ratio of land quantity to GDP, and ratio of land value to GDP. (C1) to (C3) document structure price, ratio of structure quantity to GDP, and ratio of structure value to GDP. Sources: Davis and Heathcote (2007), BEA, Author’s calculations.
Figure 14: **Model performances under different substitution elasticity between land and structure** This figure compares model outputs of different substitution elasticities. (A1) to (A3) document housing price, ratio of housing quantity to GDP, and ratio of housing value to GDP. (B1) to (B3) document land price, ratio of land quantity to GDP, and ratio of land value to GDP. (C1) to (C3) document structure price, ratio of structure quantity to GDP, and ratio of structure value to GDP. Sources: Davis and Heathcote (2007), BEA, Author’s calculations.
Figure 15: **Mortality risk in 1960, 2010 and 2050.** This figure shows a long-term decline in mortality risk. Sources: United States Census Bureau.

Figure 16: **Land shares under different substitution elasticities between land and structure** This figure compares land share in the model economy with the data. Sources: Davis and Heathcote (2007), BEA, Author’s calculations.
Figure 17: RS Means Cost Index, Price Indices of Residential and Non-residential Investment in New Structure  This figure compares RS Means construction cost index and price indices of residential and non-residential investment. All nominal series are deflated using the price index for personal consumption. Sources: RS Means, BEA.
Figure 18: **Comparisons of Raw and Developed Land Price Indices** This figure suggests that the developed land price indices seem to be more consistent across construction methods. Sources: Davis and Heathcote (2007), BEA, Author’s calculations.
Figure 19: **Comparison of Land Price Indices** This figure shows that without removing the value added of the land development sector from the structure value, my land price indices are close to those constructed by Davis and Heathcote (2007). Sources: Davis and Heathcote (2007), BEA, Author’s calculations.
Figure 20: Secular trends in the housing market of the United States documented using data from Davis and Heathcote (2007) This figure plots stylized facts in the housing market using the data constructed by Davis and Heathcote (2007). All nominal series are deflated using the price index for personal consumption. Sources: Davis and Heathcote (2007).