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Heterogeneity, Frictional Assignment and Home-ownership

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Heterogeneity, Frictional Assignment and Home-ownership*

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Abstract

A model of the distribution of home-ownership in a city is developed. Heterogeneous houses are built by a competitive development industry and either rented competitively or sold through directed search to households which differ in wealth and sort over housing types. In the absence of both financial restrictions and constraints on house characteristics, higher income households are more likely to own and lower quality housing is more likely to be rented. Calibrated to match average features of housing markets *within* U.S. cities, the model is qualitatively consistent with U.S. data on the relationships between observed differences in median income, inequality, median household age, and construction/land costs *across* cities and both home-ownership and the average cost of owning vs. renting. Policies designed to improve housing affordability raise both housing quality and ownership for lower income households while lowering housing quality (but not ownership) for high income ones.

Journal of Economic Literature Classification: E30, R31, R10

Keywords: House Prices, Liquidity, Search, Income Inequality.

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1 Introduction

We study the joint allocation of housing units and households, both of which are heterogeneous, across city-level ownership and rental markets using a model of frictional assignment. Calibrated to match several features of housing markets *within* U.S. cities, the model’s qualitative predictions for the effects of median income, inequality, household age, land costs and amenities on both average home-ownership and the average cost of owning relative to renting (the *price-rent ratio*) are broadly consistent with empirical relationships *across* cities. Quantitatively, we find that cross-city differences in construction costs and average amenities affect both the composition of the housing stock and rent vs. sell decisions, accounting for much of the variation in average price-rent ratios. Policies designed to increase the affordability of housing significantly increase both ownership and housing quality for low income households; while lowering quality (but not ownership) for high income ones.

Average rates of home-ownership and the relative average costs of owning and renting vary dramatically across cities. For a sample of 366 U.S. metropolitan statistical areas (MSA’s) in the 2010 American Community Survey (ACS), for example, home-ownership rates vary from 51% to 81% and ratios of average prices to average rents from 8.7 to 54.2.¹ What drives this cross-city variation? Much of the variation in average price-rent ratios likely reflects differences in the composition of the housing stock across cities. But what are the likely determinants of these differences?

To study these phenomena we develop a dynamic equilibrium model of a city in which the distribution of the housing stock across owner-occupied and rental markets is determined by the endogenous decisions of households, landlords and developers. The main assumptions of our theory are motivated by two broad observations: First, the likelihood of home-ownership is strongly increasing in household income and wealth after controlling for other household characteristics (including age and family composition), neighbourhood characteristics and cyclical factors.² Second, the likelihood that a given housing unit is owner-occupied rather than rented rises with the value of the unit. Halket, Nesheim and Oswald (2015), for example, summarize their findings as follows: “Despite their relatively high gross yield in the rental sector, properties with high value physical characteristics are less likely to be bought up by landlords and supplied to renters.”³ Notwithstanding these overall tendencies,

¹For this calculation we use the ratio of the mean price-asked for each MSA to mean annual rent (see Appendix B). Note that this is not the relative price and rent of a specific unit. Indeed, much of the large variation in the data, as in our model, is due to composition effects.

²See, for example, Rosen (1979), Goodman (1988), Kan (2000) and Carter (2011).

³Glaeser and Gyourko (2007) document that the composition of rental housing is systematically

home-ownership is significant even for the lowest income quintile and some low value housing units are owned while many high value ones are rented.

The model consists of a city comprised of housing units differentiated by quality (taken to represent size, proximity to amenities, etc.) and inhabited by a growing population of households with stochastic lifetimes who are differentiated permanently by income/wealth. New houses may be of any type and are built by a development industry comprised of a large number of firms with free entry. Construction/land costs increase with quality and, once built, a house's quality is permanently fixed. All households require housing, but may choose whether to rent or own.

In equilibrium, ownership patterns solve a frictional assignment problem in the sense of Shi (2001, 2005). Vacant houses of any quality may be either rented in Walrasian markets or offered for sale through directed search.⁴ Unmatched households either rent or purchase an affordable home of their preferred quality. Whether and how quickly they buy depends on the incentives facing supply side participants. These are the owners of new or vacant homes which are either offered for sale or rented.

The surplus associated with ownership, as opposed to rental, of a given housing unit rises with its quality. In our baseline specification, this occurs because maintenance costs incurred by landlords increase more rapidly with quality than those for owner-occupiers. This assumption is intended to reflect the idea that the costs of moral hazard associated with renting increase with house quality (*e.g.* Sweeney, 1974; Henderson and Ioannides, 1983). It may also reflect economies of scale in maintaining buildings with multiple low-quality apartments in comparison with detached houses. The model allows for other potential sources of this rising surplus, including preference for ownership that increases with quality or the implications of mortgage interest deductibility. We show, however, that the exact source matters very little for our main results.

We calibrate the model's balanced growth path to match several median features of U.S. MSA housing markets, including average time to sell, average ownership duration, the average price-rent ratio and the distribution of ownership across income quintiles.⁵ Under this calibration, rental housing is generally of lower quality than owner-occupied housing. Price-rent ratios fall with house quality as the relative costs

different from that which is owner-occupied. For example, owned units often consist of single-family detached dwellings, while rental units are more commonly part of multi-unit buildings. The average owner-occupied unit is roughly double the size of the typical rental unit.

⁴Search is motivated by the idea that while houses of a given objective quality are in some sense alike, they have idiosyncratic differences which appeal only to certain households.

⁵The assumed income distribution is log-normal, with inequality measured by the Gini coefficient.

of renting rise owing to higher maintenance costs (see also Halket, Nesheim and Oswald, 2015). Using this calibrated version of the model, we characterize the steady-state effects of variation in several key fundamentals. In particular, the model predicts that the ownership rate increases with median income and age and decreases with inequality and construction costs. Average price-rent ratios increase with median income, inequality and construction costs.⁶

We then characterize, using the 2010 ACS, the empirical relationships between both ownership rates and average price-rent ratios and median income, inequality, age and land costs using cross-city regressions.⁷ Controlling for other factors affecting the desirability of living in a given city, we find that, qualitatively, the patterns observed in cross-city data are remarkably consistent with the predictions of our model. Moreover, these patterns are robust to alternative specifications and samples.

To study the theory's quantitative predictions, we use the calibrated model to generate predicted cross-city variation in outcomes resulting from observed and inferred variation in MSA-level characteristics. We find that, while the distribution of income and age play a key role, differences in construction/land costs and average amenities across cities are the most important factor in accounting for observed cross-city variation in both ownership and average price-rent ratios.

Given the observed variation in fundamentals, the model generates substantial variation in the *affordability* of housing across cities. Having less affordable housing reduces housing quality for all households, but affects ownership mainly for relatively low income ones. We consider policies aimed at improving housing affordability by subsidizing the provision of relatively low quality/size units to both the rental and owner-occupied markets. Such policies improve the well-being of lower income households relative to that of higher income ones, mainly by increasing housing quality. These policies nevertheless do increase home-ownership in spite of not targeting it directly. High income households (who effectively bear the cost of the policy) continue to own at roughly the same rate, but live in lower quality houses. They compensate for this to some extent by increasing their non-housing consumption.

Several other studies have emphasized search frictions in housing markets (*e.g.* Wheaton, 1990; Krainer, 2001; Albrecht, Anderson, Smith and Vroman, 2007; Diaz and Jerez, 2013; Head, Lloyd-Ellis and Sun, 2014; Ngai and Sheedy, 2017; Hedlund, 2015; Halket and Pignatti Morano di Custozza, 2015; Garriga and Hedlund, 2017;

⁶The relationship between median age and the price-rent ratio is ambiguous.

⁷For our sample of 366 MSA's, median incomes range from \$31,264 to \$86,286 and income Gini's from .388 to .537 (see also Glaeser, Resseger, and Tobin, 2009).

Anenberg and Bayer, 2018). Our paper differs from these in its emphasis on *both* the rent-versus-sell decisions of developers and moving owners *and* the rent-versus-buy decisions of heterogeneous buyers in determining the composition of owned and rental housing stocks. Accounting for the interactions between these decisions is crucial for understanding the variation in ownership rates and price-rent ratios across cities.

In studying home ownership, a common modelling strategy is to assume that rental units must be of a strictly lower quality than owned units. Combined with a preference for ownership and an exogenous minimum downpayment, this forces lower wealth households to rent (see Gervais, 2002; Iacovello and Pavan, 2013; Sommer, Sullivan and Verbrugge, 2013; Floetotto, Kirker and Stroebel, 2016; Sommer and Sullivan, 2018). This approach does not explain *why* lower quality houses cannot be owned. Nor does it allow for the fact that many wealthier households rent.⁸ In our theory, ownership patterns are driven by the optimal decisions of sellers faced with a choice between competitive rental markets and frictional markets for owner-occupied houses. Rental housing is more likely to be of lower quality because the relative supply of low quality housing to the owner-occupied market is low.

The remainder of the paper is organized as follows. Section 2 describes the theoretical environment which will be used to study housing tenure in equilibrium and for comparisons across cities, both qualitative and quantitative. Section 3 defines a stationary balanced growth path for this economy. The calibration is detailed in Section 4 along with the implied characteristics of housing markets within the city. Section 5 describes variation across cities with regard to housing tenure and the average price-rent ratio in both the data and the model. The affordability of housing and the effects of policies designed to improve it are considered in Section 6. Section 7 concludes and outlines future work.

2 A Model of Construction and Housing Tenure

2.1 The environment

Consider a dynamic economy in discrete time, consisting of a single city populated by a growing number of households with stochastic life-times. Each period new households enter the city either through migration from elsewhere or by its members

⁸Moreover, quantitative analyses often impose a substantial minimum downpayments of 20%, which appears counterfactual.

attaining an age at which they live independently. The rate of entry/household formation is constant, and denoted by ν . Households die with probability δ each period.⁹ The population of the city, L_t , thus evolves:

$$L_{t+1} = (1 + \nu - \delta)L_t. \quad (1)$$

Households differ *ex ante* with regard only to their lifetime income. For simplicity, we think of this coming in the form of a constant income, y .¹⁰ Household incomes are distributed according to cumulative distribution function, F , with positive and continuous support.

Households consume both goods and housing services. In particular, each period they must live in a single *house*, which they may either rent or own. Houses differ with regard to their characteristics, and we represent these by a single index of *quality*, $q \in \mathbb{R}_+$. Households maximize expected utility over their stochastic lifetimes. Preferences are represented by

$$U = \sum_{t=0}^{\infty} \beta^t [u(c_t) + h(z_t, q_t)], \quad (2)$$

where β is the household's discount factor adjusted for the probability of survival. That is, $\beta/(1 - \delta)$ reflects the pure rate of time preference. The discount factor satisfies $\beta = (1 - \delta)/(1 + \rho)$ with ρ the exogenous world interest rate.¹¹

In (2), $h(z_t, q_t)$ represents the current period utility flow from living in a house of quality q_t . Here $z_t \in \{0, 1\}$ is an indicator of housing tenure; $z_t = 1$ if the household owns the house in which it lives in period t and $z_t = 0$ if it rents. This formulation allows for the potential existence of an *ownership premium*: an additional utility benefit to a household from owning the house in which it lives. We assume that $h(z, q)$ is increasing and strictly concave in q and that $h(z, 0) = 0$, for $z \in \{0, 1\}$. Also, for all q , $h(1, q) \geq h(0, q)$.¹²

Each period, with probability π , a household receives an idiosyncratic preference shock which results in them no longer liking their current house. Specifically, they no

⁹Rather than dying, households could leave the city for elsewhere randomly. This would make little difference for our results, although it would require a re-interpretation of certain parameters.

¹⁰Given our assumption below of complete markets, households could face idiosyncratic shocks to their income flow with no changes to our analysis or results.

¹¹This assumption is necessary for there to be a stationary balanced growth path. One justification is that ρ is set in a stationary "rest of the world", and taken as given in the city.

¹²In our baseline calibration below, we set this premium to zero, so that $h(1, q) = h(0, q)$. See Appendix D for discussion of an alternative formulation with a non-zero ownership premium.

longer receive housing services from living in *that particular house*. The household can, however, obtain housing services by moving to a *different* house of their preferred quality. This *mobility shock* is intended to capture a household’s evolving taste for the idiosyncratic features of a house, and generates turnover in housing markets.¹³

Houses of different qualities are built using a construction technology through which the cost of land and construction required to build a house of quality q is $T(q)$, where $T'(q) > 0$. Construction is undertaken by an industry comprised of a large number of identical, risk neutral *developers* under conditions of free entry. Once produced, the quality of a given house is fixed, permanently. Construction of a house takes one period, and development firms are owned by households, remitting their profits (if any) lump-sum. Because of free entry, firms build houses of each type as long as the discounted future value of a house exceeds the current cost of construction.

An owner of a vacant house, whether a developer or household, may either rent it to a prospective tenant or offer it for sale. Rental markets are perfectly competitive, and $x_t(q)$ represents the current rent for a house of quality q .¹⁴ In contrast, house sales take place through a directed search process. Vacant houses of a given quality (a market *segment*) are offered for sale in sub-markets characterized by a posted price and a pair of matching probabilities, one each for both buyers and sellers. We assume a CRS matching function and refer to the ratio of buyers to sellers as market tightness, denoted θ_t . The matching rates for buyers and sellers (λ and γ , respectively) are functions of tightness and satisfy:¹⁵

Assumption 1. *The matching probabilities have the following properties:*

- (i) $\lambda(\theta) \in [0, 1]$ and $\gamma(\theta) \in [0, 1]$ for all $\theta \in [0, \infty)$;
- (ii) $\lambda'(\theta) < 0$ and $\gamma'(\theta) > 0$ for all $\theta \in (0, \infty)$; and
- (iii) $\lim_{\theta \rightarrow 0} \gamma(\theta) = 0$ and $\lim_{\theta \rightarrow \infty} \gamma(\theta) = \bar{\gamma} \leq 1$.

¹³In general, mobility risk may depend on house quality and/or age. For example, a case in which $\pi'(q) < 0$ is consistent with the finding of Piazzesi, Schneider and Stroebel (2013) that in the San Francisco Bay area, less expensive market segments tend to be less “stable” (*i.e.* moving shocks occur more frequently). For simplicity, however, here we hold π constant across house types.

¹⁴While there may be search frictions in the rental market as well, we assume that they are such that matching *always* occurs well within the period (which is a quarter in our calibration). While we do not model this process explicitly, we assume it implies that the rental market is Walrasian to a first approximation.

¹⁵The likelihood of a match could, in principle, depend on the quality of the house. This could reflect, for instance, higher quality houses being more diverse and thus specifically appealing to a smaller fraction of buyers who visit them. Here we assume that the matching probabilities depend only on market tightness.

There is no restriction on how many houses a household can own. Each household must, however, live in (and thereby receive housing services from) one, and only one, house at a time.

Occupancy of houses results in depreciation which we assume to be completely offset by maintenance, the cost of which depends on quality and whether or not the house is occupied by its owner. Specifically, $Z_R(q)$ represents the per period cost of maintaining a house of quality q when rented and $Z_N(q)$ denotes that cost when owner-occupied. We assume that $Z_R(q) \geq Z_N(q)$ and that $Z'_R(q) \geq Z'_N(q)$. Houses depreciate when rented or owner-occupied, but not while vacant.

Assumption 2. *The joint properties of the functions u , h , T , λ , γ , Z_R and Z_N are such that the optimal choices of households and developers in equilibrium generate a bijective mapping between household income, y , and house quality, q , in the owner-occupied market.*

While we do not characterize these properties in general, in Section 4 we specify specific functional forms and use them to compute an equilibrium with this feature. Eeckhout and Kircher (2010) discuss the general properties required for positive assortative matching in a related but static environment.

At each point in time, the total stock of housing in the city is given by

$$M_t = \int_0^\infty M_t(q) dq \quad (3)$$

Each of these houses may be either owned by or rented to its occupant, or held vacant for sale. Let N_t denote the measure of owner-occupied houses (or, equivalently, the measure of homeowners), R_t denote the measure of houses for rent (or of renting households), and S_t the measure of houses vacant for sale. We then have

$$M_t = N_t + S_t + R_t \quad (4)$$

$$L_t = N_t + R_t. \quad (5)$$

Thus, in each period, the measure of houses in the city exceeds that of resident households by vacancies, S_t . Note that for each fixed house quality, q , equations analogous to (4) and (5) hold also.

Finally, there exist competitive markets in a complete set of one-period-ahead state-contingent claims paying off in units of the non-storable consumption good. These enable households to fully insure their idiosyncratic risks in the housing market (associated with λ and γ) and of losing the housing services from their current house

(associated with π). Households are also required to purchase/issue contingent claims to settle their estate in the event of death (associated with δ). Households face no financial constraints beyond that implied by their life-time budgets.

3 Equilibrium

Throughout, we focus on balanced growth paths in which rents, house prices and values all remain constant. Along such a path, the distributions of both households and houses across rental and owner-occupied markets are time invariant.

3.1 The supply-side decision problem

The most important choice in the economy is the rent vs. sell decision, made by owners of vacant houses, be they households or developers. Let $V_t(q)$ denote the value of a vacant house of quality q at the beginning of period t . Such a house may be either rented or held vacant for sale in the current period. Its value is

$$V_t(q) = \max \left\{ \underbrace{x_t(q) - \zeta_R(q) + \frac{V_{t+1}(q)}{1 + \rho}}_{\text{rent}}, \underbrace{\frac{1}{1 + \rho} \max_p [\gamma(\theta_t(q, p))p + (1 - \gamma(\theta_t(q, p)))V_{t+1}(q)]}_{\text{sell}} \right\}. \quad (6)$$

The first term in brackets is the value of renting the house and the second is that of holding it vacant for sale. The maximization operator in the second term reflects the optimal choice of sub-market by the seller. The seller, taking as given the search behavior of buyers, anticipates how market tightness, and consequently the matching probability, responds to the price.

All sellers value vacant houses of a particular quality identically. Thus, their indifference across *active* sub-markets gives rise to an equilibrium relationship between price and tightness for houses in a given market segment:

$$\gamma(\theta_t(q, p)) = \frac{(1 + \rho)V_t(q) - V_{t+1}(q)}{p - V_{t+1}(q)}. \quad (7)$$

Moreover, as sellers may freely decide whether to rent or hold a house vacant-for-sale, we have

$$V_t(q) = x_t(q) - Z_R(q) + \frac{V_{t+1}(q)}{1 + \rho}. \quad (8)$$

Conditions (7) and (8) equate house values across rental and sales markets. Free entry then implies that house values and rents are determined by construction costs. On the balanced growth path, house values and rental costs can therefore be represented by time-invariant functions of house quality:

$$V(q) = (1 + \rho)T(q) \quad (9)$$

$$x(q) = Z_R(q) + \frac{\rho}{1 + \rho}V(q) = Z_R(q) + \rho T(q). \quad (10)$$

Moreover, tightness for active sub-markets is a time-invariant function of p and q :

$$\gamma(\theta(q, p)) = \frac{\rho V(q)}{p - V(q)}. \quad (11)$$

3.2 The household decision problem

As households are risk-averse, have separable utility and markets are complete, they carry out financial transactions to smooth consumption completely. Specifically, at the beginning of each period, through the purchase and sale of contingent claims, households insure themselves against risks associated with preference shocks (which determine whether the household remains happy with their house), matching outcomes and death, all of which are random. From this point on, where possible, time subscripts will be suppressed.

Consider first a homeowner. This household may purchase/issue w_S units of a security, each of which pays one unit of consumption good in the next period contingent on receiving a preference shock and becoming a renter, and w_N units of a security that pay contingent on remaining a homeowner.¹⁶ The homeowner may also sell up to $V(q)$ units of contingent claims which pay-off in the event that the household dies at the end of the period. The payment of these claims is financed by the sale of the household's then-vacant house.

Similarly, a household renting while searching to buy a house may purchase w_B units of insurance that pay contingent on buying a house, and w_R units of a security that pay contingent on having failed to buy and continuing to rent. Finally, we impose that a household searching to buy in sub-market p of segment q must purchase $p - V(q)$ units of a claim that pays off contingent on the household committing to buy a house but then dying at the of the period.

¹⁶All households, on losing their access to housing services due to a shock, spend at least one period as a renter.

The prices of the contingent securities, in the order defined, are denoted ϕ_S , ϕ_N , ϕ_D , $\phi_B(q, p)$, $\phi_R(q, p)$, and $\phi_D(q, p)$. The last three prices depend on the house quality and the price as they insure against outcomes in a particular sub-market of a particular housing market segment.

At the beginning of each period, renters, depending on their *total wealth*,¹⁷ choose: (i) a type/quality of house to rent, q_R ; (ii) whether or not to search for a house to buy; and, if searching, (iii) a particular sub-market, p , (associated with a particular house type, q_S) in which to search; and (iv) a consumption level, c , and savings in the form of a portfolio of claims, $\{w_B, w_R\}$. For simplicity, the decision not to search for a house to purchase will be represented by the choice of $q_S = 0$ and $p = 0$. Accordingly, $\theta(0, 0) = \infty$ and $\lambda(\theta(0, 0)) = 0$. A renter with wealth w then has value:

$$W^R(w) = \max_{\substack{c, w_R, w_B, \\ q_R, q_S, p}} \left\{ \begin{array}{l} u(c) + h(0, q_R) \\ + \beta [\lambda(\theta(q_S, p))W^N(q_S, w_B - p) + (1 - \lambda(\theta(q_S, p)))W^R(w_R)] \end{array} \right\} \quad (12)$$

subject to:

$$c + \phi_B(q_S, p)w_B + \phi_R(q_S, p)w_R + \phi_D(q_S, p)(p - V(q_S)) + x(q_R) = w, \quad (13)$$

where $W^N(q_S, w_B - p)$ is the value of entering next period as an owner of a house of quality q_S with wealth $w_B - p$. This value is given by:

$$W^N(q, w) = \max_{c, w_N, w_S, w_D} \left\{ \begin{array}{l} u(c) + h(1, q) \\ + \beta [\pi W^R(w_S + V(q)) + (1 - \pi)W^N(q, w_N)] \end{array} \right\} \quad (14)$$

subject to:

$$c + \phi_S w_S + \phi_N w_N + \phi_D w_D + Z_N(q) = w \quad (15)$$

$$w_D + V(q) \geq 0. \quad (16)$$

3.2.1 Consumption and portfolio choice

Appendix A.1 contains the solution to households' portfolio allocation problem and the derivation of the optimal consumption by income. Let q_R , q_S , and p denote the

¹⁷Total wealth, w , is defined to include all available financial resources. In particular, the present discounted value of future labor income, $y/(1 - \beta)$, is contained in w . See Appendix A.1 for details.

optimal rental and search choices for a household with permanent income y .¹⁸ This household's (constant) per period consumption is given by

$$c = y - \frac{[1 - \beta(1 - \pi)]x(q_R) + \beta\lambda(\theta(q_S, p(y)))x(q_S)}{1 - \beta(1 - \pi - \lambda(\theta(q_S, p)))} - \frac{\beta\lambda(\theta(q_S, p))[1 - \beta(1 - \pi)](p - V(q_S))}{(1 - \delta)[1 - \beta(1 - \pi - \lambda(\theta(q_S, p)))]} \quad (17)$$

This is the highest attainable constant consumption sequence satisfying the present value budget constraint given the cost of insuring against both preference shocks and the matching risks associated with housing-related transactions.

3.2.2 Renting

The rent decision is determined by the *intratemporal* Euler equation associated with the choice of q_R in (12):

$$u'(c)x'(q_R) = \frac{\partial h(0, q_R)}{\partial q} \quad (18)$$

Here $x'(q_R)$ is the derivative of the time-invariant rental cost function from equation (10). First order condition (18) combined with (17) pins down the quality of housing rented by a household with permanent income y .

3.2.3 Home-ownership

Maximizing with respect to q_S and p in (12) reflects optimal search decisions with regard to house type and sub-market, where tightness $\theta(q, p)$ is determined by (11). A pair of intertemporal Euler equations (one for segment choice, q_S , the other for choice of sub-market, p) characterize the solution to the household's search problem, derived in Appendix A.2:

$$\frac{\partial h(1, q_S)}{\partial q} = u'(c) \left\{ \frac{[1 - \beta(1 - \pi)]p - (\beta\pi + \delta)V(q_S)}{(1 - \delta)V(q_S)} V'(q_S) + Z'_N(q_S) \right\} \quad (19)$$

$$p - V(q_S) = \mathcal{L}(\theta(q_S, p)) \left\{ x(q_R) - x(q_S) + \frac{h(1, q_S) - h(0, q_R)}{u'(c)} \right\} \quad (20)$$

¹⁸We suppress the dependence of q_R , q_S , p and c on y for brevity.

where $\mathcal{L}(\theta(q, p))$ reflects housing liquidity in sub-market p of segment q . More precisely,

$$\mathcal{L}(\theta) = \frac{(1 - \delta)(1 - \eta(\theta))}{1 - \beta(1 - \pi - \eta(\theta)\lambda(\theta))}, \quad (21)$$

where $\eta(\theta) = \theta\gamma'(\theta)/\gamma(\theta)$. The right-hand side of (20) is the price premium the searching household is willing to pay to acquire owner-occupied housing.

Household optimization is then represented by the decision rules, $c(y)$, $q_R(y)$, $q_S(y)$ and $p(y)$. These satisfy (17), (18), (19) and (20), with market tightness, $\theta(y) \equiv \theta(q_S(y), p(y))$, determined by (11).

3.3 An Equilibrium with Balanced Growth

The measure of renters with income level y evolves according to:

$$R_{t+1}(y) = (1 - \lambda(\theta(y)))(1 - \delta)R_t(y) + \pi(1 - \delta)N_t(y) + \nu f(y)L_t. \quad (22)$$

Here the first term is the measure of unsuccessful, surviving searchers who remain as renters, the second term that of mismatched surviving owners who enter the renter pool and the last is that of new entrants into the housing market.

Similarly, the measure of owners with income level y evolves according to:

$$N_{t+1}(y) = (1 - \pi)(1 - \delta)N_t(y) + \lambda(\theta(y))(1 - \delta)R_t(y). \quad (23)$$

This consists of surviving owners who remain well-matched and surviving renters who successfully match and buy a home. Dividing all quantities by the population, L_t , and using lower case letters to represent *per capita* values, the relative measures along a balanced growth path can be expressed as

$$r(y) = \frac{\nu + \pi(1 - \delta)}{\nu + (1 - \delta)[\pi + \lambda(\theta(y))]} f(y) \quad (24)$$

$$n(y) = \frac{(1 - \delta)\lambda(\theta(y))}{\nu + (1 - \delta)[\pi + \lambda(\theta(y))]} f(y). \quad (25)$$

Given (24) and (25), the (normalized) stocks of owner-occupied and rental housing of type q are $n(q_S^{-1}(q))$ and $r(q_R^{-1}(q))$, where $q_S^{-1}(q)$ and $q_R^{-1}(q)$ denote the income levels for households that buy and rent in segment q , respectively. Similarly, the

(normalized) stock of vacant houses for sale in segment q is $r(q_S^{-1}(q))/\theta(q, p(q_S^{-1}(q)))$. The per capita total stock of housing of each type therefore satisfies:

$$m(q) = n(q_S^{-1}(q)) + r(q_R^{-1}(q)) + \frac{r(q_S^{-1}(q))}{\theta(q, p(q_S^{-1}(q)))}. \quad (26)$$

We then have the following:

Definition 1. *A Directed Search Equilibrium Balanced Growth Path is a list of time-invariant functions of income $y \in \mathbb{R}_+$ and house quality, $q \in \mathbb{R}_+$:*

- i. household values, $W^R(w)$ and $W^N(q, w)$, and decision rules: $w_R(y)$, $w_B(y)$, $w_N(y)$, $w_S(y)$, $w_D(y)$, $c(y)$, $q_R(y)$, $q_S(y)$, and $p(y)$;*
- ii. house values, $V(q)$, and rents, $x(q)$;*
- iii. a function for market tightness, $\theta(q, p)$;*
- iv. shares of households renting and living in owner-occupied housing $r(y)$ and $n(y)$;*
- v. per capita stocks of housing, $m(q)$;*

such that

- 1. W^R and W^S satisfy the household Bellman equations, (12) and (14), with the associated policies $q_R(y)$, $q_S(y)$, $p(y)$, $c(y)$, $w_R(y)$, $w_N(y)$, $w_B(y)$, $w_S(y)$ and $w_D(y)$ satisfying (17)—(20) and (A.16)—(A.20);*
- 2. free entry into new housing construction and rental markets: that is, $V(q)$ and $x(q)$ satisfy (9) and (10);*
- 3. optimal price posting strategies by sellers of houses in the owner-occupied market: that is, $\theta(q, p)$ satisfies (11);*
- 4. the per capita measures of households, $r(y)$ and $n(y)$, satisfy (24) and (25);*
- 5. the stock of each type of housing grows at the rate of population growth: that is, $m(q)$ satisfies (26).*

4 A Calibrated Economy

We now parameterize the model to match several characteristics of the median MSA in a sample of U.S. cities. We then assess the extent to which the predictions of the model are consistent with observations of the within-city distributions of houses and households across rental and owner-occupied markets. In Section 5, we compare the cross-city predictions of the model with the data.

4.1 Baseline Calibration

4.1.1 Functional Forms

We use the following form for preferences:

$$u(c) = (1 - \alpha) \ln c \quad \text{and} \quad h(q) = \alpha \ln q. \quad (27)$$

This form is consistent with the observation of Davis and Ortalo-Magne (2011) that the share of income allocated to rent is roughly constant across renting households. Note that in (27), we set the ownership premium to zero so that there is no utility benefit to owning one’s home, *per se*. In this case, households own their own residences only because of cost advantages to doing so, if any. Along those lines, we assume that the maintenance costs incurred by owner-occupiers are proportional to q and that those incurred by landlords are greater and rise more than proportionately with q :

$$Z_S(q) = \zeta_0 q \quad \text{and} \quad Z_R(q) = Z_S(q) + \zeta_1 q + \zeta_2 (e^q - 1). \quad (28)$$

The exact functional forms assumed allow us to fit ownership rates by income quintile (see below).

Construction costs are assumed to be linear in house quality:

$$T(q) = \tau q. \quad (29)$$

Note that since q is itself an index, the assumption of linearity in (29) is not very restrictive. For example, any homogeneous function of q will generate identical results with an appropriate adjustment of the preference specification.

Our matching probabilities correspond to the so-called “telephone line” function derived from a congestion and coordination problem (see Cox and Miller, 1965; and Stevens, 2007):

$$\lambda(\theta) = \frac{\chi}{1 + \chi\theta} \quad \text{and} \quad \gamma(\theta) = \frac{\chi\theta}{1 + \chi\theta} \quad (30)$$

Here $\chi \in (0, 1)$ is a matching efficiency parameter reflecting buyers’ search intensity. Note that these matching probabilities satisfy Assumption 1.¹⁹

¹⁹Of course, other commonly-applied matching technologies also satisfy these assumptions (*e.g.* the “urn-ball” matching function). We do not, however, believe that our calibrated balanced growth path is very sensitive to these alternatives.

We model income as a quarterly flow distributed log-normally:

$$y \sim \log\mathcal{N}(\mu, \sigma^2). \tag{31}$$

This implies that incomes are bounded below by zero and that their distribution can be summarized by its first two moments. It also implies a one-to-one relationship between the standard deviation and the implied Gini coefficient.²⁰ The log-normal distribution is a common and convenient approximation for real world income distributions, which are typically left-skewed with a long upper tail.

4.1.2 Parameterization

Table 1 contains calibrated parameter values, together with the economy statistics with which each is most closely associated. The mean of log quarterly income, μ , is chosen so that median annual income is normalized to unity and the standard deviation, σ , is set so that the Gini coefficient corresponds to the average across MSA's. Given a value of δ chosen to deliver an annual death rate of 5%, the entry rate, ν , is chosen so that steady-state population growth is 1%. Given these parameters, the moving probability, π , is chosen to match an average ownership duration of 10 years and the matching parameter, χ , is set to generate an average time-to-sell of 1.25 quarters. The preference parameter, α , is set so that the model generates a mean rent to median income ratio equal to the corresponding average across MSA's.

The parameters of the maintenance cost functions, $\{\zeta_0, \zeta_1, \zeta_2\}$, were chosen to match the average city-level price-rent ratio and to minimize the sum of the squared differences between the equilibrium ownership rates by income quintile and those reported in Table 1 which are computed using census summary tables for all U.S. households in 2010.²¹ Table 2 displays the extent to which the calibrated economy successfully matches these targets. Figure 1 depicts the maintenance cost by market segment for both rentals and owner-occupied houses.

²⁰Below we use observed Gini coefficients computed for MSA's by the U.S. Census Bureau.

²¹See <https://www.census.gov/data/tables/time-series/demo/income-poverty/cps-hinc/hinc-05.2010.html>). For the U.S. economy as a whole, ownership rates for the bottom quintiles are likely higher than for households residing in MSA's. A disproportionate fraction of lower-income households live outside MSA's and own at a higher rate than those in MSA's.

Table 1: Calibrated Parameters

statistic	targeted value	calibrated parameter	calibrated value
median annual income (normalization)	1	μ	-1.3863
Gini coefficient for income	0.445	σ	0.8348
population growth rate (%)	1.0	ν	0.0152
probability of death/exit (%)	5.0	δ	0.0127
average ownership duration (years)	10	π	0.0250
average time to sell (quarters)	1.25	χ	0.7851
average price-rent ratio	24	ζ_0	0.0110
annual interest rate (%)	4.0	β	0.9776
ratio of mean rent to median income normalization	0.186	α	0.2243
	1	τ	1.0000
average ownership rate, Q1 (%)	44		
average ownership rate, Q2 (%)	56		
average ownership rate, Q3 (%)	67	ζ_1	0.0004
average ownership rate, Q4 (%)	77	ζ_2	0.0001
average ownership rate, Q5 (%)	87		

Table 2: Calibration Results

statistic	target value	model value
average ownership rate, Q1	0.44	0.4400
average ownership rate, Q2	0.56	0.5607
average ownership rate, Q3	0.67	0.6671
average ownership rate, Q4	0.77	0.7738
average ownership rate, Q5	0.87	0.8690

4.2 The City in Equilibrium

Figure 2 illustrates the housing decisions of households by income. Clearly, quality is strictly increasing in income for both rental (q_R) and owner-occupied (q_S) housing. At low incomes, households search to own houses of slightly lower quality than those they rent. At income levels above the median, however, households of a given income

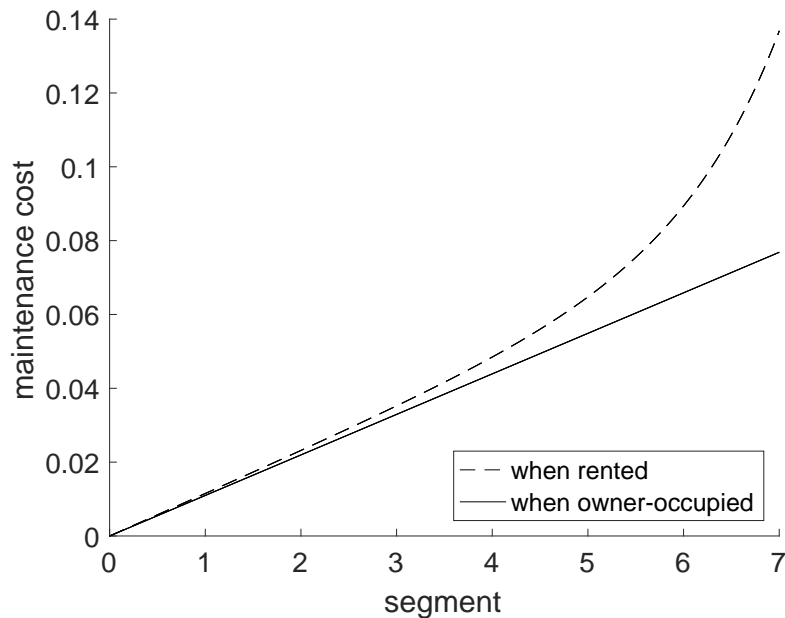


Figure 1: Maintenance costs by housing segment.

search for houses to buy of higher quality than they rent. This reflects the fact that higher quality houses are relatively expensive to rent, given their high relative maintenance costs.

Figure 3 plots home-ownership by income. The supply of owner-occupied housing to the very poorest households is low: these households choose to search in sub-markets with low prices and hence low matching rates. Beyond a point, however, home-ownership rises rapidly and then flattens out at high incomes. Intuitively, an increasing ownership rate manifests because the relatively high cost of maintaining higher quality rental houses translates into higher equilibrium rents. High income households seek high quality homes and thus search aggressively in the owner-occupied market by targeting high price sub-markets with better buying probabilities.

Figure 4 plots the relative cost of owning vs. renting by household income. For a household with a given permanent income, the figure compares the price of the house for which they search to buy to their annual rental cost while searching. The relationship in the figure reflects the differences in households' choice of house quality when renting versus owning (see Figure 2). Due to the scarcity of high quality rentals that results from their high rental costs, higher income households search to buy houses of much higher quality than they rent while searching. At levels of income

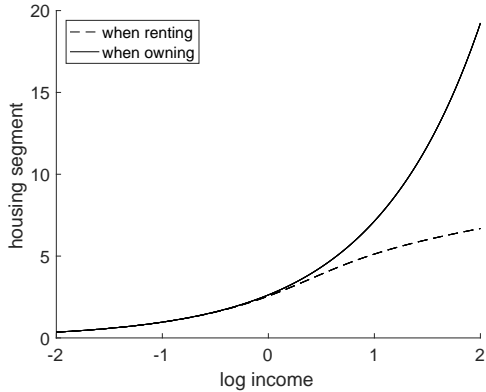


Figure 2: Market segment vs. income by housing tenure.

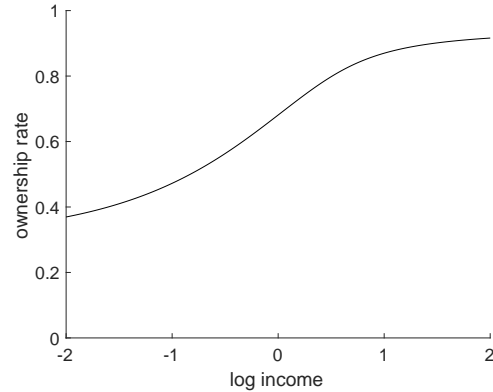


Figure 3: Ownership rate vs. household income.

below the median, the effect is small, even negligible, reflecting the relatively small gap in maintenance costs between rented and owner-occupied homes of a given quality.

The rapid rise in relative maintenance costs as quality increases results in the relationship depicted in Figure 5, which plots the price-rent ratio by market segment. These maintenance costs (which depend on an interaction between occupant household’s tenure and the physical characteristics of the house) may be seen as an example of “unobservable costs of renting” in the language of Halket, Nesheim and Oswald (2015) who, as noted above, observe a price-rent ratio declining in house quality.

The price-rent ratio for a house of a given quality is low, yet the calibrated model delivers an aggregate price-rent ratio of 24. This reflects households’ heterogeneous search strategies in the owner-occupied market. Figure 6 displays the histogram of housing market transactions by income for both sales and rentals. High income households are responsible for a large share of transactions in the owner-occupied market, whereas the opposite is true for the rental market. Both of these contribute to a high overall price-rent ratio. The distributions of transactions by income play a crucial role in the calculation of aggregate statistics and are important determinants of the cross-city implications derived below.

Overall, the balanced growth path has the following robust features:

- Within the city, home-ownership is increasing in income.
- Rental housing is generally of low quality relative to that which is owner-occupied, and renters are of relatively low income.
- The price-rent ratio is lower for high quality houses.

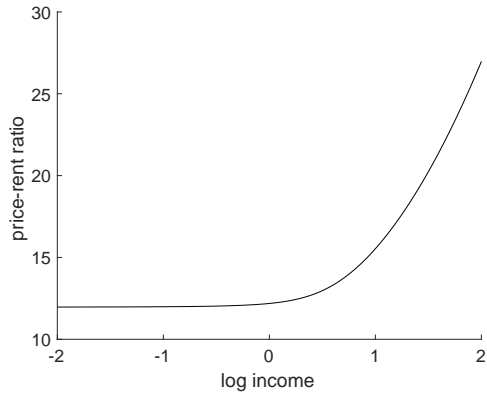


Figure 4: Price-rent ratio by household income.

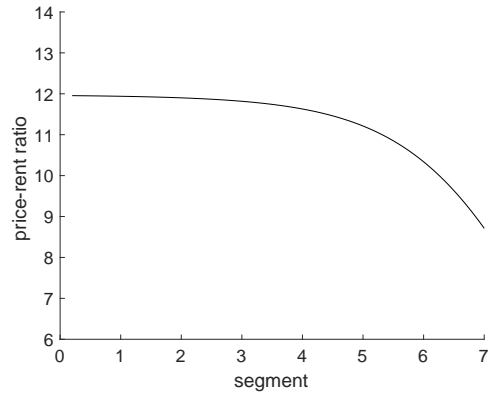


Figure 5: Price-rent ratio by housing segment.

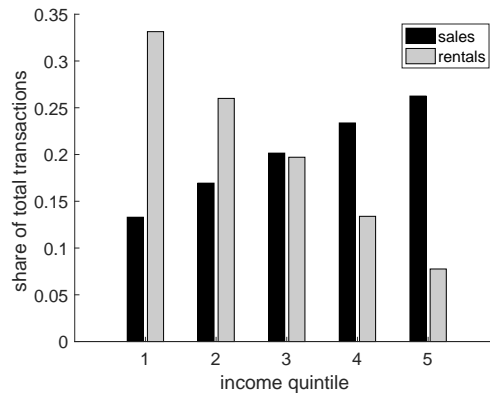


Figure 6: Histograms of house purchases and rentals by income.

As noted above, these results are broadly consistent with empirical observations. They are driven in large part by the fact that the gains to ownership are increasing in house quality. In the baseline calibration, these gains stem from the maintenance function, (28), which is calibrated to match ownership rates by income quintile.

4.3 Comparisons across equilibrium balanced-growth paths

We now consider the effects of changes in median income, income inequality (*i.e.* the Gini coefficient), median age (or population growth) and land/construction costs on both home-ownership and the relative cost of owner-occupied vs. rental housing (measured by the average price-rent ratio) along the balanced growth path. As above, these relationships depend on the relative costs of owning and renting, and reflect the equilibrium implications of both rent vs. buy decisions on the demand side and rent vs. sell decisions on the supply side.

4.3.1 Median income

As city median income increases holding inequality constant, the quality of housing desired by households rises. Moreover, since the cost of maintaining rental properties increases with quality, so also does the fraction of developers and moving households who sell rather than rent their vacant houses. In equilibrium, the search frictions in the housing market allow the increasing costs of renting to support a selling probability that *falls* (and a buying probability that *rises*) with quality. Consequently, (see Figure 7a), the rate of home-ownership increases with median income.

In general, the implication of rising city median income for the ratio of average prices to average rents is ambiguous. Since the quality of housing rises and more of it is owned, the average purchase price must increase. Average rents, however, also increase as households demand higher quality housing. Which increase is larger depends on the distribution of the home-ownership rate by income. On the balanced growth path, this depends on the relationship between matching probabilities and income, which in turn is dictated by the relative costs of renting, owning and selling. Under our calibration, the ratio of average prices to average rents rises with median income. If relative maintenance costs were independent of quality, neither home-ownership nor the average price-rent ratio would vary with median income.

4.3.2 Inequality

As inequality increases holding median income constant, the quality of housing desired by relatively high income households increases while that desired by relatively low income households declines. Since the relative costs of renting rise sharply for increases in quality at the upper end, but fall only minimally as quality declines at the lower end, the fraction of high quality houses supplied to the owner-occupied market rises while that of low quality houses falls.

The impact on the aggregate home-ownership rate is in general ambiguous and again depends on the relationship between ownership rates and household income. In our calibration, the relative costs of owning and renting imply a concave relationship over most of the income distribution (see Figure 3). Consequently (see Figure 7b), home-ownership falls with inequality as measured by the income Gini coefficient.

At the same time, increased income inequality *raises* the average price-rent ratio through a composition effect. Having more low-income households results in the construction of more low quality houses. While this lowers *both* prices and rents, the effect on the former is mitigated by the fact that low income households buy houses at a low rate. Similarly, having more high-income households results in more high quality houses being built and drives *up* both prices and rents. In this case, however, the effect on the *latter* is minor as high-income households rarely rent. Overall, as shown in Figure 8b the increase in the purchase prices of high quality homes and the reduction in rents together result in an increase in the average price-rent ratio.

4.3.3 Median age

To the extent that death rates do not vary much across cities, variation in median age largely reflects variation in entry rates and steady-state population growth. Figures 7c and 8c depict the relationships between median age and home-ownership and the average price-rent ratio, respectively, resulting from variation in the entry rate, ν . Ownership increases monotonically with median age. An older city has a lower rate of entry, and as such a smaller fraction of the population renting while searching for an initial house. This accounts directly for the effect of age on ownership. The impact of median age on the price-rent ratio is small and, while for this calibration it is negative, for others it can be positive.

4.3.4 Construction costs and city-wide amenities

The parameter τ represents the cost of building per unit of housing quality. As such, it reflects city-wide amenities (*e.g.* climate) and costs (*e.g.* regulatory hurdles) as well as the choices of developers (*e.g.* land, size, construction materials, etc.). Variations in τ capture all the costs of providing housing that are *independent* of whether the occupying household owns or rents.

An increase in τ translates into a proportional increase in the value of vacant housing required to induce competitive developers to supply new housing of any quality. The resulting rise in both rents and purchase prices causes households at every given income level to choose lower quality housing which, in turn, reduces the relative costs of renting. Consequently, as shown in Figure 7d, the aggregate ownership rate declines as τ increases.

In general, the impact of an increase in τ on the ratio of average prices to average rents is more ambiguous. While the purchase prices and rents paid for houses of a given quality rise, this is largely offset at the household level by the reduced quality of such houses. A more important factor determining the relative impact on average prices and average rents is the implied distribution of changes in the ownership rate across income levels. This, in turn, depends on the shift in the steady state mappings between income and matching probabilities.

As may be seen in Figure 8d, our calibration implies the ratio of average prices to average rents increases with τ . This results from the combination of two effects. First, overall the quality distribution shifts to the left as houses become less affordable. This results in a general reduction of relative rental costs, and hence an increase in the price-rent ratios, segment by segment (see Figure 5). The second, and more significant effect, comes from the fact that any reduction in home-ownership is overwhelmingly concentrated amongst low-income households. High-income ones continue to own, paying relatively high prices simply because they live in high quality houses.

Note, once again, that if the relative cost of renting (through maintenance) were independent of quality, neither home-ownership nor the average price-rent ratio would vary with the supply side factors represented by τ .

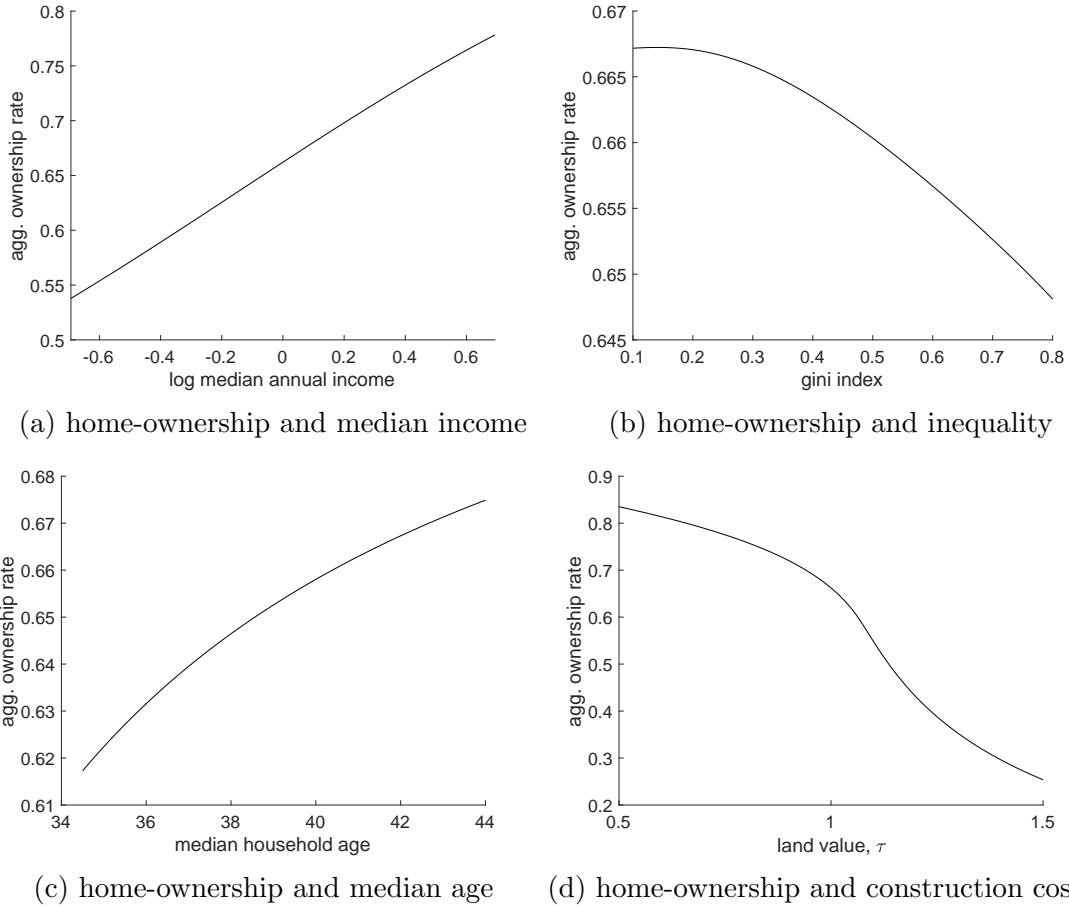


Figure 7: Cross-city relationships between home-ownership and fundamentals

5 Cross-City Variation in the Data and the Theory

We now document observed variation across U.S. cities with regard to home-ownership and the relative costs of owning and renting (price-rent ratios) and consider the extent to which it is associated with variation in median incomes, inequality, age and land values, controlling for several other factors. We then compare the corresponding variation generated by the model to these characteristics of the data.

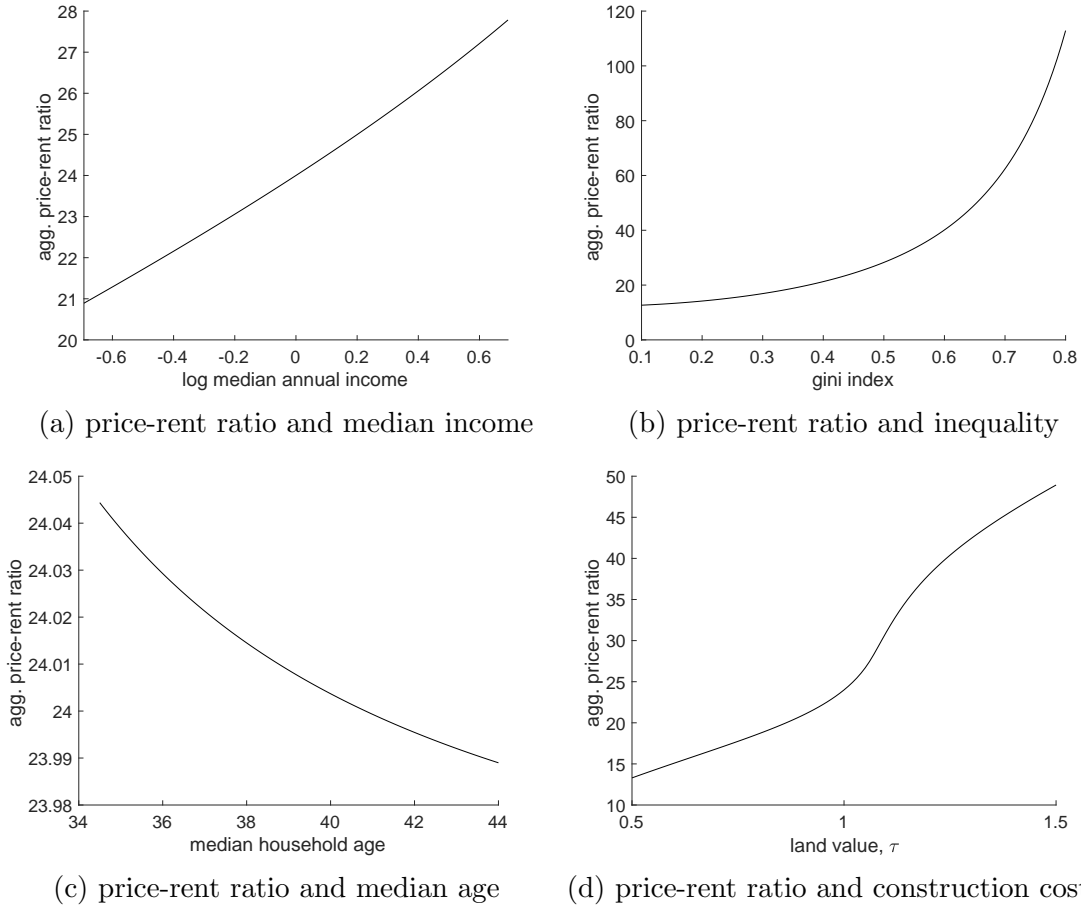


Figure 8: Cross-city relationships between the price-rent ratio and fundamentals

5.1 Variation Among a Sample of U.S. Cities

Our base sample consists of the 366 primary MSA’s from the 2010 American Community Survey (ACS).²² For all of these MSA’s ownership rates, average price-rent ratios, median incomes, Gini coefficients, median age and population density can be computed from the ACS. Since it affects average lot size, population density should be inversely related average city-wide housing quality.

We take the view that land values are the main source of variation in overall construction costs across cities. Land values are taken from Albouy *et al.* (2017) who

²²An MSA is an urban agglomeration containing at least 50,000 households. These 366 MSA’s contain over 83% of U.S. households.

compute them at the MSA level using land transactions data, adjusted to account for geographic selection in location and limited sample sizes. Their calculations are based on the 1999 OMB definitions of MSA's. There is not an exact match between MSA's in the two samples for several reasons. For example, there were several new primary MSA's in the 2010 census resulting from population growth, some MSA's were subdivided and others experienced name changes. After matching the MSA's as closely as possible and, where they were subdivided, applying the same land values to each, we were left with 332 MSA's.²³

To isolate the role of costs per unit of housing quality we must control for average quality (density and amenities). The amenity controls that we use are "natural" amenities taken from Albouy (2016). This data is also based on the 1999 OMB definitions of MSA's. Moreover, in this case some of the observations are for consolidated MSA's, which combine congruent primary MSA's. In order to maximize our sample size, we use the amenity controls computed for the consolidated MSA's to approximate those for each constituent primary MSA.

In the first column of Table 3 the dependent variable is the ownership rate by MSA, computed as the ratio of owner-occupied units to total (owner and renter) occupied units. As predicted by our model, the ownership rate is positively associated with median income and age and negatively associated with inequality. These three variables along with population density account for over 50% of the variation in the ownership rate across cities. In the second column we add land values (\$ per acre) and the amenity controls.²⁴ As predicted by the model, ownership is negatively and significantly associated with land values, controlling for amenities and density.

For the remaining columns of Table 3 the dependent variable is the average price-rent ratio by MSA. In all cases, *rent* refers to the mean gross rent of renter-occupied housing units. In the second two columns *price* refers to the mean price asked for vacant units for sale whereas in the last two columns, it refers to the mean estimated value of all owner-occupied housing units. Again, as predicted by the model, the estimates in the second two columns imply that average price-rent ratios are positively and significantly associated with median income, inequality and land values.^{25,26} The

²³See Appendix B for details.

²⁴Full estimation results are provided in Appendix C.

²⁵We also considered controlling for city-size as measured by the total number of households in each MSA. The results are robust to the inclusion of this variable and, while statistically significant in some cases, it does not add any explanatory power to the regressions.

²⁶The results in Table 3 are also robust to controlling for average property tax rates across cities using data from the Lincoln Institute of Land Policy. Table 13 in Appendix C documents the results of estimating the same regressions as in Table 3, but with the inclusion of our estimated tax rate

Table 3: U.S. Metropolitan Statistical Areas (2010)
(Median income not adjusted for local non-housing cost of living)

	Ownership Rate		Price-Rent ratio			
			(price-asked)		(estimated-value)	
Log Median Income	0.022	0.076	23.560	14.497	22.141	13.088
Robust s.e.	(0.021)	(0.021***)	(2.458***)	(2.283***)	(1.972***)	(1.653***)
Clustered s.e.	(0.024)	(0.030**)	(2.410***)	(2.833***)	(2.057***)	(2.114***)
Gini index	-0.511	-0.449	89.809	90.286	53.287	65.427
Robust s.e.	(0.116***)	(0.130***)	(13.445***)	(13.677***)	(9.682***)	(8.240***)
Clustered s.e.	(0.155***)	(0.138***)	(18.925***)	(13.395***)	(16.261***)	(8.523***)
Age	0.007	0.007	0.205	0.032	0.239	0.122
Robust s.e.	(0.001***)	(0.001***)	(0.084**)	(0.077)	(.057***)	(0.039***)
Clustered s.e.	(0.001***)	(0.001***)	(0.119*)	(0.083)	(.096**)	(0.044***)
Log Density	-0.028	-0.024	-1.631	-3.585	0.226	-1.447
Robust s.e.	(0.005***)	(0.005***)	(0.679**)	(0.680***)	(0.492)	(0.407***)
Clustered s.e.	(0.009***)	(0.006***)	(0.991)	(0.787***)	(0.947)	(0.336***)
Log Land Value		-0.010		2.680		2.321
Robust s.e.		(0.004**)		(0.606***)		(0.392***)
Clustered s.e.		(0.005**)		(0.736***)		(0.651***)
Amenity Controls	No	Yes	No	Yes	No	Yes
\bar{R}^2	0.52	0.63	0.26	0.56	0.42	0.79
# obs	366	332	366	332	366	332

- Notes: (1) Sources and definitions of variables may be found in Appendix B.
(2) Standard errors are provided in parenthesis:
heteroskedasticity-robust and clustered at the state level.
(3) *, ** and *** indicate statistical significance at the 10, 5, and 1% levels, respectively.

effect of median age is small and less robust.

Table 4 presents the same regressions but where median incomes are adjusted using a local cost of living index (COLI) for non-housing expenditures. This index is not available for every MSA, so this reduces the base sample size to 219 MSA's. When combined with the land value and amenity data, the sample size is further reduced to 199 MSA's. Nonetheless, the correlations with median income, the Gini index, age and land values remain much the same as in Table 3 and the impacts of controlling for amenities are very similar.

Overall, these results conform very well qualitatively with the cross-city predictions of our model. In Appendix C, we show that this conformity extends to smaller urban areas (micropolitan areas and urban clusters). While these estimates cannot be

variable.

Table 4: U.S. Metropolitan Statistical Areas (2010)
(Median income adjusted for local non-housing cost of living)

	Ownership Rate		Price-Rent ratio			
			(price-asked)		(estimated-value)	
Log Median Income	0.089	0.093	4.613	5.874	7.163	5.945
Robust s.e.	(0.030***)	(0.025***)	(3.582)	(3.020*)	(3.208**)	(2.105***)
Clustered s.e.	(0.031***)	(0.030***)	(2.924)	(3.120*)	(2.527***)	(2.720**)
Gini index	-0.380	-0.448	27.740	56.147	3.119	46.824
Robust s.e.	(0.134***)	(0.160***)	(19.005)	(18.544***)	(14.495)	(11.085***)
Clustered s.e.	(0.157**)	(0.148***)	(25.661)	(17.899***)	(25.131)	(14.960***)
Age	0.006	0.008	0.215	-0.066	0.324	0.097
Robust s.e.	(0.001***)	(0.001***)	(0.118*)	(0.091)	(0.086***)	(.061)
Clustered s.e.	(0.001***)	(0.001***)	(0.133)	(0.101)	(0.118***)	(.062)
Log Density	-0.038	-0.025	1.605	-2.766	2.681	-1.175
Robust s.e.	(0.005***)	(0.005***)	(0.875*)	(0.735***)	(0.754***)	(0.500**)
Clustered s.e.	(0.008***)	(0.006***)	(1.200)	(0.808***)	(1.193**)	(0.468**)
Log Land Value		-0.012		3.851		3.979
Robust s.e.		(0.005***)		(0.685***)		(0.494***)
Clustered s.e.		(0.005***)		(0.769***)		(0.874***)
Amenity controls	No	Yes	No	Yes	No	Yes
\bar{R}^2	0.52	0.65	0.07	0.49	0.24	0.77
# obs	219	199	219	199	219	199

Notes: See Table 3

interpreted as causal, they do suggest that our stylized model replicates qualitatively the patterns observed in the data.

5.2 Cross-city Variation in the Theory

Here we attempt to quantify the relative importance of variation in MSA-level characteristics in driving cross-city variation in ownership rates and price-rent ratios that is implied by our theory. While we can set median income, the Gini coefficient and median age in the model to match those observed for the corresponding city in the 2010 ACS,²⁷ there is no single variable in the data that corresponds to τ : construction costs per unit of quality.

²⁷The sample here is of the 219 U.S. MSA's for which COLI's are available. Average age is controlled by population growth, and is subject to the requirement that growth be neither less than 0% nor greater than 5% annually.

Variation in the model parameter τ ultimately depends, in the data, on variation in multiple variables related to construction/land costs and city-wide amenities. We therefore essentially impose our theory on the data in order to infer the distribution of τ 's across cities. Specifically, we compute city-specific τ 's to minimize the weighted distance between actual and predicted values of home-ownership and the average price-rent ratio, where the weights are inversely proportional to their variance.²⁸ Figures 9 and 10 depict the results. The ratio of the explained sum of squares to the total sum of squares implied by this procedure is 0.63.

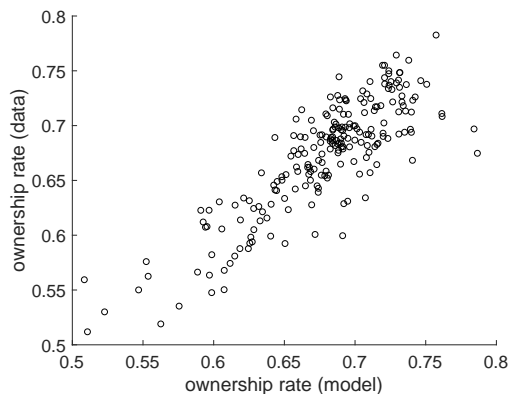


Figure 9: Ownership in the data and the model with variation in construction/land costs.

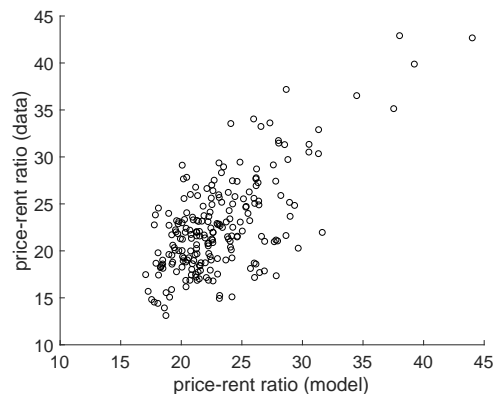


Figure 10: Price-rent ratio in the data and the model with variation in construction/land costs.

Table 5: Relationship between Inferred τ 's and Land Costs and Amenities

	Log of Inferred τ					
Cdd65	0.048 (0.014***)	0.049 (0.012***)	0.039 (0.012***)	–	–	–
Hdd65	0.031 (0.005***)	0.026 (0.005***)	0.012 (0.006**)	–	–	–
Sun_a	0.332 (0.082***)	0.169 (0.084**)	0.096 (0.081)	–	–	–
Slope_pct	0.007 (0.002***)	0.008 (0.002***)	0.005 (0.002***)	–	–	–
Inv_water	0.545 (0.122***)	0.216 (0.135)	-0.004 (0.145)	–	–	–
Latitude_w	0.010 (0.002***)	0.006 (0.002**)	0.002 (0.002)	–	–	–
Log Density	–	0.048 (0.008***)	0.023 (0.011**)	–	–	–
Log Land value	–	–	0.059 (0.011***)	0.031 (0.013**)	–	–
Log Amenity	–	–	–	0.470 (0.100***)	–	–
Constant	-0.467 (0.122***)	-0.570 (0.103***)	-0.576 (0.105***)	-0.198 (0.072***)	–	–
R^2	0.29	0.37	0.45	0.43	–	–
# obs	199	199	199	201	–	–

Notes: Heteroskedasticity-robust standard errors in parenthesis.

²⁸For details on the procedure used, see Appendix B.

To assess the validity of this procedure, Table 5 reports estimates of a least-squares regression across MSA’s of our inferred τ ’s on average land values (from Albouy *et al.*, 2017), population density and various natural amenity measures (from Albouy, 2016). As seen in the first three columns of Table 5 these explanatory variables are statistically significant and account for almost half of the variation in τ . The last column replaces the direct amenity measures with a city-level amenity index constructed by Albouy (2016). As may be seen, this more parsimonious representation accounts for almost as much of the overall variation as before. While there are obviously numerous unobserved factors which determine the variation in these inferred τ ’s, it seems clear that it does indeed reflect variation in actual land costs and amenities.

Table 6 documents the changes implied by the model in the ownership and the price-rent ratio as a result of a one standard deviation change in each of the MSA-level characteristics. Overall, these results demonstrate that while variation in income, inequality and population growth play a role in determining variation in the ownership rates and average price-rent ratios rate across cities, variation in land costs and average amenities is the most important factor, quantitatively, for understanding these relationships.

Table 6: Relative Importance of MSA-level Characteristics

	One Standard Deviation (SD) Increase			
	Median Income	Gini Index	Median Age	Construction Cost
Ownership Rate (in SD’s)	0.4528	-0.0134	0.5219	-0.9152
Price-Rent Ratio (in SD’s)	0.1239	0.3071	-0.0049	0.5093

Notes: This table displays the effects on the ownership rate and the price-rent ratio of a one SD increase (from .5 SD’s below to .5 SD’s above the mean) for each of the four factors indicated in the column headers. These effects are expressed in SD’s of the dependent variable of interest.

6 The Affordability of Housing

In the model, everyone can “afford” housing of *some* quality, as any $q > 0$ can feasibly be supplied. Moreover, all households can afford to *buy* housing, although as noted above, some households may not by choice.²⁹ Nevertheless, in the model the

²⁹In the absence of supply constraints, such “permanent renters” will be only those with incomes below a particular cutoff level which depends on parameters. In the presence of supply constraints, however, examples may be constructed in which households in any region of the support of the income distribution choose to rent permanently.

distribution of income and the cost of supplying housing interact to determine the type of housing that households at various positions in the income distribution can afford, both to rent and to buy. Exogenous wealth inequality generates inequality of well-being, in part attributable to differential access to housing. As such, redistribution can be beneficial depending on one’s definition of social welfare. To study these issues, we consider the implications of policies designed to increase the *affordability* of housing, using a standard definition taken from the National Association of Realtors (NAR).

6.1 The Housing Affordability Index (HAI)

The Housing Affordability index (HAI) is defined as:

$$\text{HAI} = \frac{y_m}{y_q} \times 100; \tag{32}$$

where y_m denotes median (annual) household income,³⁰ and y_q denotes *qualifying* income.³¹ The latter is taken to represent the annual income flow required to afford, “reasonably”, the mortgage payment on the median-priced home.³²

Our notion of “reasonableness”, with regard to affording a mortgage payment, is based on the following assumptions:

- (i) The household makes a 20% down-payment. Of course, in our model, households need not do this, nor would they choose to given the concavity of utility and the existence of complete financial markets.
- (ii) The mortgage interest rate is 4% annually; the monthly rate is thus $i_m = .04/12$.
- (iii) The amortization period is 30 years or 360 months.
- (iv) The household spends no more than 25% of its income on its mortgage payment.

Let p_m denote the price of a house of median quality (equivalently in the model, the median price of a house). We then have:

$$y_q = 4 \times \underbrace{\frac{(1 - 0.2)p_m i_m}{1 - \left(\frac{1}{1+i_m}\right)^{360}}}_{\text{monthly payment}} \times 12. \tag{33}$$

³⁰As we assume a log-normal distribution of income, y , with mean μ , and interpret it as a quarterly flow, $y_m = 4e^\mu$.

³¹Note that this HAI measures, specifically, the affordability of *home-ownership*.

³²The method used by the NAR in constructing HAI’s for various housing markets is described online at: <https://www.nar.realtor/topics/housing-affordability-index/methodology>.

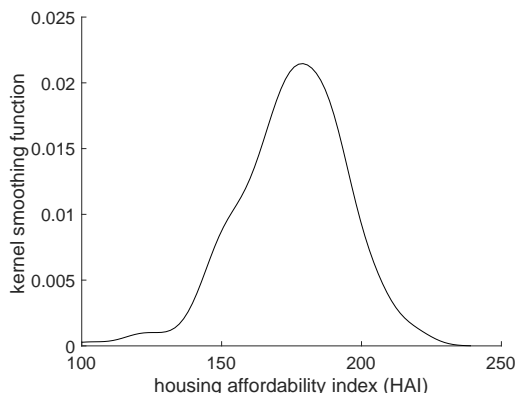


Figure 11: Housing affordability across cities (kernel density estimate).

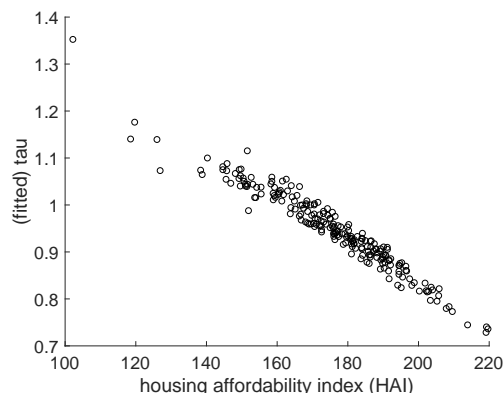


Figure 12: Fitted measure of construction costs and housing affordability.

A lower HAI indicates that housing is *less* affordable.

In our baseline calibration the $\text{HAI} = 166$. That is, a household with median income has a quarterly income flow 1.66 times that of the qualifying income. Using the values of τ fitted to match the variation in ownership rates and price-rent ratios across U.S. MSA's (see Figures 9 and 10 in Section 5), the HAI ranges from $\underline{\text{HAI}} = 119$ to $\overline{\text{HAI}} = 221$. Figure 11 depicts a kernel density estimate for the distribution of HAI's across the 219 cities in our sample. Figure 12 plots the HAI for each of these cities against the fitted value of τ . Clearly, housing affordability in the model is closely related negatively to the cost of producing a unit of housing quality.

In the model, city-level housing affordability affects *home-ownership* significantly for lower income households only. Figure 13 plots home-ownership rates for households in the 20th, 50th and 80th income percentiles against the HAI for each city in the sample. In the figure it is clear that affordability is effectively uncorrelated with home-ownership for households in the 80th percentile, and shows only a slight positive correlation for those in the 50th. For households in the bottom quintile, however, the correlation of affordability with ownership is striking.

6.2 A Policy to Improve Housing Affordability

We now consider the effects of a simple policy designed to increase the affordability of housing, with emphasis on houses targeted by low income households. We have in mind a policy through which government subsidies reduce the cost of producing

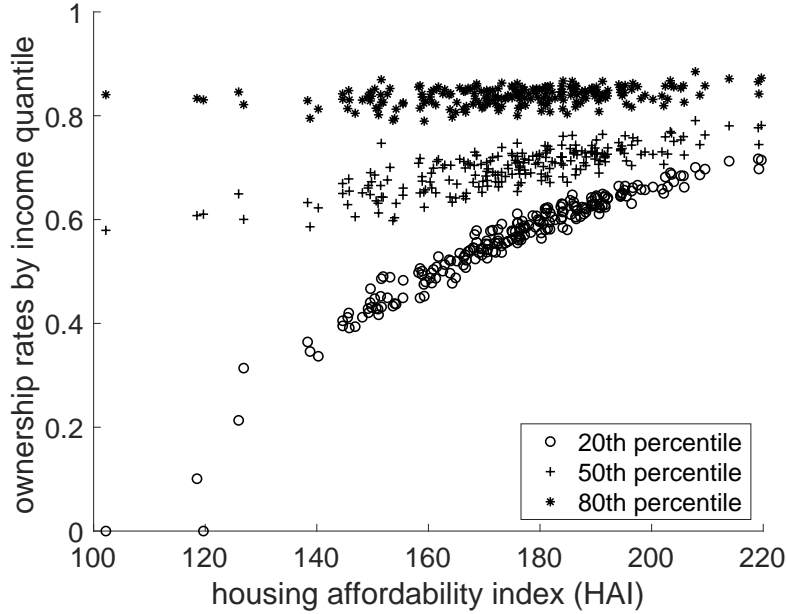


Figure 13: Ownership across cities by income quantile.

housing in the market segments targeted by these households. Specifically, consider a tax/subsidy scheme that changes the cost of construction from $T(q) = \tau q$ to

$$\hat{T}(q) = [\hat{\tau}_0 + \hat{\tau}_1(q - \hat{q})] \tau q \quad (34)$$

where $\hat{\tau}_0 \leq 1$, $\hat{\tau}_1 > 0$, and $\hat{q} > 0$. Under the policy, developers building houses of quality $q < \hat{q} + (1 - \hat{\tau}_0)/\hat{\tau}_1$ receive subsidies, while those building houses of quality $q > \hat{q} + (1 - \hat{\tau}_0)/\hat{\tau}_1$ are taxed. This policy is chosen not to mimic any specific policy observed, but rather to illustrate the implications of policies of a general form. The construction cost changes its effects are passed through to home buyers through competition in the directed search equilibrium.

We think of (34) as representative of a number of different possible policies designed to make housing more affordable in the sense of raising the HAI. For example, alternatively we could specify a subsidy to construction overall, coupled with an appropriately progressive property tax on both homeowners and rental properties.³³ That said, it is not representative of all policies that change the relative costs of supplying and/or occupying houses of different qualities. For example, the policy

³³A proportional income tax will make no difference; such a tax is effectively already present in the baseline model.

treats rental and owner-occupied houses symmetrically, and as such neither encourages nor discourages home-ownership directly. In any case, the particular allocation of consumption, housing quality, ownership rates, etc. that arises in the presence of the policy clearly could be implemented via a number of different policies with observationally equivalent results.

Now, consider a relatively “unaffordable” city with a construction cost parameter $\tau = 1.0362$. This corresponds to an HAI one standard deviation below the average for the 219 simulated MSA’s in Section 5.2. Specifically, the city has an HAI = 157 whereas the average HAI = 178. We construct a policy of the form (34) that

- (i) raises the HAI for the city to the *average* affordability, and
- (ii) balances the budget at the city level. That is, the total taxes collected in equilibrium equal the total subsidies paid out.

The following policy satisfies these requirements in the stationary equilibrium:

$$\{\hat{\tau}_0, \hat{\tau}_1, \hat{q}\} = \{0.9007, 0.0171, 0.1779\}. \quad (35)$$

Construction costs with and without the affordability policy are displayed in Figure 14. As may be seen, under this particular policy, the effective costs of relatively high quality housing must be increased substantially in order to achieve somewhat lower costs of relatively low quality housing. This reflects first the fact that given the distribution of households across housing quality levels (which depends on the distribution of income) the majority of households are effectively subsidized while relatively few are taxed. Second, it reflects, as we will see, substitution of relatively high income households into lower quality housing units.

The affordability policy affects the levels and distributions of home-ownership, housing quality, consumption, and welfare. It generally redistributes from upper to lower income households. It has, however, effects throughout the distribution.

6.2.1 Home-ownership

While the net effect on construction costs is small (as the budget is balanced) overall home-ownership rises significantly, from 63.08% in the baseline to 68.57% under the policy. This occurs in spite of the fact that the policy does not favor home-ownership *per se*. The increase in home-ownership is concentrated overwhelmingly in the bottom half of the income distribution, as can be seen in Figure 15.

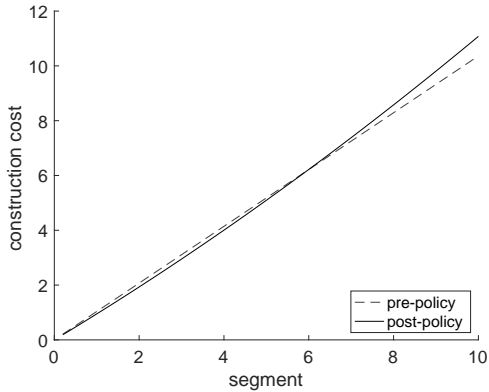


Figure 14: Construction costs.

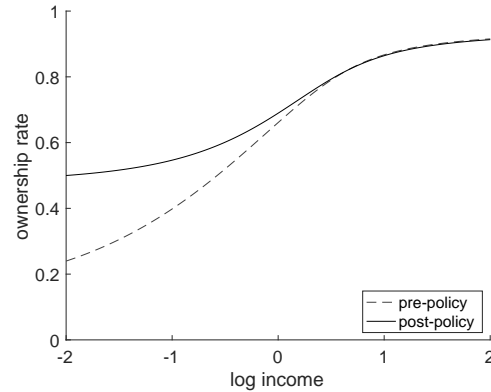


Figure 15: Ownership rate vs. income.

The increase in home-ownership is driven by the relative cost of renting vs. owning. In equilibrium, the cost of renting depends on the both the construction cost *and* the cost of maintenance. Construction costs, of course, are changed directly by the policy. The cost advantage to owning, then, lies in avoiding increased relative costs of renting, which stem from relative maintenance costs that increase with quality.

For low quality housing, the relative cost of renting is small and importantly, does not change much with q (see Figure 1). A small reduction in the construction cost lowers the cost of housing services (regardless of tenure), induces households to demand higher quality houses, and thus increases the relative cost of renting. This, together with the fact that a significant share of the population lives in relatively low quality rental housing, leads to a large increase in home-ownership for this segment of the population.

In contrast, houses occupied by above median income households are sold (rather than rented) at high rates even in the baseline. The policy *increases* both rents and prices for these houses. Market tightness rises, sending prospective buyers into lower quality sub-markets. While the policy reduces the *quality* of their housing, it has only very minor effects on their rates of ownership.

6.2.2 Housing quality and costs

While the affordability policy changes home-ownership significantly only for households in the bottom 50% of the income distribution, it affects housing quality and both prices and rents throughout the distribution. Table 7 documents the average

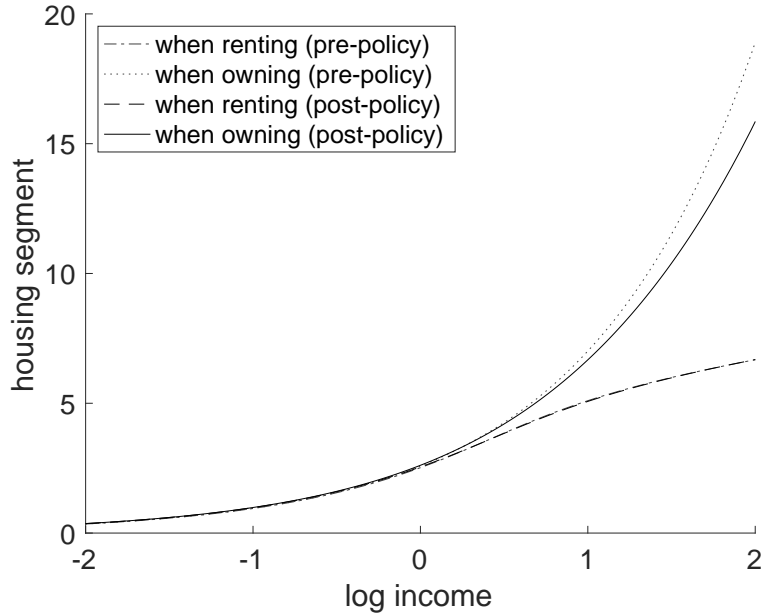


Figure 16: Market segment vs. income by housing tenure.

quality of housing consumed by a “representative” household at the midpoint of each quintile of the income distribution both before and after the policy change. As can be seen, the average quality of housing for the representative household rises for the bottom three quintiles and falls for the top two quintiles. The decline in housing quality is large for households in the top quintile.

The effects of the policy are not surprising given that it affects directly the construction cost and hence the rent and return to selling differentially for low and high quality houses. As noted above, the rents on high quality houses (inhabited by high income households) rise, sending households into lower quality segments as both renters (due to the direct increase in rent) and as prospective owners (due to the increase in tightness associated with diminished returns to selling in this quality range). Similar forces are at work (in reverse) for lower quality houses which see their construction costs reduced; rents fall, inducing lower income households to rent better houses and to search in higher quality segments where tightness has declined.

Overall, the city-wide average quality of rented housing rises while that of owner-occupied housing declines. The former effect reflects mainly the increase in housing quality for low income households who rent at a high rate. The latter reflects the combined effects of the increase in ownership (of low quality housing) by low income

households and the decline in quality for high income ones.

The affordability policy lowers the average sale price from 4.69 to 4.25, by reducing the cost of building low quality homes. The policy, however, *raises* average rent slightly (from 0.18 to 0.19) by raising the average quality of homes rented, most commonly by low-income households. The policy reduces the average price/rent ratio from 25.80 to 22.06 and, as intended, raises the HAI from 157 to 178.

Table 7: Housing Quality under the Policy to Improve Housing Affordability

Household Income	q When Renting		q When Owning		Average q	
	<i>Pre-</i>	<i>Post-</i>	<i>Pre-</i>	<i>Post-</i>	<i>Pre-</i>	<i>Post-</i>
$F^{-1}(0.1)$	0.8796	0.9113	0.8823	0.9153	0.8806	0.9135
$F^{-1}(0.3)$	1.6487	1.6881	1.6636	1.7050	1.6567	1.6984
$F^{-1}(0.5)$	2.5147	2.5424	2.5777	2.6059	2.5563	2.5862
$F^{-1}(0.7)$	3.6725	3.6642	3.9924	3.9546	3.9207	3.8909
$F^{-1}(0.9)$	5.2329	5.2068	7.4817	7.0778	7.1960	6.8350
Agg. Average q	2.0377	2.2053	4.4184	3.9590	3.5450	3.4125

6.2.3 Consumption and welfare

The affordability policy affects the consumption of both goods and housing services for all households. The bottom row of Table 8 measures the impact on welfare for the median household in each quintile using the percentage change in goods consumption that would have the effect on household utility equivalent to that of the policy. Overall, the policy increases welfare for the median household in each of the bottom four quintiles while reducing welfare for that of the top quintile. The percentage welfare gain is largest for the bottom quintile and falls as income rises.

The first five rows of Table 8 report the welfare effects of the affordability policy emanating from changes in goods consumption (row one), consumption of housing services (overall, row two; while renting and owning respectively, rows three and four) and home-ownership (row five).

For households in the bottom two quintiles, welfare gains come mainly from increases in housing quality. This is true even for the bottom quintile which experiences

a large increase in home-ownership. Given the quality of the houses these households own, home-ownership *per se* does not contribute much to welfare.

For households in the top quintile, the effects of reduced housing quality are paramount. The overall welfare losses to these households are mitigated significantly, however, by a relatively large increase in goods consumption. The results for the second and third quintiles diverge from those of the first in that they gain from the affordability policy overall; and from those for the bottom two quintiles in that their gains are driven by increased goods consumption. These households experience small changes in housing quality and negligible effects on home-ownership.

Table 8: Percentage Welfare Effects (Expressed in Consumption Equivalents)

Post-Policy Outcome(s)	Household Income				
	$F^{-1}(0.1)$	$F^{-1}(0.3)$	$F^{-1}(0.5)$	$F^{-1}(0.7)$	$F^{-1}(0.9)$
Consumption	0.1706	0.3162	0.4772	0.6971	1.1715
Housing Services	1.0423	0.6988	0.3160	-0.2185	-1.3683
Quality While Renting	0.6899	0.3571	0.1248	-0.0177	-0.0225
Quality While Owning	0.3500	0.3405	0.1909	-0.2009	-1.3462
Home Ownership	0.0133	0.0195	0.0220	0.0131	-0.0333
All Post-Policy Outcomes	1.2339	1.0391	0.8168	0.4892	-0.2415

7 Conclusion

We have developed a theory of rent vs. own and rent vs. sell decisions based on search and frictional assignment. Households have no preference for owning *per se*, but may buy in order to avoid the relatively high costs of renting stemming from the higher cost of maintaining a rental home relative to an owner-occupied one. Those households that do rent, do so mainly because it takes time to find an affordable home to buy in their preferred market segment. Higher income households demand higher quality houses and, due to the relatively high cost of renting high quality houses, are willing to pay more to own them. Consequently, developers and other owners of high quality homes are more likely to offer them for sale than are sellers of lower quality houses.

The model can be calibrated to replicate relevant features of the median U.S. city's

housing market: specifically, the average time to sell, ownership duration, price-rent ratio and distribution of ownership by income quintile. In the calibrated model, within the city average cost of renting vs. owning rises with house quality. Across cities, we find that variation in median income, inequality, average age (population growth) and land/amenity values generates variation in both rates of ownership and average price-rent ratios that is qualitatively consistent with those observed across U.S. MSA's.

We use the calibrated model to study the effects of policies designed to increase the affordability of housing. Specifically, we consider the implications of a policy which taxes construction of high quality housing and uses the proceeds to subsidize that of low quality housing in a way which lowers the cost of the median quality house. The main impacts of such a policy are (1) to raise the quality of housing for low income households and lower it for high income ones and (2) to raise the rate at which housing is sold rather than rented to low income households. The particular policy modeled increases the welfare of households in the bottom four quintiles at the expense of those in the top quintile.

In future work, we intend to relax some of the theory's limiting assumptions: in particular, that household incomes are certain and permanent, that moves both within the city and to/from outside are exogenous, and that there is no aggregate uncertainty. The transitional dynamics of the model are complex but potentially very interesting. At the same time, we plan to consider empirical applications of the current environment which take account of specific amenities exhibited and constraints existing in particular cities.

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A Additional Model Details

A.1 The consumption-saving decision

Owners issue claims to achieve zero wealth in the event of death: $w_D = -V(q_S)$. These claims work essentially as a reverse mortgage. The intertemporal Euler equations are

$$\phi_R(q_S, p) = \beta(1 - \lambda(\theta(q_S, p))) \frac{u'(c_R^{+1})}{u'(c_R)} \quad (\text{A.1})$$

$$\phi_B(q_S, p) = \beta\lambda(\theta(q_S, p)) \frac{u'(c_B^{+1})}{u'(c_R)} \quad (\text{A.2})$$

$$\phi_N = \beta(1 - \pi) \frac{u'(c_N^{+1})}{u'(c_N)} \quad (\text{A.3})$$

$$\phi_S = \beta\pi \frac{u'(c_S^{+1})}{u'(c_N)} \quad (\text{A.4})$$

The no-arbitrage conditions are:

$$\phi_N = \beta(1 - \pi) \quad (\text{A.5})$$

$$\phi_S = \beta\pi \quad (\text{A.6})$$

$$\phi_D = \frac{\beta\delta}{1 - \delta} \quad (\text{A.7})$$

$$\phi_R(q, p) = \beta(1 - \lambda(\theta(p; q))) \quad (\text{A.8})$$

$$\phi_B(q, p) = \beta\lambda(\theta(p; q)) \quad (\text{A.9})$$

$$\phi_D(q, p) = \frac{\beta\delta\lambda(\theta(p; q))}{1 - \lambda} \quad (\text{A.10})$$

The Euler equations then imply a constant consumption stream. To achieve this, wealth positions, $\{w_R, w_B, w_N, w_S\}$, must satisfy $w_B = w_N + p$, $w_S = w_R - V(q_S)$ and the following budget constraints:

$$c + \beta\lambda(\theta) [w_N + p] + \beta(1 - \lambda(\theta))w_R + \frac{\beta\delta\lambda(\theta)}{1 - \delta} [p - V_S] + x_R = w_R \quad (\text{A.11})$$

$$c + \beta\pi [w_R - V_S] + \beta(1 - \pi)w_N - \frac{\beta\delta}{1 - \delta} V_S + \zeta q = w_N \quad (\text{A.12})$$

For convenience, the notation here has been simplified by replacing, for example, $\theta(q_S, p)$ with θ , $V(q_S)$ with V_S , and $x(q_R)$ with x_R . Combining both budget constraints

to eliminate c yields

$$w_R - w_N = V_S + \frac{\beta\lambda(\theta)(p - V_S) + (1 - \delta)(x_R - x_S)}{(1 - \delta)[1 - \beta(1 - \pi - \lambda(\theta))]}.$$
 (A.13)

This relationship and a budget constraint determine the level of consumption:

$$c = (1 - \beta)w_R - x_R - \frac{\beta\lambda(\theta)}{1 - \delta} \left(\frac{[1 - \beta(1 - \pi)](p - V_S) - (1 - \delta)(x_R - x_S)}{1 - \beta(1 - \pi - \lambda(\theta))} \right).$$
 (A.14)

A household with permanent income y initially enters the city as a renter with wealth equal to the present discounted value of lifetime income: $w_R = y/(1 - \beta)$. The constant consumption level for this household is therefore

$$c = y - \frac{[1 - \beta(1 - \pi)]x_R + \beta\lambda(\theta)x_S}{1 - \beta(1 - \pi - \lambda(\theta))} - \frac{\beta\lambda(\theta)[1 - \beta(1 - \pi)](p - V_S)}{(1 - \delta)[1 - \beta(1 - \pi - \lambda(\theta))]}.$$
 (A.15)

Note that (A.15) is (17) in the text. The financial wealth of a household changes with every transition to a different ownership status and in the event of death according to

$$w_R = \frac{y}{1 - \beta}$$
 (A.16)

$$w_B = \frac{y}{1 - \beta} + p - V_S - \frac{\beta\lambda(\theta)(p - V_S) + (1 - \delta)(x_R - x_S)}{(1 - \delta)[1 - \beta(1 - \pi - \lambda(\theta))]}$$
 (A.17)

$$w_N = \frac{y}{1 - \beta} - V_S - \frac{\beta\lambda(\theta)(p - V_S) + (1 - \delta)(x_R - x_S)}{(1 - \delta)[1 - \beta(1 - \pi - \lambda(\theta))]}$$
 (A.18)

$$w_S = \frac{y}{1 - \beta} - V_S$$
 (A.19)

$$w_D = -V_S$$
 (A.20)

$$(A.21)$$

A.2 The search decision

Households direct their search by choosing a particular sub-market (price) and market segment (quality). The search decision appears in the Bellman equation for a household that is currently renting:

$$W^R(w) = \max_{q_S, p} \left\{ \begin{array}{l} u(c) + h(0, q_R) \\ + \beta\lambda(\theta(q_S, p))W^N(q_S, w_B - p) \\ + \beta[1 - \lambda(\theta(q_S, p))]W^R(w_R) \end{array} \right\}$$
 (A.22)

subject to

$$c = w - x(q_R) - \beta\lambda(\theta(q_S, p))w_B - \beta(1 - \lambda(\theta(q_S, p)))w_R - \frac{\beta\delta\lambda(\theta(q_S, p))}{1 - \delta}(p - V(q_S))$$

and

$$\beta\gamma(\theta(q_S, p)) [p - V(q_S)] = (1 - \delta - \beta)V(q_S). \quad (\text{A.23})$$

where the latter constraint imposes that the searching household correctly anticipates that market tightness, θ , is determined by the free entry of sellers according to (11). By substituting this constraint into the household's objective function, the optimal choice of segment and sub-market solve the following:

$$W^R(w) = \max_{q_S, \theta} \left\{ \begin{array}{l} u(c) + h(0, q_R) + \beta [1 - \lambda(\theta)] W^R(w_R) \\ + \beta\lambda(\theta)W^N \left(q_S, w_B - V(q_S) - \frac{1-\delta-\beta}{\beta\gamma(\theta)}V(q_S) \right) \end{array} \right\} \quad (\text{A.24})$$

subject to

$$c = w - x(q_R) - \beta\lambda(\theta)w_B - \beta(1 - \lambda(\theta))w_R - \frac{\delta(1 - \delta - \beta)}{\theta(1 - \delta)}V(q_S).$$

The first order condition with respect to q_S is

$$u'(c) \frac{\delta[1 - \delta - \beta]V'(q_S)}{1 - \delta} + \beta\gamma(\theta) \left[\frac{\partial W^N}{\partial q} - \frac{\partial W^N}{\partial w} \left(1 + \frac{1 - \delta - \beta}{\beta\gamma(\theta)} \right) V'(q_S) \right] = 0 \quad (\text{A.25})$$

and the first order condition with respect to θ is

$$\begin{aligned} & \beta \left[\frac{1 - \alpha}{c} (w_R - w_B) + W^N - W^R \right] \frac{\theta\lambda'(\theta)}{\lambda(\theta)} \\ & + \frac{[1 - \delta - \beta]V(q_S)}{\gamma(\theta)} \frac{\theta\gamma'(\theta)}{\gamma(\theta)} \frac{\partial W^N}{\partial w} + u'(c) \frac{\delta[1 - \delta - \beta]V(q_S)}{(1 - \delta)\gamma(\theta)} = 0. \end{aligned} \quad (\text{A.26})$$

The value associated with home-ownership satisfies

$$W^N(q_S, w) = u(c) + h(1, q_S) + \beta\pi W^R(w_s + V(q_S)) + \beta(1 - \pi)W^N(q_S, w_N) \quad (\text{A.27})$$

subject to

$$c = w + \beta\pi w_s - \beta(1 - \pi)w_N + \frac{\beta\delta}{1 - \delta}V(q_S) - \zeta_N(q_S).$$

The Benveniste-Scheinkman conditions are therefore

$$\frac{\partial W^N(q_S, w)}{\partial w} = u'(c) \quad (\text{A.28})$$

$$\frac{\partial W^N(q_S, w)}{\partial q} = \frac{1}{1 - \beta(1 - \pi)} \left\{ \begin{array}{l} \frac{\partial h(1, q_S)}{\partial q} \\ + u'(c) \left[\left(\beta\pi + \frac{\beta\delta}{1 - \delta} \right) V'(q_S) - Z'_N(q_S) \right] \end{array} \right\} \quad (\text{A.29})$$

Substituting (A.23), (A.28) and (A.29) into first order conditions (A.25) and (A.26) yields

$$\begin{aligned} & \left(\frac{1 - \alpha}{c} \right) \left[\frac{p}{(1 - \delta)V(q_S)} - \frac{\delta}{1 - \delta} \right] V'(q_S) \\ &= \frac{1}{1 - \beta(1 - \pi)} \left\{ \frac{\partial h(1, q_S)}{\partial q} + u'(c) \left[\left(\beta\pi + \frac{\beta\delta}{1 - \delta} \right) V'(q_S) - Z'_N(q_S) \right] \right\} \end{aligned} \quad (\text{A.30})$$

and

$$[u'(c)(w_R - w_B) + W^N - W^R] (1 - \eta(\theta)) = u'(c) \left[\eta(\theta) + \frac{\delta}{1 - \delta} \right] (p - V(q_S)) \quad (\text{A.31})$$

where $\eta(\theta) = \theta\gamma'(\theta)/\gamma(\theta) = \theta\lambda'(\theta)/\lambda(\theta) + 1$. Condition (A.30) simplifies to

$$u'(c) \left[\frac{[1 - \beta(1 - \pi)]p - (\beta\pi + \delta)V(q_S)}{(1 - \delta)V(q_S)} V'(q_S) + Z'_N(q_S) \right] = \frac{\partial h(1, q_S)}{\partial q}.$$

With substitutions from (A.16), (A.17), (A.24), (A.27), condition (A.31) simplifies to

$$p - V(q_S) = \frac{(1 - \delta)(1 - \eta(\theta))}{1 - \beta(1 - \pi - \eta(\theta)\lambda(\theta))} \left[x(q_R) - x(q_S) + \frac{h(1, q_S) - h(0, q_R)}{u'(c)} \right].$$

These correspond to conditions (19) and (20) in the text.

B Data Definitions, Sources and Calculations

B.1 Definitions and sources

All data on housing and households is from the American Community Survey (2010, 5-year estimates) accessed via the Census Bureau at <http://factfinder.census.gov>.

House price: To compute mean house prices by urban area, we use the data on housing value obtained from Housing Question 16 in the ACS. The question was asked at housing units that were owned, being bought, vacant for sale, or sold and not occupied at the time of the survey. The estimated value is the respondent's estimate of how much the property (house and lot, mobile home and lot, or condominium unit) would sell for if it were for sale. We also used the average price-asked on vacant housing for sale only and on housing sold but unoccupied. This was calculated by dividing the aggregate price-asked by the number for sale and sold but unoccupied.

Rent: To compute mean rent for each urban area, we use the data on gross rent obtained from answers to Housing Questions 11a-d and 15a in the ACS. Gross rent is the contract rent plus the estimated average monthly cost of utilities if these are paid by the renter.

Housing tenure: To compute the number of owning and renting households we use data obtained from Housing Question 14 in the ACS. The question was asked at occupied housing units. Occupied housing units are classified as either owner occupied or renter occupied:

Owner occupied – A housing unit is owner occupied if the owner or co-owner lives in the unit even if it is mortgaged or not fully paid for.

Renter occupied – All occupied housing units which are not owner occupied, whether they are rented or occupied without payment of rent, are classified as renter occupied.

Households – the number of households was computed as the sum of owner and renter occupied units.

Vacant housing units – A housing unit is vacant if no one is living in it at the time of interview. Units occupied at the time of interview entirely by persons who are staying two months or less and who have a more permanent residence elsewhere are considered to be temporarily occupied, and are classified as “vacant.” New units not

yet occupied are classified as vacant housing units if construction has reached a point where all exterior windows and doors are installed and final usable floors are in place.

Median household income: The data on income during the last 12 months were derived from answers to Questions 47 and 48, which were asked of the population 15 years old and over. Household income includes the income of the householder and all other individuals 15 years old and over in the household. “Total income” is the sum of the amounts reported separately for wage or salary income; net self-employment income; interest, dividends, or net rental or royalty income or income from estates and trusts; Social Security or Railroad Retirement income; Supplemental Security Income (SSI); public assistance or welfare payments; retirement, survivor, or disability pensions; and all other income

Gini coefficient: The Gini index of income inequality for each urban area comes from the ACS and measures the dispersion of the household income distribution.

Population-weighted density for metropolitan and micropolitan areas is from http://www.census.gov/population/metro/data/pop_pro.html. It is calculated as a weighted-average of population densities for each census tract where the weights are the share of the total area population in each census tract. It is intended to reflect the population density experienced by the average person in the urban area.

Median age refers to the median age of the population taken from the 2010 ACS. (It is not the median age of the head of the household, which does not appear to be easily obtainable.)

Land values are taken from column 5 of Albouy *et al.* (2017) appendix Table A2. The MSA’s for which they provide these estimates are based on the 1999 OMB definitions. The MSA’s used in the current paper are from the 2010 census and are slightly different and greater in number. This is in part because some MSA’s have been subdivided and also because there are some new MSA’s.³⁴ Where MSA’s have been subdivided, we use the same average land values for both. Where we could find no match, we dropped the MSA from the data set.

COLI: The local cost of living index is the ACCRA Cost of Living Index provided by Council for Community and Economic Research (<https://www.c2er.org/>). It measures relative price levels for consumer goods and services in participating areas for

³⁴The MSA’s in 2010 are based on the concept of Core Based Statistical Areas.

a mid-management standard of living. Weights are based on the Bureau of Labor Statistics' 2004 Consumer Expenditure Survey. We use these weights to extract a COLI for non-housing expenditures only. Data are for selected urban areas within the larger MSA. In the few cases where there are multiple areas within a given MSA, we used a simple average.

Amenity controls: “Natural” amenities taken from Albouy (2016):

Heating and cooling degree days (Annual) – Degree day data are used to estimate amounts of energy required to maintain comfortable indoor temperature levels. Daily values are computed from each day’s mean temperature, $(\max + \min)/2$. Daily heating degree days (**hdd65**) are equal to $\max\{0; 65 - \text{meantemp}\}$ and daily cooling degree days (**cdd65**) are $\max\{0; \text{meantemp} - 65\}$. Annual degree days are the sum of daily degree days over the year. The data here refer to averages from 1970 to 1999.

Sunshine – Average percentage of possible sunshine (**sun_a**). The total time that sunshine reaches the surface of the earth is expressed as the percentage of the maximum amount possible from sunrise to sunset with clear sky conditions.

Average slope (**slope_pct**) – The slope of the land in the metropolitan area (percent), using an average maximum slope technique based on a 30 arcsec x 30 arcsec grid.

Coastal proximity (**inv_water**) – Equal to the logarithm of the inverse distance in miles to the nearest coastline from PUMA centroid.

Latitude (**latitude_w**) – Measured in degrees from the equator.

B.2 Fitting construction costs (τ) to cross-city data

We compute MSA-level construction cost parameter values that best match the observed ownership rates and price-rent ratios. We allow median income, the income Gini and median age to match the characteristics of each MSA. For a given construction cost parameter value τ , the resulting simulated economies yield predicted ownership rates and aggregate price-rent ratios. For each MSA, we choose the value for τ that best matches the observed MSA-level statistics in the following sense: we minimize a weighted average of the squared differences between the simulated statistics and their empirical counterparts. For the weights, we use the inverse of the variances of the MSA ownership rates and price-rent ratios.

C Additional Empirical Results

Tables 9 and 10 contain full parameter estimates for Tables 3 and 4, respectively.

Table 9: Full results for Table 3

	Ownership Rate		Price-Rent Ratio			
			(price-asked)		(estimated-value)	
Log Median Income	0.076	(0.030**)	14.497	(2.833***)	13.088	(2.114***)
Gini index	-0.449	(0.138***)	90.286	(13.395***)	65.427	(8.523***)
Age	0.007	(0.001***)	0.032	(0.083)	0.122	(0.044***)
Log Density	-0.024	(0.006***)	-3.585	(0.787***)	-1.447	(0.336***)
Log Land Value	-0.010	(0.005**)	2.680	(0.736***)	2.321	(0.651***)
cdd65	-0.024	(0.006***)	2.710	(0.790***)	2.998	(0.455***)
hdd65	-0.013	(0.003***)	0.554	(0.319*)	0.903	(0.236***)
sun_a	-0.067	(0.035*)	18.869	(6.491***)	19.239	(5.357***)
slope_pct	-0.001	(0.002)	0.692	(0.184***)	0.717	(0.104***)
inv_water	-0.064	(0.056)	41.339	(8.294***)	28.713	(4.453***)
latitude_w	-0.003	(0.001*)	0.082	(0.182)	0.263	(0.114**)
Constant	-0.076	(0.302)	-174.27	(33.08***)	-168.5	(25.35***)
$\overline{R^2}$	0.63		0.56		0.79	
# obs	332		332		332	

Notes: Standard errors (in parentheses) are clustered at the state level.

In Tables 11 and 12 we consider samples which also include smaller urban agglomerations. Table 11 includes *Micropolitan* areas which are urban agglomerations containing fewer than 50,000 households but more than 10,000. This increases the number of urban areas to 942 but we have no data for land values or amenities. Table 12 includes all urban areas with more than 1000 households, which increases the number of observations to 3360. Controlling for population density, the results documented in Table 11 are qualitatively similar to those of Table 3: (1) The price-rent ratio is positively correlated with median income, the Gini index and age and (2) the ownership rate is positively correlated with median income and age but negatively correlated with the Gini index. In Table 12, we have no data on density for smaller urban clusters and so cannot control for it. Nevertheless, the same qualitative correlations for median incomes, inequality and median age are obtained.

A potentially important factor that varies considerably across US cities are property taxes. Property taxes are incurred by both owner-occupiers and landlords and therefore enter into the effective cost of supplying housing of a given quality, τ . Unfortunately, we have not been able to obtain details data on average property taxes

Table 10: Full results for Table 4

	Ownership Rate		Price-Rent Ratio			
			(price-asked)		(estimated-value)	
Log Median Income	0.093	(0.030***)	5.874	(3.120*)	5.945	(2.720**)
Gini index	-0.448	(0.148***)	56.147	(17.899***)	46.824	(14.960***)
Age	0.008	(0.001***)	-0.066	(0.101)	0.097	(.062)
Log Density	-0.025	(0.006***)	-2.766	(0.808***)	-1.175	(0.468**)
Log Land Value	-0.012	(0.005***)	3.851	(0.769***)	3.979	(0.874***)
cdd65	-0.024	(0.005***)	3.216	(1.064***)	3.419	(0.537***)
hdd65	-0.013	(0.004***)	0.433	(0.449)	0.732	(0.374*)
sun_a	-0.028	(0.036)	14.454	(8.165*)	14.872	(6.111**)
slope_pct	-0.002	(0.001**)	0.745	(0.260***)	0.639	(0.111***)
inv_water	-0.095	(0.053*)	50.33	(10.33***)	29.017	(5.816***)
latitude_w	-0.003	(0.002)	-0.059	(0.165)	0.175	(0.150)
Constant	0.299	(0.002)	-40.138	(22.633*)	-60.04	(22.58**)
\overline{R}^2	0.65		0.49		0.77	
# obs	199		199		199	

Notes: Standard errors (in parentheses) are clustered at the state level.

at the MSA level. However, the Lincoln Institute of Land Policy does provide data on the property taxes paid per person within 150 or so “Fiscally Standardized Cities” (FSC).³⁵ While these do not correspond to MSAs, it is possible to match them with the main cities within many MSA’s. We then estimate an index of the average property tax as a percentage of land value in 2010 using available data as follows:

Estimated MSA average property tax rate index =

$$\frac{\text{Property Tax rate per person for FSC} \times \text{population density of MSA}}{\text{Estimated Land value per acre in MSA containing FSC}}.$$

Table 13 documents the results of estimating the same regressions as in Table 3, but now including the estimated tax rate variable. If we do not adjust incomes for the non-housing cost of living, the resulting sample contains 118 MSA’s. As may be seen, the qualitative nature of the results regarding the other factors are unchanged from Table 3. As is consistent with our model, ownership rates exhibit a statistically significant negative partial correlation with tax rates whereas price-rent ratios exhibit a positive one.

³⁵Lincoln Institute of Land Policy. Fiscally Standardized Cities database. <http://www.lincolinst.edu/subcenters/fiscally-standardized-cities/>.

Table 11: All U.S. Metropolitan and Micropolitan Areas

Dependent Variable	Ownership Rate	Price-Rent Ratio	
		(price-asked)	(estimated-value)
Log Median Income	0.011	14.315	21.396
Robust s.e.	(.012)	(2.369***)	(1.395***)
Clustered s.e.	(.018)	(2.579***)	(2.346***)
Gini index	-0.599	59.731	45.261
Robust s.e.	(.070***)	(13.009***)	(6.848***)
Clustered s.e.	(.113***)	(18.471***)	(15.951**)
Median age	0.006	0.120	0.101
Robust s.e.	(.000***)	(0.096)	(.038***)
Clustered s.e.	(.001***)	(0.126)	(.051**)
Log Density	-0.017	-1.078	-0.238
Robust s.e.	(.002***)	(0.442**)	(.262)
Clustered s.e.	(.003***)	(0.537**)	(.407)
Adjusted R^2	0.47	0.05	0.43
# obs	942	937	942

Table 12: U.S. Urban Areas with more than 1000 Households
(Median income not adjusted for local non-housing cost of living)

	Ownership Rate		Price-Rent ratio	
Log Median Income	0.103	0.119	13.328	13.222
Robust s.e.	(.006***)	(.008***)	(.522***)	(.615***)
Clustered s.e.	(.012***)	(.016***)	(1.013***)	(1.280***)
Gini index	-0.530	-0.438	37.639	37.023
Robust s.e.	(.038***)	(.040***)	(2.851***)	(3.328***)
Clustered s.e.	(.038***)	(.044***)	(4.185***)	(5.944***)
Median age	0.007	0.006	0.044	0.046
Robust s.e.	(.000***)	(.000***)	(.018**)	(.018**)
Clustered s.e.	(.000***)	(.000***)	(.035)	(.037)
Log Households	–	-0.007	–	0.050
Robust s.e.		(.001***)		(.0.091)
Clustered s.e.		(.002***)		(.183)
Adjusted R^2	0.42	0.43	0.29	0.29
# obs	3360	3360	3360	3360

Table 13: U.S. Metropolitan Statistical Areas (2010)
(Median income not adjusted for local non-housing cost of living)

	Ownership Rate	Price-Rent ratio	
		(price-asked)	(estimated-value)
Log Median Income	0.111 (0.038***)	12.549 (3.034***)	9.929 (1.964***)
Gini index	-0.413 (0.282)	102.333 (20.030***)	62.695 (12.259***)
Age	0.004 (0.002**)	-0.231 (0.140)	0.062 (0.083***)
Log Density	-0.034 (0.010***)	-4.442 (1.010***)	-2.784 (0.713***)
Log Land Value	-0.016 (0.009*)	4.043 (0.865***)	4.161 (0.613***)
Property Tax Rate	-0.008 (0.004**)	0.990 (0.398**)	0.825 (0.321***)
Amenity Controls	Yes	Yes	Yes
R^2	0.60	0.73	0.87
# obs	118	118	118

Notes: (1) Sources and definitions of variables may be found in the appendix.
(2) Heteroskedasticity-robust standard errors are provided in parenthesis.
(3) *, ** and *** indicate statistical significance at the 10, 5, and 1% levels, respectively.

D An Alternative Formulation

Here we describe briefly an alternative formulation of the baseline model with an explicit utility benefit to home ownership that rises with quality.³⁶ In this environment, maintenance costs are assumed to be equivalent across owned and rented units of a given quality. When we calibrate this version of the model to match the same targets as above, we find that the implications are qualitatively unchanged and quantitatively very similar. The only substantive difference is that the price-rent ratio for equivalent housing units now *rises* with quality, in contrast to the negative relationship depicted in Figure 5. This implication is consistent with several studies, using various approaches and in different locations.³⁷ Using data from London, Halket, Nesheim and Oswald (2015), however, attribute much of this to the effects of selection on unobservable quality. Once they correct for this bias, they find that the price-rent ratio falls with value.

Specifically, we deviate from our baseline specification by assuming the following functional forms for preferences

$$h(z, q) = \alpha(\ln q + zg(q)), \quad (\text{D.1})$$

with the ownership premium

$$g(q) = \psi_0 + \frac{\psi_1 q}{1 + e^{\psi_2 - \psi_3 q}} \quad q > 0, \quad (\text{D.2})$$

and maintenance costs

$$Z_R(q) = Z_N(q) = \zeta q. \quad (\text{D.3})$$

As noted above, the calibration results, cross-city implications and analysis of housing affordability for this alternative formulation are essentially identical to those reported above for the baseline specification. All are available on request.

³⁶That owners derive greater utility than renters from a given dwelling is a common assumption (Rosen, 1985; Poterba, 1992; Kiyotaki et al., 2011; Iacovello and Pavan, 2013, Floetotto, Kirker, and Stroebel, 2016). One explanation is that owners can customize the unit to suit their own preferences.

³⁷See, for examples, Verbrugge (2008), Heston and Nakamura (2009), Garner and Verbrugge (2009), Verbrugge and Poole (2010), Epple, et al. (2013), Landvoigt et al. (2015), Bracke, (2015) and Hill and Syed (2016).