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Housing market and labor market search

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Abstract:
Current models fail to concurrently account for several important empirical regularities in the housing and labor markets. I augment the Diamond-Mortensen-Pissarides (DMP) search and matching model of the labor market with a housing market characterized by search and matching frictions, integrating both markets in a coherent macroeconomic model. The model provides a framework to explain how shocks and frictions which originate in the labor market spill over into the housing market and vise versa. The model accounts for procyclical, serially correlated real estate values, rental rates and expected real estate appreciation. Further, it accounts for increases in wages, housing costs and willingness to commute as a result of increases in geographic amenities. The model is also consistent with the empirical relationship between vacancy rates in the housing market and separation rates in the labor market. Simulations demonstrate that certain land-use policies can mitigate permanent shocks to labor productivity and the level of geographic amenities.

Keywords: housing frictions, labor frictions, search models

JEL classification: E24 (Employment, Unemployment, Wages), J64 (labor search)

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1 Introduction

What accounts for the serially correlated increase in housing costs in locations which experience an increase in labor productivity? What accounts for the increase in wages, housing costs and workers' willingness to commute and the decrease in housing vacancy in locations which experience an increase in geographic amenities? Finally, what accounts for the high correlation between labor match separations and housing vacancies?

In this paper, I augment the basic Diamond (1982)Mortensen and Pissarides (1994) (DMP) labor search model with a housing market, which is also characterized by search and matching frictions, in order to answer these three questions. The integration of the labor and housing markets results in the relaxation of the assumption that labor markets are frictionless in the spatial dimension, so that distance-to-work becomes an important characteristic of employment to a prospective worker. The concept that the non-wage value of jobs is important is established in Hall and Mueller (2015), where the authors argue that commute time represents a likely element of non-wage job value.[1]

In the model, once an unemployed worker secures a labor match, the newly employed worker turns to a housing market to secure a housing unit, so that there are now two subsets of the employed: those matched with a residence and those unmatched, but searching.[2] When an unemployed worker matches with a firm, the wage is derived via Nash bargaining between counterparties over the match surplus. Symmetrically, when the employed worker is looking for a housing unit, the worker searches in a decentralized housing market, matches with a counterparty, and bargains over the match surplus to determine the price of housing for that period. A new feature in the housing market of this model is that housing units differ only in their distance from the worker's place of employment, with units with a shorter commute having a higher match value to the worker. In order to study how commuting behavior is impacted by the interaction of the housing and labor market, I incorporate an endogenous commute threshold into the model. Since the worker's commute cannot surpass this threshold, a novel result emerges: only the subset of housing matches within the threshold progress to the bargaining stage. When a firm and worker bargain over the employment match surplus, a portion of this surplus is made up of the worker's anticipated housing match surplus. The firm then takes expected future housing market conditions into consideration before posting a job vacancy. This new driving factor is contingent on the extent to which the firm can extract anticipated housing market value from the worker during the wage-bargaining process. Since the labor side of the model anticipates what occurs on the housing side, shocks to the housing market manifest themselves as real labor market effects.

The structure of the model of this paper is motivated by models such as those in Wasmer and Weil (2004) and Petrosky-Nadeau and Wasmer (2013) where agents, namely entrepreneurs, have three "stages" they are in at any one point: a credit stage to seek to match with a bank, followed by a labor stage to seek to match with

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a worker, followed by a production stage. The workers in the model of this paper also progress between three states/stages. However, unlike Wasmer and Weil (2004) and Petrosky-Nadeau and Wasmer (2013), who assume the tightness of credit and labor markets is constant, my model has the tightness in both markets endogenously fluctuate, reflecting relative supply and demand conditions.

Search models, much in the flavor of DMP, have also been used to model housing markets as early as Wheaton (1990). In that paper, the author uses a simple search and matching model to explain the existence of structural vacancy in the housing market. In his model, agents search for better housing matches when their current housing no longer meets their requirements. Once agents secure another home they then sell their mismatched home. Since the research question involved explaining the structural vacancy rate in housing, the labor market is ignored.

Rupert and Wasmer (2012) integrates a DMP model of the labor market with housing by assuming each job offer to an agent comes with a commute distance drawn from a distribution and by relaxing the assumption that agents are indifferent between employment locations. The authors focus on the trade-off between commuting time and locational decisions and use that model to explain the mobility patterns of US workers and their European counterparts. Rupert and Wasmer (2012) assumes that the employment locations themselves serve as housing units and the only housing cost agents face is commuting; while the labor market is modelled using DMP, the housing market is essentially ignored.

Ioannides and Zabel (2017) extends the model of Head and Lloyd-Ellis (2012) by incorporating labor frictions. As Head and Lloyd-Ellis (2012) models a decentralized housing market which interacts with a Walrasian labor market, the modeling extension in Ioannides and Zabel (2017) allows for an elegant means of both isolating a Beveridge curve for housing and for studying its interaction with the Beveridge curve for labor. The authors show that the theoretical predictions of the model are consistent with the impulse responses generated by a VAR which is built upon their model's housing and labor Beveridge curves.

All of the aforementioned papers largely employ a steady state or comparative static analysis of the theoretical model, as solving and simulating stochastic versions would indeed prove a challenge. Since my model is largely built upon a discrete time version of the DMP framework, the policy experiments and simulations I execute in the numerical analysis section are performed using the same, simple first-order perturbation methods which are employed in the simulation of rational expectations DSGE models.

The model's results are consistent with many other studies in the literature. The model is able to account for the positive co-movement with pricing and sales [Wheaton (1990) and Rios-Rull and Sanchez-Marcos (2007)], the negative correlation between prices/sales and time on the market [Krainer (2008), Albrecht et al. (2007), and Genesove and Han (2011)], and the negative correlation of price growth and vacancies (Caplin and Leahy 2011). Since the model integrates the housing market with the labor market, in addition to its ability to explain the aforementioned empirical relationships, the model is also able to account for the positive co-movement between commuting distance to work and neighborhood and housing amenities (Albouy and Lue 2015).

Several implications for policy can be drawn from this study; an important one in particular involves land-use. The model highlights several important linkages between the labor and housing market and demonstrates that ceteris paribus, a large increase in labor productivity will lead to increased housing costs, commute times, and decreased housing vacancies. This is particularly relevant at present in many of the United States' large cities such as San Francisco. According to the model, a policy which augments the mass of available housing by as little as 0.4% can significantly decrease the volatility of housing costs, the expected rate of housing appreciation, commuting times and the vacancy rate resulting from a 10% permanent increase in labor productivity. Simulation results of such experiments are included in the numerical analysis portion of the paper.

The model is constructed in the following section, calibration in Section 3, Section 4 reports the numerical results, and Section 5 concludes.

2 Model

Housing in the model is defined as in Rupert and Wasmer (2012): *a bundle of services generating utility to individuals or a household, for which individuals pay a "rent" or a "mortgage", and where the defining characteristic of a dwelling is that the services provided are attached to a fixed location.* This then implies that for a given set of amenities (space, comfort, proximity to theaters, recreation, shops), the commuting distance to one's job becomes an important determinant of both job and housing choice, under the assumption that commuting time drives a wedge between a worker's leisure and the time representing the worker's supply of labor.

In what follows, I frame the modeling of the housing market using the narrative of a rental market. Thus, while the assumption of 0% homeownership is technically flawed, the model's main goal is to provide the reader with a deeper understanding of the *fundamental* drivers of housing value – in this case, the market for housing services – which is more accurately captured by rents [for empirical evidence, see Ambrose, Eichholtz, and Lindenthal (2013)].[3]

The economy is populated by workers, firms, and landlords. Unemployed workers will be referred to as U, the workers which are employed but without a residence as unmatched renters RU, and the workers which are employed with a residence as matched renters RM.

The timing is as follows:

1. The unemployed worker searches for a job.
2. Once the unemployed worker matches with a searching firm, they bargain over the surplus to the employment match and redistribute the surplus according to an equilibrium wage.
3. Once the worker secures employment, the employed worker, now an unmatched renter, begins searching for a residence.
4. Once the renter matches with a searching landlord, the renter draws a commute from a distribution – the shorter (longer) the commute, the higher (lower) the value of this surplus. The only difference in rental units is the commute distance to the renter's employment location.[4]
5. The renter and landlord then bargain over the surplus to the residence match and redistribute the surplus according to an equilibrium rental rate.
6. An endogenous commute cutoff marks the point where the surplus to the residence match net of the opportunity cost of other potential residences[5] is non-negative. This implies that the portion of the residential matches which satisfy the endogenous commute cutoff progress to the bargaining stage.

Once an employment match is formed, the firm and the worker always face the possibility that the match will exogenously terminate. The same holds true of the match between the employed worker and the landlord, implying two potentially different, stochastic separation rates. If a successfully matched renter exogenously separates from their employment match, they *also* separate from their residence match and become unemployed. The exogenous separation of employment by a worker which is also currently renting is one which is said to "destroy all specificity". This modelling assumption follows Petrosky-Nadeau and Wasmer (2013) and Wasmer and Weil (2004).[6] The workers in this economy do not save. Thus, if there is an employment separation, this constitutes an interruption in income which implies the worker (while unemployed) cannot meet their housing costs, resulting in a separation from their residential match. This assumption allows the model to ignore complex issues such as optimal/precautionary saving and/or credit, thus remaining tractable.

I will assume that the firms endogenously post employment vacancies at constant cost. I will also assume that while firms endogenously enter their respective markets, there is a time-invariant unit mass of workers and a time-varying mass of housing. Additionally, all unemployed workers and some employed workers are technically "homeless"; I will assume that these individuals occupy an unmodeled living arrangement.[7] Finally, I will assume that workers currently renting do not have the option to sub-lease to other workers searching for housing.

A schematic of the model is given in Figure 1 below.

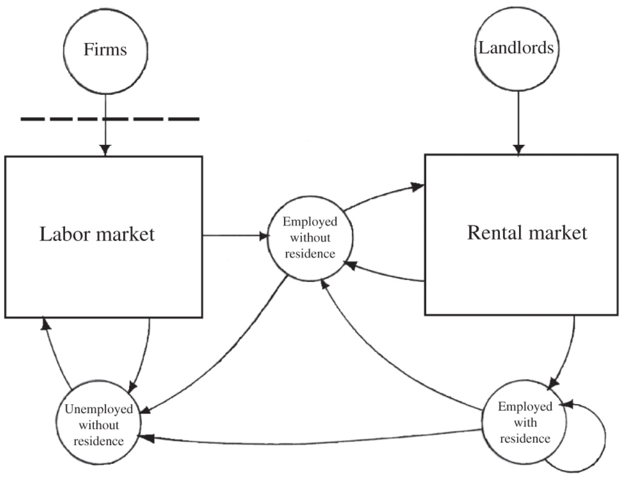


Figure 1: Illustration of the flows of workers, firms and landlords in the economy. The dashed line is there to indicate the endogenous entry of firms into the labor market. Unemployed workers immediately enter the labor market and either match and become employed without a residence, or become unemployed again. Workers who are employed without a residence attempt to find a landlord in the rental market. If successful, they move on to being employed and with residence type workers. At all times, renters who are matched with landlords may separate from their homes, and/or separate from their employer. If renters separate from employment in any state, they start the next period as unemployed.

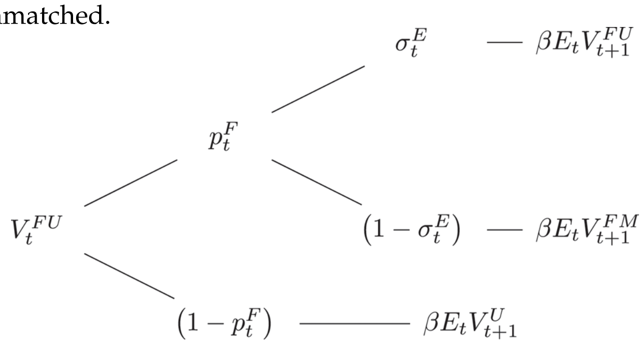
2.1 Value functions and laws of motion for the state variables

Both the firms and the landlords are either matched or unmatched, hence there will be two value functions for each of these agents. The worker will be in one of three states, implying there will be three value functions for this agent – one for each state. The surpluses for the firms and the landlord will be the difference in value of each state. The agent, however, will have a set of 2 surpluses, each of which will be used in bargaining with the respective counterparty. Thus, there will be a worker's employment surplus (renter surplus) which will contribute towards the joint surplus of the match between the worker and the firm (landlord). Since the worker, the firm, and the landlord have access to the same information set, when the firm is bargaining with the worker for a wage, this bargaining internalizes the worker's anticipated housing match surplus.[8] So, for example, if a firm (and the newly matched employee; both the worker and the firm share the same information set) expects a new employee's future housing prospects to be high, the firm uses this as a bargaining chip against the employee when negotiating the wage.[9] The corollary to this is that if an employee, going into wage negotiations, knows that their future housing prospects will be high, they won't be as demanding regarding the wage.

2.1.1 The firm's value functions

An unmatched firm which has entered the labor market pays γ to post a job vacancy, and matches with a worker with probability p^F. If the match then survives the exogenous separation probability σ^E, the firm enters the following period as a matched firm which receives value V^{FM}. If the new match separates, or if the firm fails to locate a worker, the firm enters the following period as an unmatched firm.

The decision tree below illustrates the potential paths and resulting states facing a firm which starts off as unmatched.



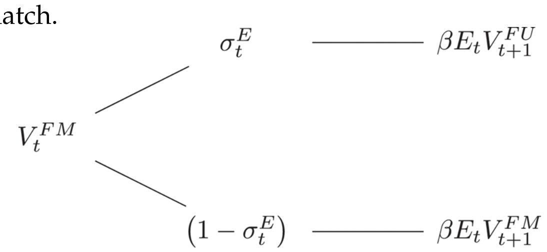
The value function which describes this sequence of events is

$$V_t^{FU} = -\gamma + p_t^F \beta E_t \left[(1-\sigma_t^E) V_{t+1}^{FM} + \sigma_t^E V_{t+1}^{FU} \right] + \left(1 - p_t^F\right) \beta E_t V_{t+1}^{FU}, \tag{1}$$

where V^{FU} is the value the unmatched and searching firm receives.

A matched firm receives the output y produced from the employment match and pays the worker an endogenous wage w. If the match survives the exogenous separation, then the firm is once again matched the following period and receives value V^{FM}. If the match exogenously terminates, the firm becomes unmatched and receives V^{FU}.

The decision tree below illustrates the potential paths and resulting states facing a firm which starts off in a match.



The value function describing this scenario is

$$V_t^{FM} = y_t - w_t + \beta E_t \left[\left(1 - \sigma_t^E\right) V_{t+1}^{FM} + \sigma_t^E V_{t+1}^{FU} \right]. \tag{2}$$

The surplus to a firm is the difference in value of being matched over being unmatched. Denoting this surplus as $V^{F\Sigma}$,

$$V_t^{F\Sigma} = y_t - w_t + \gamma + \left(1 - p_t^F\right) \beta \left(1 - \sigma_t^E\right) E_t V_{t+1}^{F\Sigma}, \tag{3}$$

which states that the firm's net surplus is the revenue net of labor costs plus the vacancy posting costs saved and the expected value of the net surplus in the following period.

Free entry in the labor market for firms implies that $V^{FU} = 0$. From (1), the resulting entry condition is

$$\gamma = p_t^F \beta \left(1 - \sigma_t^E\right) E_t V_{t+1}^{F\Sigma}, \tag{4}$$

which shows that in equilibrium, the expected benefit of the labor match is equal to the per-period cost of posting a job vacancy.

The entry condition can be combined with a time-advanced version of (3), resulting in

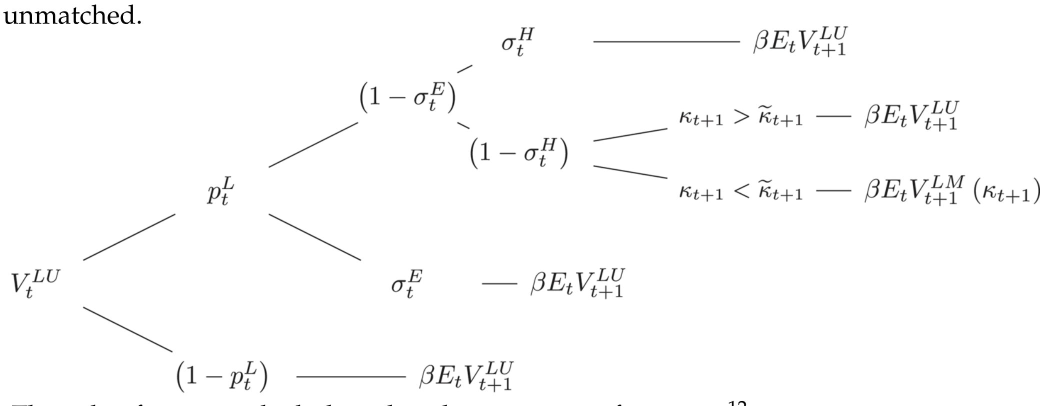
$$\frac{\gamma}{p_t^F} = \beta \left(1 - \sigma_t^E\right) E_t \left(y_{t+1} - w_{t+1} + \frac{\gamma}{p_{t+1}^F} \right). \tag{5}$$

(5) is an Euler equation which illustrates that the present expected cost of a match[10] γ / p_t^F, is also equal to future expected net revenue $y_{t+1} - w_{t+1}$ plus the future expected search costs saved $E_t \gamma / p_{t+1}^F$, as long as the match survives, which occurs with probability $\left(1 - \sigma_t^E\right)$.

2.1.2 The landlord's value functions

An unmatched landlord pays ξ to post the vacancy, and matches with a searching (employed) worker with probability p^L. If the match then survives both the exogenous probability that the worker's new housing match and employment match separates (σ^H and σ^E, respectively), the worker draws a commute κ from a distribution G which has support $\left[\underline{\kappa}, \overline{\kappa}\right]$. If this commute is below (above) the cutoff, the landlord enters the following period as a matched (unmatched) landlord who receives value V^{LM} (V^{LU}). If the new match separates,[11] or if the landlord fails to locate a searching, employed worker, the landlord enters the following period unmatched.

The decision tree below illustrates the potential paths and resulting states facing a landlord which starts off as unmatched.



The value function which describes this sequence of events is[12]

$$V_t^{LU} = -\xi + p_t^L \beta E_t \left\{ \left(1 - \sigma_t^E\right)\left(1 - \sigma_t^H\right) \int_{\underline{\kappa}}^{\overline{\kappa}} V_{t+1}^L \left(\kappa_{t+1}\right) dG\left(\kappa\right) + \left[\left(1 - \sigma_t^E\right) \sigma_t^H + \sigma_t^E \right] V_{t+1}^{LU} \right\} + \left(1 - p_t^L\right) \beta E_t V_{t+1}^{LU}, \tag{7}$$

A landlord who is matched receives an endogenous rental rate $r_t\left(\kappa_t\right)$ and pays a fixed cost λ of running the rental.[13] If the match survives the worker's exogenous employment and housing separation, then the landlord is once again matched the following period with the same commute and receives value $V_{t+1}^{LM}\left(\kappa_t\right)$. If the worker's employment or housing match exogenously terminates, the landlord becomes unmatched and enters the following period receiving value V_{t+1}^{LU}.

The decision tree below illustrates the potential paths and resulting states facing a landlord who starts off as matched.

$$
\begin{tikzcd}[arrows=dash]
 & & \left(1-\sigma_t^H\right) \arrow[r] & \beta V_{t+1}^{LM}\left(\kappa_t\right) \\
 & \left(1-\sigma_t^E\right) \arrow[ur] \arrow[dr] & & \\
V_t^{LM}\left(\kappa_t\right) \arrow[ur] \arrow[dr] & & \sigma_t^H \arrow[r] & \beta E_t V_{t+1}^{LU} \\
 & \sigma_t^E \arrow[r] & \beta E_t V_{t+1}^{LU} &
\end{tikzcd}
$$

The value function describing this scenario is

$$V_t^{LM}\left(\kappa_t\right)=r_t\left(\kappa_t\right)-\lambda+\beta E_t\left\{\left(1-\sigma_t^E\right)\left(1-\sigma_t^H\right)V_{t+1}^{LM}\left(\kappa_t\right)+\left[\left(1-\sigma_t^E\right)\sigma_t^H+\sigma_t^E\right]V_{t+1}^{LU}\right\}. \tag{8}$$

The following two equations keep account of the proportions of the mass of landlords in each of their two respective states. For each state, we can reverse-engineer the paths on the trees in order to derive the laws of motion.[14] For the unmatched landlords, the law of motion governing that proportion is

$$LU_t=\left[\sigma_t^E+\left(1-\sigma_t^E\right)\sigma_t^H\right]LM_{t-1}+\left[1-p_t^L\left(1-\sigma_t^E\right)\left(1-\sigma_t^H\right)\int_{\underline{\kappa}}^{\tilde{\kappa}_t}dG\left(\kappa\right)\right]LU_{t-1}, \tag{9}$$

while for the matched landlords, the law of motion governing that state is

$$LM_t=\left(1-\sigma_t^E\right)\left(1-\sigma_t^H\right)\left[LM_{t-1}+p_t^L\int_{\underline{\kappa}}^{\tilde{\kappa}_t}dG\left(\kappa\right)LU_{t-1}\right]. \tag{10}$$

The surplus to being a landlord is the difference in value of being matched over being unmatched, accounting for the opportunity cost of carrying the match and associated commute into the future.[15] Thus, *at the commute cutoff* $\tilde{\kappa}_t$, the landlord's surplus is defined as

$$V_t^{L\Sigma}\left(\tilde{\kappa}_t\right)\equiv V_t^{LM}\left(\tilde{\kappa}_t\right)-V_t^{LU}-\beta\left(1-\sigma_t^E\right)\left(1-\sigma_t^H\right)E_t\left[V_{t+1}^{LM}\left(\tilde{\kappa}_{t+1}\right)-\int_{\underline{\kappa}}^{\overline{\kappa}}V_{t+1}^{L}\left(\tilde{\kappa}_{t+1}\right)dG\left(\kappa\right)\right]. \tag{11}$$

Substituting (8) and (7) into (11) yields

$$V_t^{L\Sigma}\left(\tilde{\kappa}_t\right)=r_t\left(\tilde{\kappa}_t\right)-\lambda+\xi+\beta(1-\sigma_t^E)(1-\sigma_t^H)E_t\left(1-p_t^L\right)\int_{\underline{\kappa}}^{\tilde{\kappa}_{t+1}}V_{t+1}^{L\Sigma}\left(\kappa_{t+1}\right)dG\left(\kappa\right), \tag{12}$$

which shows that the landlord's surplus is comprised of the net rental income (rent net of management costs), the vacancy cost saved and the net[16] discounted continuation value.

Remark 1

The surplus definition (11) differs from the typical definition encountered in the search literature where the surplus is defined as $V_t^{L\Sigma}\left(\tilde{\kappa}_t\right)\equiv V_t^{LM}\left(\tilde{\kappa}_t\right)-V_t^{LU}$. The reason for this difference is that unlike the labor search literature [for example, Mortensen and Pissarides (1994)] where a match-specific productivity is drawn each time period, a commute distance tied to a housing match is carried into the future for the $1/\left[\left(1-\sigma_t^E\right)\sigma_t^H+\sigma_t^E\right]$ quarters the match is expected to last. The definition outlined in (11) correctly encapsulates this opportunity cost; consequentially, (11) ensures that housing matches do not endogenously terminate. To my knowledge, this paper is the first to deploy a search and matching framework in which a non-pecuniary match-specific characteristic is randomly drawn and kept into the future for as long as the match lasts.

While a housing unit is unoccupied, a landlord always has the option to sell the residence in a frictionless market at price P. Incorporating the alternative to sell the rental while the landlord is unmatched $V_t^{LU}=P_t$ into (7) results in

$$\xi + P_t - \beta E_t P_{t+1} = p_t^L \beta E_t \left(1 - \sigma_t^E\right)\left(1 - \sigma_t^H\right) \int_{\underline{\kappa}}^{\tilde{\kappa}_{t+1}} V_{t+1}^{L\Sigma}\left(\kappa_{t+1}\right) dG\left(\kappa\right), \tag{13}$$

which states that in equilibrium, the landlord's expected opportunity cost of matching with a renter - the cost of posting the vacancy ξ and the expected, present discounted value of the capital gain given up by not selling the residence - is balanced by the expected benefit of the match.

In equilibrium, the sales price of the residence must also satisfy a rent-parity equation and thus, following Poterba (1984) and Himmelberg, Mayer, and Sinai (2005), I define

$$P_t = \theta\left[\left(1 - \tau^W\right)\left(i - \tau^H\right) + \delta^H + \alpha + \lambda - \pi_t^e\right]^{-1} r_{t-1}\left(\tilde{\kappa}_{t-1}\right), \tag{14}$$

where θ is a level parameter, τ^W is the marginal tax rate on earnings, i is the (exogenous) risk-free interest rate, τ^H is the property tax as share of the value of the residence, δ^H is the property depreciation rate, α is a risk measure of owning the property over renting, λ is the landlord's management cost, π_t^e is the expected rate of appreciation, defined as

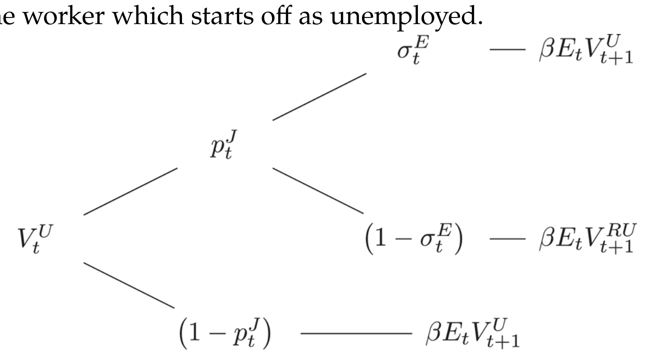
$$\pi_t^e = E_t \frac{P_{t+1} - P_t}{P_t}, \tag{15}$$

and r represents the endogenous rental rate.[17] Equation (14) does not emerge from the model, but rather is a definition. Since government is ignored, the taxes τ^W and τ^H , along with the additional parameters, serve a calibration purpose and satisfy the exact definition specified in the two references mentioned.[18] One can also assume that these taxes can be utilized as a means of financing the unemployment benefit b paid out to searching workers.

2.1.3 The worker's value functions

Recall that the worker is always in one of three states: unemployed (and without residence), unmatched renter (employed and without residence), and matched renter (employed with residence). I denote the value functions for each of these states as V^U, V^{RU}, and V^{RM}, respectively. An unemployed worker receives unemployment benefit b, and with probability p^J matches with a searching firm. If the match survives the exogenous separation rate σ^E, the worker then enters the following period as employed and without residence. If the match exogenously terminates, or if the worker fails to match with a firm, the worker enters the following period as unemployed.

The following plot illustrates a decision tree which shows the propogation from one state to the other for the worker which starts off as unemployed.

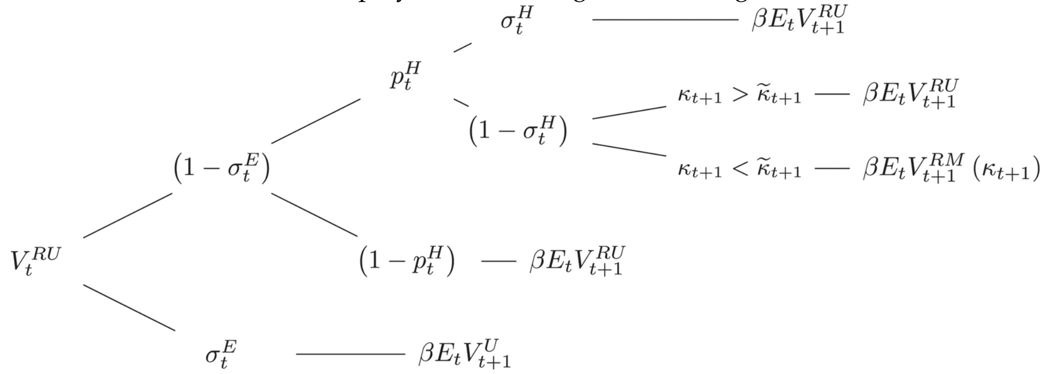


The value function which describes this state is

$$V_t^U = b + \beta E_t \left\{p_t^J \left[\left(1 - \sigma_t^E\right) V_{t+1}^{RU} + \sigma_t^E V_{t+1}^U\right] + (1 - p_t^J) V_{t+1}^U\right\}. \tag{16}$$

The worker who has secured employment and is now searching for a residence receives a wage w and, surviving the exogenous employment separation rate, matches with a searching landlord with probability p^H. If this new residential match survives the exogenous housing separation σ^H, the agent then draws a commute associated with the new residence; if the commute is below (above) the cutoff, the worker becomes employed with (without) residence the following period. If the worker matches with a landlord, survives the employment termination, but doesn't survive the housing termination, they enter the following period as employed without residence. If the worker survives the exogenous employment separation rate but fails to match with a landlord, the worker enters the following period as employed without residence. If the worker's employment match exogenously terminates, the worker enters the following period as unemployed.

The following plot illustrates a decision tree which shows the propogation from one state to the other for the worker which starts off as employed, but looking for a housing unit.

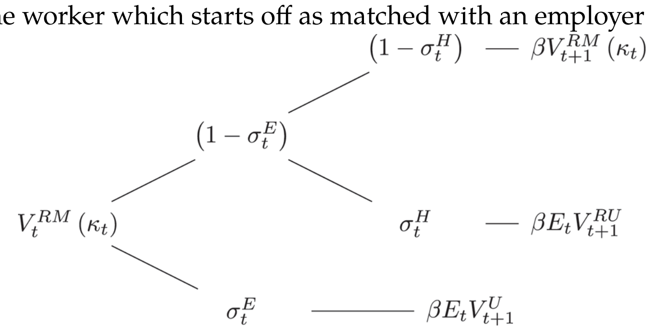


The value function which describes this state is[19]

$$V_t^{RU} = w_t + \beta E_t \left(\left(1-\sigma_t^E\right) \left\{ p_t^H \left[\left(1-\sigma_t^H\right) \int_{\underline{\kappa}}^{\overline{\kappa}} V_{t+1}^R(\kappa_{t+1}) dG(\kappa) + \sigma_t^H V_{t+1}^{RU} \right] + \left(1-p_t^H\right) V_{t+1}^{RU} \right\} + \sigma_t^E V_{t+1}^U \right), \quad (17)$$

The worker who is employed and matched with residence enjoys value V^{RM} which is made up of the agent's utility value associated with the residence (inversely related to the commute distance) net of the rent paid,[20] plus the wage received from the employer, plus the discounted continuation value. If the worker survives the exogenous employment and housing separations, the worker enters the following period matched with the same rental (and hence the same commute). If the worker survives the employment separation, but suffers the housing match separation, they enter the following period as employed without residence. If the worker's employment match exogenously separates, the worker enters the following period as unemployed.

The following plot illustrates a decision tree which shows the propogation from one state to the other for the worker which starts off as matched with an employer and a housing unit.



The value function associated with this state is

$$V_t^{RM}(\kappa_t) = u_t(\kappa_t) - r_t(\kappa_t) + w_t + \beta E_t \left\{ \left(1-\sigma_t^E\right) \left[\left(1-\sigma_t^H\right) V_{t+1}^{RM}(\kappa_t) + \sigma_t^H V_{t+1}^{RU} \right] + \sigma_t^E V_{t+1}^U \right\}, \quad (18)$$

where utility is dictated by the function[21]

$$u_t(\kappa_t, \zeta_t) = \frac{\zeta_t}{\kappa^\omega}. \quad (19)$$

I am assuming that a renter derives two sources of utility from a housing unit they're matched with. κ_t is the commute associated with the housing unit, while ζ_t is a time varying level variable illustrating the geographic amenities[22] of the housing market.

As there is a fixed mass of workers, the following three equations keep account of the proportions of the mass of workers in each of their three respective states. As performed in the section describing the landlord's value functions, we can reverse-engineer the paths on the trees in order to derive the laws of motion[23] for the workers' states. Since the mass of workers has been normalized to 1, the equation which defines the unemployed[24] is

$$U_t = 1 - (RU_t + RM_t). \quad (20)$$

For this period's unmatched renters RU_t, the law of motion is

$$RU_t = \left(1 - \sigma_t^E\right)\left\{p_t^J U_{t-1} + \left[1 - p_t^H\left(1 - \sigma_t^H\right)\int_{\underline{\kappa}}^{\tilde{\kappa}_t} dG(\kappa)\right] RU_{t-1} + \sigma_t^H RM_{t-1}\right\}, \tag{21}$$

while the law of motion for the matched renters is given by

$$RM_t = \left(1 - \sigma_t^E\right)\left(1 - \sigma_t^H\right)\left[RM_{t-1} + p_t^H \int_{\underline{\kappa}}^{\tilde{\kappa}_t} RU_{t-1} dG(\kappa)\right]. \tag{22}$$

The value of the worker's net employment surplus $V^{E\Sigma}$ is the difference between the value of the worker in the employed and without residence (unmatched renter) state and the unemployed state, so that

$$V_t^{E\Sigma} = w_t - b + \left(1 - p_t^J\right)\beta\left(1 - \sigma_t^E\right)E_t V_{t+1}^{E\Sigma} + p_t^H \beta\left(1 - \sigma_t^E\right)\left(1 - \sigma_t^H\right)E_t \int_{\underline{\kappa}}^{\tilde{\kappa}_{t+1}} V_{t+1}^{R\Sigma}\left(\kappa_{t+1}\right) dG(\kappa). \tag{23}$$

The worker's net employment surplus is the wage net of the unemployment benefit plus the expected value of the net employment surplus in the following period plus a term representing the expected housing surplus in the following period, scaled by the probability of a housing match p^H.

Remark 2

This is a key result of the framework I have set forth – (23) illustrates quantitatively how the worker's employment surplus also includes their future expected housing surplus. The reason for this is that in order for the worker to participate in the housing market, they have to have employment secured in order to pay the rental rate. Thus, one of the benefits of being matched with an employer is that employment now affords the worker an additional expected benefit.

The value of the worker's net housing surplus $V^{R\Sigma}$ is the difference between the value of the worker in the employed with residence state and the employed and without residence state, accounting for the opportunity cost of carrying the match and associated commute into the future,[25] so that

$$V_t^{R\Sigma}\left(\tilde{\kappa}_t\right) = u_t\left(\tilde{\kappa}_t\right) - r_t\left(\tilde{\kappa}_t\right) + \beta\left(1 - \sigma_t^E\right)\left(1 - \sigma_t^H\right)E_t\left(1 - p_t^H\right)\int_{\underline{\kappa}}^{\tilde{\kappa}_{t+1}} V_{t+1}^{R\Sigma}\left(\kappa_{t+1}\right) dG(\kappa), \tag{24}$$

which shows that the renter's surplus is comprised of the utility flow over the rent paid[26] and the net[27] discounted continuation value.

2.2 The surplus sharing rules and the equilibrium wage and rental rates

In accordance with Nash bargaining, the joint surplus to the match is redistributed to both counterparties via the equilibrium wage (rental rate) consistent with each counterparty's relative bargaining weight. For the bargaining between the firm and the worker to result in an equilibrium wage, if $1 - \eta$ represents the bargaining power of the firm and η represents the bargaining power of the worker, optimization[28] leads to the sharing rule

$$\eta V^{F\Sigma} = (1 - \eta) V^{E\Sigma}. \tag{25}$$

For the bargaining between the renter and the landlord, if $1 - \overline{\eta}$ is the bargaining weight of the landlord while $\overline{\eta}$ represents the bargaining weight of the renter, then the sharing rule for the housing surplus is

$$\overline{\eta} V^{L\Sigma} = (1 - \overline{\eta}) V^{H\Sigma}. \tag{26}$$

Substituting the corresponding surpluses into the sharing rule described in (25) and then using (26) and (13) results in the following wage equation

$$w_t = (1 - \eta)\left[b - \left(\frac{\overline{\eta}}{1 - \overline{\eta}}\right)\left(\xi + P_t - \beta E_t P_{t+1}\right)\left(\frac{p_t^H}{p_t^L}\right)\right] + \eta\left[y_t + \gamma\left(\frac{p_t^J}{p_t^F}\right)\right]. \tag{27}$$

The equilibrium wage takes the form of a weighted average of two expressions. The first expression is the worker's unemployment benefit net of their expected housing surplus (which is normalized by the bargaining power against the landlord) and the second expression is the sum of the output of the match and the worker's outside option.[29] The two terms are weighted according to the worker and firm bargaining powers. As mentioned in the introduction, here we can see the mechanism by which the present wage is counter-balanced by the worker's future expected housing surplus.[30]

Substituting the landlord and renter surpluses (12) and (24) into the sharing equation (26) and then using the sharing equation and incorporating (13) results in the rental rate

$$r_t\left(\kappa_t\right) = \left(1-\overline{\eta}\right) u_t\left(\kappa_t\right) + \overline{\eta}\left[\lambda + \left(1 - \frac{p_t^H}{p_t^L}\right)\left(P_t - \beta E_t P_{t+1}\right) - \left(\frac{p_t^H}{p_t^L}\right)\xi\right]. \tag{28}$$

The rental rate is also made up of the bargain-weighted average of two expressions. While the first expression is the utility value associated with the housing unit, the second expression is the landlord's management costs minus the expected capital gain net of the renter's outside option.[31]

2.3 The endogenous commute cutoff

The cutoff commute $\tilde{\kappa}$ is defined as the point where the joint surplus associated with the housing match is equal to zero. The joint surplus to the housing match is derived by taking the sum of the landlord's surplus (12) and the renter's surplus (24), incorporating the sharing rule and landlord's sales-parity condition (13), the utility function (19) and simplifying. Setting the result equal to zero and solving for $\tilde{\kappa}$ results in

$$\tilde{\kappa}_t = \left[\frac{\zeta_t\left(1-\overline{\eta}\right)p_t^L}{\left(1-\overline{\eta}\right)p_t^L\left(\lambda + P_t - \beta E_t P_{t+1}\right) - \left(1-\overline{\eta}p_t^H\right)\left(\xi + P_t - \beta E_t P_{t+1}\right)}\right]^{\frac{1}{\omega}} \tag{29}$$

Equation (29) illustrates how the threshold commute is:

- *increasing* in ζ: If the utility parameter ζ increases, this implies the flow value to the renter increases for all commute draws, resulting in an increase in the joint surplus, implying the threshold cutoff increases. An increase in the utility flow value for all commute draws would result from an increase in housing amenities exogenous to this model. For example, a decrease in the crime rate, or an increase in the quality of the school district may offset some of the disutility of commuting.
- *decreasing* in ω: If the utility parameter ω increases, this implies that the renter is less tolerant to commuting, resulting in a decrease in the flow value, eroding the joint surplus, resulting in a fall in the threshold commute.
- *decreasing* in λ: An increase in management costs facing the landlord will necessarily be transferred to the renter in the form of a higher rental rate, driving down the cutoff commute; in other words, it would take a very short commute to justify paying the increase in rent resulting from the increased costs facing the landlord.
- *increasing* in ξ: An increase in the cost of posting the vacancy/vetting renters implies that turning away from a potential match carries a larger cost, which in turn motivates the renter and landlord to be less demanding of a shorter commute draw.

2.4 Functional forms for the probabilities

I follow the literature and assume a Cobb-Douglas form for the matching function, so that if U_t represents the mass of unemployed workers and V_t represents the mass of job openings posted by firms, then matches in the labor market are written

$$m_t^E = M\left(V_t, U_t\right) = \mu^E V_t^{\epsilon}\left(U_t\right)^{1-\epsilon},$$

where μ^E and ϵ are the level and matching parameter for the function, respectively. This results in the following matching probabilities for the unemployed worker and the searching firm:

$$p_t^J = \frac{m_t^E}{U_t} = \frac{\mu^E V_t^{\epsilon} (U_t)^{1-\epsilon}}{U_t} = \mu^E \left(\tau_t^E\right)^{\epsilon} \tag{30}$$

$$p_t^F = \frac{m_t^E}{V_t} = \frac{\mu^E V_t^{\epsilon} (U_t)^{1-\epsilon}}{V_t} = \mu^E \left(\tau_t^E\right)^{\epsilon-1}, \tag{31}$$

where $\tau_t^E = V_t/U_t$ represents the tightness of the labor market.

I use the same Cobb-Douglas functional form for the matches in the housing market so that if RU_t represents the mass of agents which are employed, but searching for a rental and LU_t represents the mass of unmatched landlords, then

$$m_t^H = M(LU_t, RU_t) = \mu^H (LU_t)^{\chi} (RU_t)^{1-\chi},$$

with parameters μ^H and χ. The corresponding matching probabilities for the prospective renter and searching landlord are

$$p_t^H = \frac{m_t^H}{RU_t} = \frac{\mu^H (LU_t)^{\chi} (RU_t)^{1-\chi}}{RU_t} = \mu^H \left(\tau_t^H\right)^{\chi}$$
$$p_t^L = \frac{m_t^H}{LU_t} = \frac{\mu^H (LU_t)^{\chi} (RU_t)^{1-\chi}}{LU_t} = \mu^H \left(\tau_t^H\right)^{\chi-1},$$

where $\tau_t^H = LU_t/RU_t$ represents the tightness in the rental market.

I model the distribution of commutes using a Rayleigh distribution which has cumulative density function

$$P(\kappa \le \tilde{\kappa}) = \int_{\underline{\kappa}}^{\tilde{\kappa}} dG(\kappa) = 1 - e^{-\tilde{\kappa}^2/2\sigma^2},$$

where σ is a shape parameter. This distribution was chosen primarily for its analytical simplicity (thus allowing the CDF to be conveniently embedded into the laws of motion for the states) and its fairly close approximation to the empirical distribution of commute times (see Figure 2).

2.5 Housing market clearing

Clearing the housing market implies that the number of matched landlords is equal to the number of matched renters, so that

$$LM_t = RM_t.$$

The total measure of housing units L_t is equal to the sum of matched landlords and unmatched (but searching) landlords

$$L_t = LM_t + LU_t. \tag{32}$$

Finally, vr_t is the housing vacancy rate and it is given as the ratio of unmatched landlords to the stock of housing

$$vr_t = \frac{LU_t}{L_t}. \tag{33}$$

3 Model calibration

To calibrate the model, I use US quarterly employment and housing data spanning[32] 2001Q1 through 2015Q2. The calibration exercise undertaken consists of setting the parameter values in the model consistent with as many of the available literature counterparts and setting the remaining parameter values in accordance with an empirically consistent steady state of the model.

3.1 Steady state targets

Following the literature, I normalize output y to one.[33] The total mass of workers is set to unity, and thus the unemployment rate and level coincide. I set unemployment to $U = 0.065$ to match the mean over the data period. While I model the job-finding rate theoretically using the matching function approach as in (30), I construct the empirical data series to be used to isolate a steady state target for p^J using a similar decomposition as in Shimer (2005) which differentiates between the unemployed and the *short-term* unemployed.[34] Specifically, if the total number of unemployed next period U_{t+1} is made up of the unemployed this period who failed to find a job and the next period's short-term unemployed U^s_{t+1} so that

$$U_{t+1} = U_t\left(1 - p^J_t\right) + U^s_{t+1},$$

then the job-finding rate is

$$p^J_t = 1 - \frac{U_{t+1} - U^s_{t+1}}{U_t}. \tag{34}$$

The target for the job-finding rate is $p^J = 1.131$ to match the mean of the constructed series[35] from equation (34).

The rental vacancy rate for the US is set to $rv = 0.093$ to match the series from the US Department of Commerce: Census Bureau. Those targets can be substituted into the steady state versions of the worker's laws of motion between all three states to pin down calibrations for the measure of workers which are employed, but without a home $RU = 0.182$, the measure of workers which are employed and matched with a home $RM = 0.748$, the rate at which employed workers match with landlords $p^H = 0.939$, the rate at which landlords match with employed workers[36] $p^L = 2.215$, and the resulting housing market tightness $\tau^H = 0.424$. Tightness in the labor market is targeted to match the empirical series of vacancies per unemployed (both in levels) $\tau^E = V/U = 0.421$, implying that the target for the rate that firms match with the unemployed[37] is $p^F = p^J/\tau^E = 2.689$.

Following the empirical average of the share of labor compensation in GDP over the 1950–2011 period, I target[38] $wN/y = 0.649$. I target $r = 0.34w$ to match the rent-income ratio from data provided by Zillow.[39] The price-rent ratio data provided by Zillow gives me a target for the price of real estate of $P = 10.6403r$.

I target a value for the cutoff commute $\tilde{\kappa}$ of 0.202. In the "Journey to Work" portion of the American Community Survey questionnaire, the shortest commute time is 0 minutes, while the longest is 125. In the 1980 Census, mean travel time to work was 21.7 minutes, in the 1990 Census it was 22.4 minutes in the 2000 Census it was 25.5 minutes and in the 2009 Census it was 25.1. Since I am looking at data spanning 2001–2015, I take the linear average between the 2000 and 2009 Census and arrive at a mean travel time of approximately 25.3 minutes. Normalizing this value over the range of reponses results in the target $\tilde{\kappa} = \frac{25.3}{125} \approx 0.202$.

All targets are summarized in Table 1 below.

Table 1: Steady state targets for endogenous variables.

Variable	Description	Target	Model
y	Output	1.000	1.000
U	Unemployed workers/unemployment rate	0.065	0.065
p^J	Job-finding rate	1.131	1.131
rv	US rental vacancy rate	0.093	0.093
τ^E	Labor market tightness	0.421	0.421
p^F	Job-filling rate	2.690	2.690
w	Wage	0.694	0.694
r	Rental rate	0.236	0.236
P	Price of real estate	2.511	2.511
$\tilde{\kappa}$	Commute	0.202	0.202

3.2 Parameterization

As is standard in the literature, the discount parameter is set to $\beta = 0.984$ from $1/(1+i)$, where i is the average real interest rate from the quarterly series for the 3-Month Treasury Bill.

I again differentiate between the unemployed and the *short-term* unemployed[40] in constructing the series for the labor match destruction rate σ^E. Once a job is exogenously destroyed, the former employee is considered unemployed (part of the short-term unemployed) approximately 2 weeks after the job terminated. This then implies that the following period's short-term unemployed U^s can be written

$$U^s_{t+1} = \sigma^E_t e_t \left(1 - \frac{1}{2} p^J_t\right),$$

where σ^E_t is the labor match separation rate, e_t is the number of employed individuals, and p^J_t is the job-finding rate from (34). If one wants to express the separation rate as that rate which dictates the flow from employment to short-term unemployment, counting the separations which quickly become new jobs within 2 weeks would overstate the extent of job separation. Using the above formulation corrects for this bias by isolating the actual rate of flow from employed to short-term unemployment. Solving for σ^E_t gives

$$\sigma^E_t = \frac{U^s_{t+1}}{e_t \left(1 - \frac{1}{2} p^J_t\right)}. \tag{35}$$

The job-destruction rate is set to $\sigma^E = 0.073$ to match the mean constructed series from equation (35).

Unemployment benefits are set to $b = 0.54w$, where w is the target calibration for steady-state wages.[41] The proportion of wages 0.54 is sourced from my own weighted average of unemployment benefit calculators for various states in the US[42] Pissarides (1998) and Koskela and Thadden (2008) discuss the importance of how unemployment benefits are specified in search and matching models; For example, rather than specifying the benefits as a constant, b, they can be indexed to the wage so that $b_t = zw_t$, where z represents a constant replacement rate. While I follow the majority of the macro literature and specify unemployment benefits as a constant, a robustness check with this alternative specification is conducted in the technical appendix.[43]

ϵ, the matching function parameter, is set to 0.40; this is the value chosen by Walsh (2005) and Blanchard and Diamond (1989) and further, is a value consistent with the literature. A robustness check demonstrates that the model's responses remain largely insensitive to alternative values for this parameter.[44]

For the parameters in the rental parity condition (14), I set employment taxes, τ^W equal to 0.25 in accordance with the tax rate schedules provided by the IRS[45] for the tax bracket which covers the average level of income given by the data series for median household income in the United States.[46] For property taxes, I set $\tau^H = 0.013$ in accordance with Moody's, RealtyTrac, and the American Community Survey. Following Harding, Rosenthal, and Sirmans (2007), for the depreciation rate on housing, I set $\delta^H = 0.0293$. As there is no real source for data on the risk of owning a home over renting, I choose a parameter value for α such that the terms in brackets in (14) sum to unity; I then choose a value for the level parameter $\theta = 10.6403$ to match the US rent-price ratio provided by Zillow.

The separation rate for housing matches is set to $\sigma^H = 0.039$, the average of the series titled "Table A-4. Geographical Mobility by Tenure: 1988–2015" from the US Census Bureau, Current Population Survey.[47] The landlord's rental management costs are set to $\lambda = 0.09r$, where r is the target calibration for the steady-state rental rate.[48] A sample of 12 residential property management firms[49] was conducted and nine percent of monthly rentals is the industry average. Further, property management costs is an appropriate proxy for this parameter as all property management firms only charge their management fee when the unit managed is occupied; this matches the structure of the landlord's value function (8), where λ only shows up when the landlord is matched with a renter.

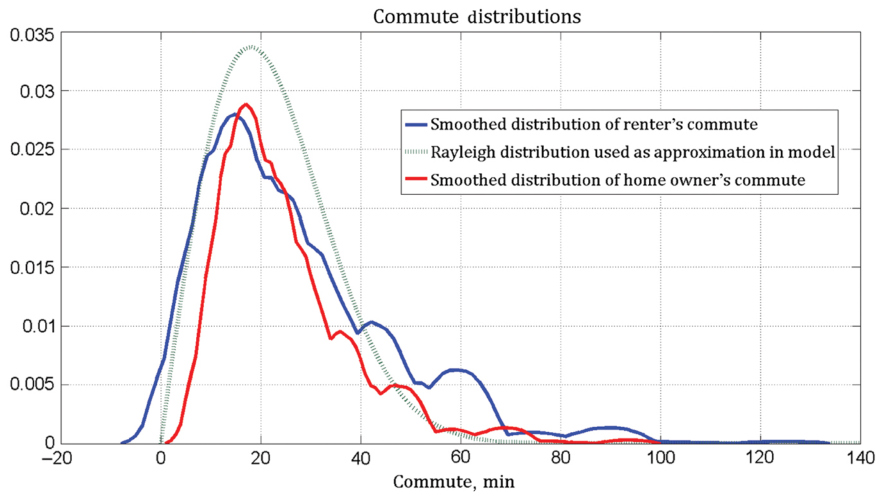


Figure 2: Smoothed densities for the commute times (in minutes) for both home owners and renters, along with a Rayleigh distribution. Source: American Community Survey P.U.M.S. (2010). The states included in the sample were California, Florida, Indiana, and New York.

Figure 2 illustrates the smoothed[50] distribution of the commute times for both renters and homeowners taken from the 2010 American Community Survey, alongside the fitted[51] Rayleigh distribution. As mentioned in the steady-state section, the empirical mean of commutes in the US was 25.3 minutes. The implied mean given by the fitted Rayleigh distribution for renters is $\sigma\sqrt{\pi/2} = 29.424$ minutes, where $\sigma = 23.477$ is the estimated Rayleigh parameter.[52] Although the implied mean from the estimated distribution does not eclipse the actual empirical mean of 25.3 minutes, the real benefit of using the Rayleigh distribution lies in the simplicity of its analytical cumulative distribution function, enabling it to be embedded in the model with ease. I set the σ parameter in the model consistent with the steady-state target[53] for the commute cutoff of 25.3/125 = 0.202. Thus, $\sigma = 0.162$.

As is customary in the literature [Albrecht, Gautier, and Vroman (2015), Mortensen and Pissarides (1994), Ravenna and Walsh (2011), Rupert and Wasmer (2012), and Walsh (2005)], bargaining weights are assumed symmetric and set to $\overline{\eta} = \eta = 0.5$. ϵ, the matching function parameter, is set to 0.50 so that the Hosios condition is satisfied.[54]

The job vacancy posting cost γ, which is consistent with the empirically-justified targets, is 8.655, which while extremely high is due to equation (5). In steady state, (5) reads $\gamma = p^F\beta(1-\sigma^E)(y-w)/[1-\beta(1-\sigma^E)]$. Given the empirically justified targets for p^F, σ^E, y and w, the value for γ which holds the equation in steady state is 8.655. Likewise, for the housing vacancy cost parameter ξ, the value which is consistent with the steady state is 8.522, also a (relatively) high value. I can pursue a lower target for ξ, but this comes at the cost of an increase in the parameter value for $\overline{\eta}$ in order to preserve a consistent steady state. A parameter value for $\overline{\eta}$ above 1/2 implies that renters have more bargaining power than landlords, but this is not consistent empirically.[55] Since there is no real consensus in the literature regarding these parameters, I set both in accordance with the parameters and targets which do have consensus from the literature/empirical justification.

Table 2 contains an inventory of parameters and their values.

Table 2: Parameter values set.

Parameter	Description	Value
β	Discount	0.985
σ^E	Labor match destruction rate	0.073
b	Unemployment benefits	0.375
ϵ	Labor matching function parameter	0.500
σ^H	Housing match separation rate	0.039
λ	Property management costs	0.021
$\underline{\kappa}$	Lower support of commute distribution	0.000
$\overline{\kappa}$	Upper support of commute distribution	$+\infty$
η	Bargaining weight over labor match surplus	0.500
$\overline{\eta}$	Bargaining weight over housing match surplus	0.500
θ	Level parameter in the rent-price ratio equation	0.094
τ^W	Tax rate on earnings	0.250
τ^H	Property taxes	0.010
δ^H	Housing depreciation rate	0.029
α	Parameter governing the risk to home ownership	0.954
σ_R	Rayleigh distribution shape parameter	0.162
γ	Labor vacancy posting cost	8.655
ξ	Housing vacancy posting cost	8.522

4 Numerical analysis

I solve the model using a first-order perturbation method. I conduct two sets of experiments involving temporary and permanent shocks to geographic amenities and labor productivity, and lastly, a stochastic simulation to study the model's implied relationship between labor separations and housing vacancies.

The first experiment entails shocking the housing side of the model in order to study the impact on both housing and labor market variables. Specifically, I conduct an experiment in which the level of geographic amenities undergoes a temporary shock in order to study how the increase in amenities impacts key housing and labor market variables. The second experiment entails shocking the labor side of the model in order to study the impact on key housing market variables. A temporary shock to labor productivity is carried out and the response of the costs and the expected appreciation rate of housing is studied. I follow these two experiments with a second set of experiments which demonstrate how policies aimed at adjusting the measure of the stock of housing may be implemented in an effort to offset some of the results of a permanent rise in labor productivity or a permanent fall in the level of geographic amenities.

Lastly, I follow these two sets of experiments with a stochastic simulation of the entire model. The purpose of this simulation is to demonstrate how the model is able to capture the empirical relationship between the rate of labor market separations σ^E and the housing vacancy rate vr. I first analyze the empirical relationship between these two variables and then I compare this with the model's simulated paths for these variables.[56]

4.1 Housing market spillovers into the labor market: geographic amenities

This experiment entails analyzing the response of some key labor market and housing market variables resulting from a temporary shock to the level of geographic amenities. Some examples of geographic amenities include climate, scenic beauty, access to parks, shops, the provision of reliable public transportation, public safety/crime rate, and high quality schools. As many of these amenities result from public expenditure, understanding the housing market impacts a policy focused on increasing amenitites results in is important.

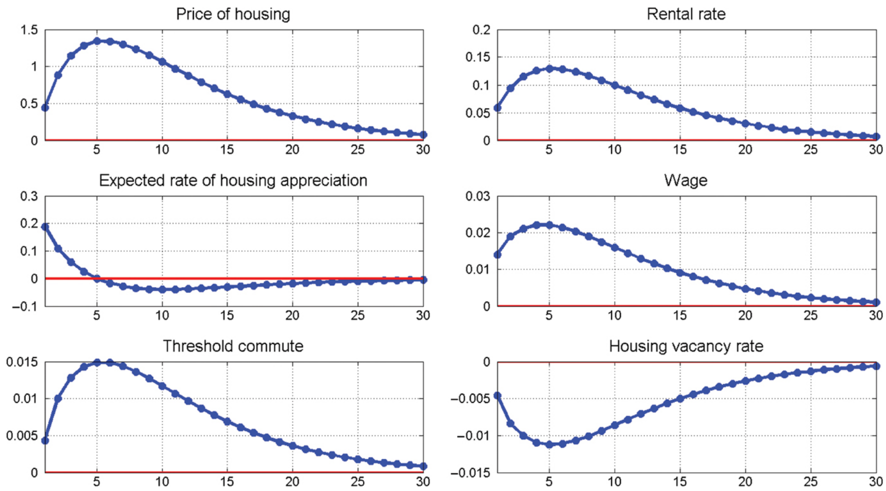


Figure 3: Impulse responses of housing costs, the expected appreciation rate of housing, wages, commuting behavior and the housing vacancy rate to a one-time persistent shock to geographic amenities. The persistence parameter on the shock process is 0.85 while the standard deviation of the shock is 0.06 (6%).

Figure 3 shows the dynamic responses of the price and rental rate of housing, the expected appreciation rate of housing, wages, the threshold commute, and the housing vacancy rate resulting from a temporary shock to the level of geographic amenities. I consider this shock to be a version of a "taste shock", and model it as an AR(1) process where I follow Stockman and Tesar (1995) and set the persistence parameter to 0.85 with a standard error of 0.06.

The increase in amenities has the initial impact of increasing the utility flow value of the housing matches formed. The resultant increase in the joint surplus to housing matches increases the rental rate which transfers upward pressure on the price and the expected appreciation rate of housing via the rent-price parity condition. The increase in the expected price of housing decreases the worker's anticipated housing surplus since this increases the value of the landlord's option to sell the home rather than having to seek out a match. As the worker's anticipated housing surplus impacts the equilibrium wage negatively, the increase in amenities results in an increase in the worker's wage. From the commute threshold equation, the counterparties to housing matches are less demanding of short commutes and thus the threshold commute rises, motivating more matches to successfully form, resulting in a fall in the rental vacancy rate.

Several recent papers [Glaeser et al. (2014), Guren (2016), and Head, Lloyd-Ellis, and Sun (2014)] have highlighted the difficulty of generating price "momentum" in models with frictionless housing markets.[57] The rent-price parity equation (14) includes (recursively, as it should) all future rents through the expected appreciation π^E term. Thus, an increase in amenities increases the rental rate on impact, exerting upward pressure on the price through the rent-price parity equation. The resulting increase in expected appreciation π^E amplifies the response of prices (through the rent-price parity equation), allowing housing prices to exhibit a hump-shaped, persistent response to the increase in amenities.

4.2 Labor market spillovers into the housing market: labor productivity

This experiment entails analyzing the response of the price of housing, the rental rate of housing, and the expected rate of appreciation following a temporary shock to the productivity of labor. I follow the literature and model the labor productivity shock as an AR(1) process. I follow Shimer (2005) and calibrate the exogenous shock process to match the empirical moments of the series for real output per hour in the manufacturing sector. I estimate a persistence parameter of 0.852 and then I store the residuals from the empirical model and form a frequency distribution which I use to extract the standard deviation for the error term of 0.020. The dynamic responses are shown in Figure 4 below.

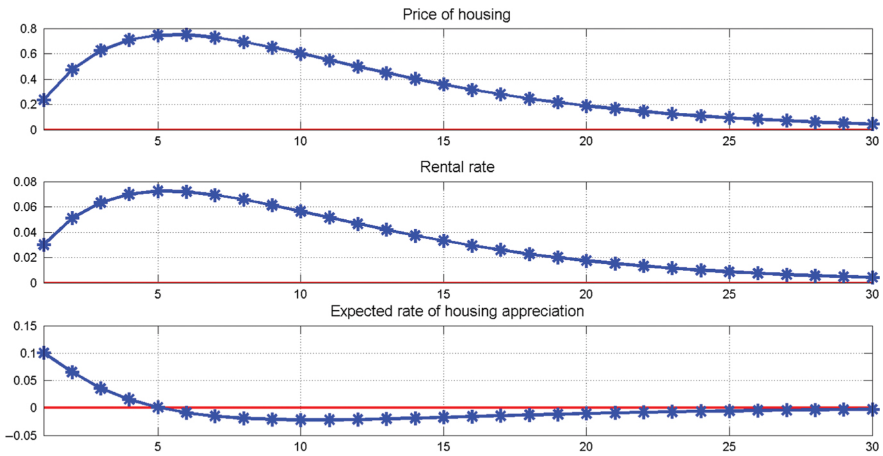


Figure 4: Impulse responses of housing costs and the expected appreciation rate of housing to a one-time persistent shock to labor productivity. The shock to productivity was modelled as an AR(1) process with persistence parameter 0.852 and standard deviation of 0.020 for the white noise.

The increase in labor productivity works to increase the surplus to labor matches, motivating more firms to post more employment vacancies, resulting in more employment matches formed. This increases the probability that searching landlords will successfully find a match, which decreases the unmatched renter's outside option, resulting in an increase in the equilibrium rental rate. The increase in the rental rate results in an increase in the expected rate of housing appreciation along with an increase in the price of housing.

Once again,[58] as a result of the rent-price parity equation (14) (correctly) including the expected appreciation π^E term, housing prices and rents exhibit a hump-shaped, persistent response to labor productivity.

4.3 Implications for policy: are there land use policies which can offset these shocks?

I will now turn to two policy experiments which investigate the potential for land use policies to dampen permanent shocks to the level of labor productivity and geographic amenities. I model changes in land use policies as an altering of the measure of housing units, and thus landlords L, so that a policy which is aimed at the expansion of housing units or the approval of more construction permits to build housing would be represented by an increase in L, while a policy aimed at the re-zoning of a residential area into commercial, for example, leading to a decrease in the level of housing units, would be represented as a decrease in L.

4.3.1 A permanent rise in productivity

Figure 5 illustrates the trajectories of the levels of the price, the rental rate and the expected appreciation rate of housing, the wage, the threshold commute, and the housing vacancy rate following a permanent rise in the level of labor productivity. The variables all commence at their steady state levels and at time $t = 20$, a permanent 10 percent increase in the level of labor productivity hits. The solid red lines represent trajectories without a land-use policy, while the dashed blue lines represent a policy which expands the measure of housing by four-tenths of a percent.

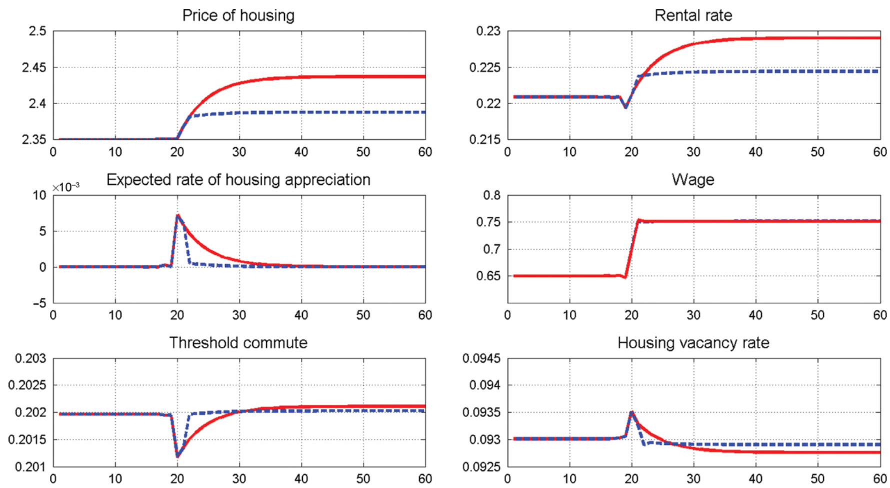


Figure 5: Simulation results illustrating the path of important housing variables along with the wage and threshold commute following a permanent increase in productivity of 10% with and without a housing policy aimed at increasing the measure of housing units by 4/10% (four-tenths of a percent).

Housing prices experience an increase of approximately four and one half percent without the policy; with the policy, the rise is approximately two percent. The magnitudes are identical for rental rates. While the expected rate of appreciation exhibits an increase of the same magnitude with and without the policy, the return to baseline is much quicker in the case with the policy. Interestingly, the wage undergoes the same fifteen percent increase with or without the policy. Finally, both the threshold commute and the rental vacancy rate return to their new baseline levels quicker under the policy, where the baseline for the commute under the policy is lower than without, while the new baseline for the housing vacancy rate ends up higher.

The application of such a policy may have some practicality in markets with a highly evolving technological sector in combination with strict land use laws in place.[59] However, the benefits of a policy such as one which frees up space for development must be weighed against the costs of designating the land-usage. According to the model's response, the cost increases due to the permanent increase in productivity are fairly sensitive to the policy, as a less-than one percent increase in the measure of housing resulted in a mitigation of both variables' increase by more than fifty percent.

This demonstrates that even housing markets with the strictest of land use laws already in place can benefit from a consideration of a policy which adds housing units in an effort to ease the burden of shelter for some of its residents.

4.3.2 A permanent fall in amenities

Just as important as trying to understand the housing and labor markets' response to an increase in amenities is the study of potential policies which may provide a means to mitigate the losses resulting from a permanent fall in the level of geographic amenities. This policy experiment involves the result of altering the measure of housing units at the onset of a permanent decrease in the level of amenities. Figure 6 displays the trajectory of housing costs, the expected appreciation rate of housing, wages, commuting behavior and the housing vacancy rate following a permanent fall in amenities of half a percent with (in blue, dashed) and without (in red, solid) a housing policy which reduces the measure of housing units by a tenth of a percent.

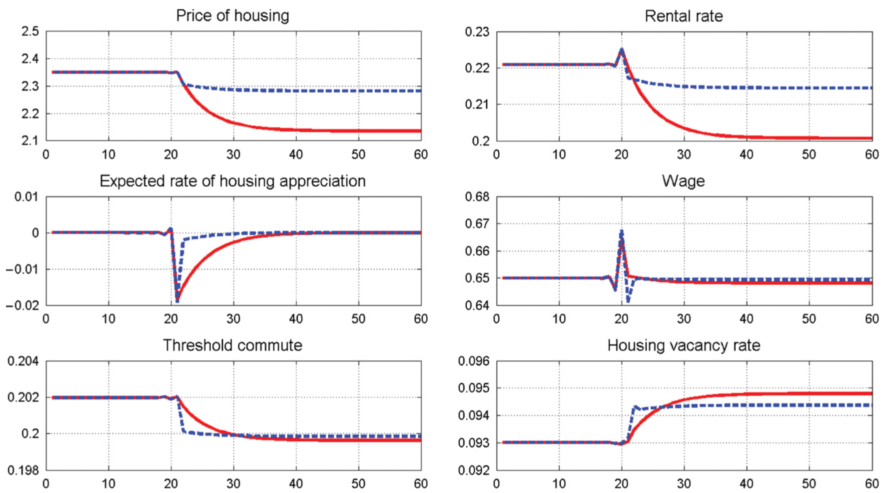


Figure 6: Simulation results illustrating the path of housing costs, the expected appreciation rate of housing, wages, commuting behavior and the housing vacancy rate following a permanent fall in amenities of −0.5% with and without a housing policy aimed at decreasing the measure of housing units by −0.10%.

Housing prices experience a decrease of approximately eight and one half percent without the policy while with the policy, the fall is approximately two percent. The magnitudes are identical for rental rates. While the expected rate of appreciation exhibits a fall of the same magnitude with and without the policy, the return to baseline is much quicker in the case with the policy. The wage is the one variable which seems to actually exhibit a higher level of volatility under the land use policy. Finally, both the threshold commute and the rental vacancy rate return to their new baseline levels quicker under the policy, where the baseline for the commute under the policy ends up slightly higher than without, while the baseline for the housing vacancy rate ends up lower.

Although a policy in which the government steps in, purchases houses from landlords, and bulldozes them whenever amenities decline may be extreme, this experiment demonstrates that a policy which perhaps entails tightening/curtailing the issuance of building permits to construction companies has the potential to offset the results of an amenity decrease.

4.4 Rental vacancy rates and labor separation rates

I now simulate the model for 10,000 periods, dropping the first 2,500 observations and then take a random sample of the simulated series for labor separations and the home vacancy rate and compare them to their empirical counterparts. Figure 7 displays both the empirical series alongside the series of the model's simulations.

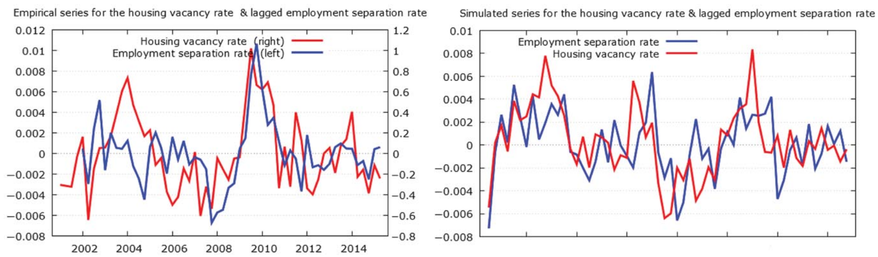


Figure 7: The empirical series for labor market separation and the vacancy rate in housing (left) versus the model's simulated results for the same variables (right).

From the cross-correlogram, the highest correlation between the two empirical series is achieved when labor separations are lagged by four quarters with a correlation[60] of 0.517. Over the entire simulated series, the correlation between the vacancy rate and lagged labor separations is $corr(vr_t, \sigma^E_{t-4}) = 0.465$, while over the sample[61] shown in Figure 7, $corr(vr_t, \sigma^E_{t-4}) = 0.530$.

Kydland, Rupert, and Sustek (2012) and Leamer (2015) document similar empirical findings; while residential investment leads the business cycle, non-residential investment lags the business cycle.[62] Indeed if I repeat the above empirical exercise using the homeowner vacancy rate, the cross-correlogram reveals that the homeowner vacancy rate leads (rather than lags) the labor separation rate by 6 quarters.

As my model is calibrated primarily to data sourced from the rental market, I interpret the empirical findings as renter sorting following separation in the labor market. Given the greater level of housing liquidity renters have over homeowners, a renter which separates from their employment arrangement faces less costs in relocating themselves in a different housing market in order to accept their next job.[63] We would then expect to see an uptick in the vacancy rate of rentals following an increase in labor separations.

As shown in the plot on the right-hand side of Figure 7, the model captures this empirical relationship. Recall that the structure of the model is such that once a renter suffers a labor market separation, they also separate from their housing relationship which would then increase the vacancy rate in housing. A persistent shock to labor separations also dissuades firms from posting vacancies as the expected benefits have decreased against the expected costs (as per equation (4)), lengthening the persistence of the effect that the labor market shock has on the housing market, even up to four quarters out. Lastly, note that while the correlation between the model's simulated variables matches the data closely, the model falls short in generating the observed level of volatility in the rental vacancy rate.[64]

4.5 Discussion: how do the results of this model relate to others?

Table 3 provides a handful of relevant correlation coefficients from the model in order to compare the results of this model with some of the other results of related papers in the literature.

Table 3: Correlation of simulated variables (HP filter, λ =1600).

Variable	P	ρ	π^E	p^L	$\tilde{\kappa}$	vr	ζ
P	1.0000	0.9926	0.0146	0.9826	0.9072	−0.9857	0.5510
ρ	0.9926	1.0000	0.1328	0.9978	0.8747	−0.9795	0.6327
π^E	0.0146	0.1328	1.0000	0.1981	−0.1195	−0.0576	0.7931
p^L	0.9826	0.9978	0.1981	1.0000	0.8570	−0.9725	0.6786
$\tilde{\kappa}$	0.9072	0.8747	−0.1195	0.8570	1.0000	−0.9520	0.5085
vr	−0.9857	−0.9795	−0.0576	−0.9725	−0.9520	1.0000	−0.6220
ζ	0.5510	0.6327	0.7931	0.6786	0.5085	−0.6220	1.0000

There are three sets of relationships which are fairly important to focus on. The models studied in Krainer (2008), Albrecht et al. (2007), and Genesove and Han (2011) were consistent in generating a negative relationship between prices and time on the market. This is a relationship which is prevalent in the data which indicates that in "hotter" real estate markets, successful matches occur quicker with prices on a rising trajectory. Referring to the first two entries of row 4 in Table 3 we can see that both prices P and rental rates ρ share a positive relationship with the house-filling rate p^L. Recall, that p^L is the probability that a landlord successfully matches with a renter, and thus $1/p^L$ represents the expected length of time it will take to find a match, or time on the market. Thus, the model is successful in generating this negative relationship.

In "hotter" residential markets, as matches are successfully formed, the available supply of housing contracts and the vacancy rate will falls with prices rising. This is an empirical relationship studied in Caplin and Leahy (2011), and if we refer to the first two entries of row 6 in Table 3 we can see that both prices P and rental rates ρ share a negative relationship with the vacancy rate vr.

Albouy and Lue (2015) study a quality of life model and measure the tradeoff individuals make by commuting more in order to be able to enjoy the amenities that some suburban neighborhoods offer over urban areas. Referring to the 5th entry of the last row in Table 3, we can see that the model successfully captures this relationship, generating a correlation coefficient of 0.5085 between amenities ζ and the commute threshold $\tilde{\kappa}$.

5 Conclusion

This paper introduces a model which integrates a labor market with a housing market, both characterized by search and matching frictions, into a single, coherent macroeconomic model which can be solved and simulated using standard, first-order perturbation methods. This paper improves upon the literature in a variety of ways. The model accounts for the procyclicality of housing prices, rental rates and the expected appreciation rate of housing, while also accounting for the increase in wages, housing prices, rental rates and workers' willingness to commute as a result of an increase in geographic amenities. Simulations demonstrate how certain land-use policies dampen the results of permanent shocks to labor productivity and the level of geographic amenities. The model is also able to account for the positive comovement between vacancy rates in the housing market and separation rates in the labor market.

An interesting extension to the model would be the incorporation of optimal saving by workers to safeguard against employment separations. This would allow for a worker which separated from their employer to stay in their current housing arrangement (instead of automatically separating from their housing match), paying their housing costs with their savings until another job is secured. This extension would not come without cost, however. Once the worker again matches with a searching firm, the firm knows the exact commute, potentially motivating a strategic game of hidden information on the part of the unemployed worker. An additional extension may include a supply side to the model, where the measure of housing responds endogenously to shocks originating from the labor market or housing market. I leave these extensions for future work.

Acknowledgments

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Notes

1 The authors find that, conditional on personal productivity, the wage-value of job offers has moderate dispersion, however the dispersion of implied non-wage values is substantially larger.
2 This specification for the timing follows urban models such as Alonso (1960) where employment locations were predetermined and assumed to be located in a central business district, resulting in a "negative rent gradient". Coulson and Engle (1987) and Tse and Chan (2003) tested whether or not a rent gradient exists using housing and commute data with both papers concluding that increases in transportation costs raise the price of centrally-located housing. As I ignore saving and/or credit in the model presented in this paper, the timing relies on the assumption that workers need to secure employment *prior* to housing since the wage will be used to pay their housing costs. This timing assumption greatly increases the tractability of the model.
3 Nonetheless, the model can be extended to a framework of owner-occupied. In that case, a landlord may be replaced with a combined real estate broker-bank which searches for home buyers, holds the physical home as collateral and charges the worker a monthly mortgage payment instead of a rental rate. The monthly payment would be equivalent to a monthly user cost embedded with the present discounted value of a down-payment. The equivalence between the rental rate, the monthly user cost and the equilibrium price of a residence is defined in (14).
4 While it may be peculiar to have commute time as an exogenous random variable, this modeling assumption follows Rupert and Wasmer (2012) and avoids having to further complicate the model with directed search.
5 In this framework, the survival of the housing match not only relies on the housing separation rate, but also on the worker's employment match not exogenously terminating. Thus the landlord and the (renting) worker need to take employment into consideration, because while renting (and employed), the worker gives up the opportunity to switch to a closer residence if conditions in the housing market improve. The landlord also gives up the opportunity to rent to a different worker which may happen to come along with a shorter commute than the current one (and thus a higher housing value to contribute to the joint surplus); this opportunity cost to matching is a new feature of this model, as well.
6 Both papers study search and matching frictions in financial and labor markets; in their models, if a firm is matched with a lender and a laborer, and the match with the lender exogenously destroys itself, the match with the laborer ends up separating as well. While this assumption may seem unreasonable in the context of housing (i.e. geographic amenities can be enjoyed regardless of employment status) it allows the model to remain tractable.
7 Examples may include staying with their parents or friends.
8 The worker's anticipated housing match surplus is contingent on the tightness of the housing market and the distance of the worker's housing match to their employment match (the worker's commute, which is drawn from a distribution).
9 Some employers in San Francisco, for example, may pay their new employees a wage which is lower than the market wage but will "substitute" the difference by paying for the employees' bridge toll or commuter train tickets or even provide a commute shuttle (Google Bus).
10 Equation (4) shows that the expected cost of a match γ/p_t^F is equal to the expected benefit of a match.
11 Separation here includes the worker surviving the housing (employment) separation, but suffering the employment (housing) separation, or suffering both.
12 I've used the abbreviation

$$E_t \int_{\underline{\kappa}}^{\overline{\kappa}} V_{t+1}^{L}\left(\kappa_{t+1}\right) dG\left(\kappa\right) = E_t \int_{\underline{\kappa}}^{\widetilde{\kappa}_{t+1}} V_{t+1}^{LM}\left(\kappa_{t+1}\right) dG\left(\kappa\right) + E_t \int_{\widetilde{\kappa}_{t+1}}^{\overline{\kappa}} V_{t+1}^{LU} dG\left(\kappa\right). \tag{6}$$

13 I assume this cost is the associated property management fee. More details in the calibration Section.
14 See the appendix for details.
15 A landlord which matches with a prospective renter internalizes the expected $1/\left[\left(1-\sigma^{E}\right)\sigma^{H}+\sigma^{E}\right]$ quarters duration of the match – unlike the rest of the search literature where match-specific productivity is "drawn from a distribution each period [Pissarides (1985), Mortensen and Pissarides (1994), Walsh (2005), and Beaubrun-Diant and Tripier (2015)] – here, the commute does not change for the entire duration of the match. If jobs terminated every period (i.e. $\sigma^E = 1$), then the cutoff commute $\widetilde{\kappa}$ would simply satisfy $V^{LM}\left(\widetilde{\kappa}_t\right) = V_t^{RU}$ as a commute would be drawn each period. However, employment on average lasts $\frac{1}{\sigma^E}$ months and, as a result has to be taken into consideration (along with the housing separation rate) when calculating the commute cutoff. Since the only way a housing match terminates is if the renter exogenously loses their job or if the renter exogenously separates from the home, both the renter and landlord understand that they will be matched with each other for an expected length of time, implying that both will be giving up the opportunity to match with a more favorable counterparty (renter could potentially match with a closer home which increases utility value of home; landlord could potentially match with a more local renter which increases the joint surplus of the housing match).

16 "net" here refers to the $1 - p_t^L$ factor. The current surplus takes into account that the landlord which is unmatched matches with probability p_t^L.
17 Note that (14) includes recursively all future rents through the term π_t^e.
18 The interested reader is encouraged to see Poterba (1984) and Himmelberg, Mayer, and Sinai (2005) for more details on price-rent ratio equations such as (14).
19 In this equation, I've used the abbreviation

$$E_t \int_{\underline{\kappa}}^{\overline{\kappa}} V_{t+1}^{R}(\kappa_{t+1}) dG(\kappa) = E_t \int_{\underline{\kappa}}^{\widetilde{\kappa}_{t+1}} V_{t+1}^{RM}(\kappa_{t+1})\, dG(\kappa) + E_t \int_{\widetilde{\kappa}_{t+1}}^{\overline{\kappa}} V_{t+1}^{RU} dG(\kappa).$$

20 The motivation for modelling the value function in manner follows Albrecht, Gautier, and Vroman (2015). In their model, a home buyer would realize value $x - p$, where x represents a (constant) utility flow value and p represents the cost of housing. Wheaton (1990) implements a similar value function structure.
21 u satisfies the basic properties:

$$\frac{du}{d\kappa} < 0, \ \frac{d^2u}{d\kappa^2} > 0.$$

22 Geographic amenities include, but are not limited to parks, shops, public transport provision, public safety/crime rate, high quality schools, etcetera.
23 See section 1.9 of the technical appendix for details.
24 The law of motion for this period's unemployed workers can also be derived by reverse-engineering the flows from the tree so that

$$U_t = \left[1 - p_t^J\left(1 - \sigma_t^E\right)\right] U_{t-1} + \sigma_t^E\left(RU_{t-1} + RM_{t-1}\right).$$

25 As with the landlord's surplus equation (12), the renter's threshold commute distance $\widetilde{\kappa}$ internalizes the opportunity cost of progressing into the future with the current match; See footnote 2.1.2 on page 8.
26 One can compare u to r on pecuniary terms if the amenity parameter ζ was represented by the dot-product of a vector of amenities and the coefficients of a hedonic (home value) regression and the commute was put into cost terms by multiplying the commute time by the wage.
27 "net" here refers to the $1 - p_t^H$ factor. The current surplus takes into account that the unmatched renter matches with probability p_t^H.
28 The optimization problem is fleshed out in the model appendix.
29 The outside option can also be written as $p_t^J \times \gamma / p_t^F$, where γ / p_t^F is the average/expected cost of a labor match, which in equilibrium is equal to the expected benefit of a match.
30 This is consistent with Hall and Mueller (2015), where the authors argue that commute time represents a likely element of non-wage job value.
31 To show this, we can re-express the term in the curly brackets as $\lambda - (\beta P_{t+1} - P_t) - p_t^H (\xi + P_t - \beta P_{t+1}) / p_t^L$.
32 The time frame is chosen based on the availability of detailed JOLTS data. Although the JOLTS data is available monthly, the housing data is limited to the quarterly frequency; In an effort to remain consistent across the labor and housing market data, a quarterly frequency is chosen.
33 Matched labor output is also set to unity in Petrosky-Nadeau and Wasmer (2013).
34 Differentiating between unemployed and short-term unemployed corrects for the upward bias in the separation rate by isolating the actual rate of flow from employed to short-term unemployment. Refer to the explanation pertaining to (35).
35 I interpret a job-finding rate of greater than one implying that on average it takes less than one quarter (1/1.131 quarters ≈2.5 months) for a worker to find a job.
36 It takes, on average, less than one quarter (1/2.215 quarters ≈1.25 months) for a landlord to fill a rental vacancy.
37 It takes, on average, less than one quarter (1/2.689 quarters ≈1.1 months) for a firm to fill a job vacancy.
38 Petrosky-Nadeau and Wasmer (2013) and Golin (2002) set w/y =2/3. Labor's share over the 2000–2011 period is 0.642.
39 See the data appendix for details.
40 See the explanation pertaining to (34).
41 This target is discussed in the steady state subsection.
42 See the data appendix for details.
43 See section 3.1.2 of the technical appendix for details.
44 ϵ was set to 0.40, 0.50, and 0.60; see section 3.1.1 in the technical appendix for details.
45 Publication 17 on the IRS forms and publications page.
46 Over the 2001Q1 through 2015Q2 period.
47 Using Table A-5 (Reasons for move) I normalize the time series in Table A-4 to only reflect separations from housing solely due to reasons *other than employment separation*. If employment separations were not extricated from Table A-4, then employment separations would be counted twice by the theoretical model.
48 This target is discussed in the steady-state subsection.
49 See the data appendix for individual details. One large firm was contacted in each of the following cities: Los Angeles, CA; San Francisco, CA (2 firms); San Diego, CA; Dallas, TX; Oklahoma City, OK; Minneapolis, MN; Chicago, IL; Miami, FL; Charlotte, NC; Boston, MA; New York, NY. Additionally, there were a couple of firms which also offered a contract where an amount equivalent to 1 month's rent of the property would satisfy a year's worth of property management.
50 Epanechnikov kernel smoother with bandwidth parameter equal to 4.
51 The Matlab function raylfit(data) returns the maximum likelihood estimates of the parameter of the Rayleigh distribution given in the data vector.
52 For owners, the estimated Rayleigh parameter is σ = 23.302, implying a mean of 29.204 minutes.
53 See the discussion involving the steady-state target for $\widetilde{\kappa}$ in the steady-state Section.
54 Blanchard and Diamond (1989); Walsh (2005) choose ϵ = 0.40. Please refer to the appendix for a robustness check. This involves simulating the model using ϵ = 0.40, ϵ = 0.50, and ϵ = 0.60. The simulation results are are insensitive to the value of that parameter.
55 For example, if I follow Diaz and Jerez (2013) and define buyer bargaining in the housing market as the inverse of the ratio of the sales price to the listing price for a specific home, for an increase in $\overline{\eta}$ I would expect to see many homes purchased at a price below listed value; this is contrary to the real estate data provided by Zillow which shows that while approximately 5% of listings close at a price below the original listing price, approximately 95% close above listing.

56 Section 3.1.3 in the technical appendix provides the model's theoretical second moments for some additional variables and compares them against their empirical counterparts.
57 This difficulty is notable in Head, Lloyd-Ellis, and Sun (2014), where a claim to future rents traded in a frictionless market exhibits no momentum, while houses traded in decentralized markets do.
58 Refer to the paragraph preceding subsection 4.2.
59 Coastal California near the Silicon Valley area, for example.
60 Under the null hypothesis of no correlation: $t(52) = 4.35486$, with two-tailed p-value 0.000.
61 Under the null hypothesis of no correlation: t(9994) = 52.471, with two-tailed p-value 0.000 for the full sample and under the null hypothesis of no correlation: $t(56) = 4.678$, with two-tailed p-value 0.000 for the sub-sample.
62 It is important to point out that Kydland, Rupert, and Sustek (2012) perform a cross-correlogram and with the result that residential investment leads GDP by one quarter and non-residential investment lags GDP by one quarter; while they analyzed the relationship between investment and GDP, I am analyzing the relationship between separations and vacancy rates.
63 Head and Lloyd-Ellis (2012) illustrate how homeowners accept job offers from other cities at a lower rate than do renters.
64 One key well-documented shortcoming of search models similar to DMP is the inability of the model to generate empirically consistent levels of volatility in some key variables. See Shimer (2005).

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