

# Understanding Booms and Busts in Housing Markets

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Some booms in housing prices are followed by busts. Others are not. It is generally difficult to find observable fundamentals that are useful for predicting whether a boom will turn into a bust or not. We develop a model consistent with these observations. Agents have heterogeneous expectations about long-run fundamentals but change their views because of “social dynamics.” Agents with tighter priors are more likely to convert others to their beliefs. Boom-bust episodes typically occur when skeptical agents happen to be correct. The booms that are not followed by busts typically occur when optimistic agents happen to be correct.

## I. Introduction

Some booms in housing prices are followed by busts. Others are not. It is generally difficult to find observable fundamentals that are useful

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for predicting whether a boom will turn into a bust or not. We develop a model that is consistent with this observation. Agents have heterogeneous expectations about long-run fundamentals. Some agents are optimistic while others are not. Agents change their views as a result of “social dynamics.” They meet randomly, and those with tighter priors are more likely to convert other agents to their beliefs. The model generates a “fad” in the sense that the fraction of the population with a particular view rises and then falls. These fads lead to boom-busts or protracted booms in house prices, even if uncertainty about fundamentals is not realized. According to our model, an econometrician would not be able to predict whether a boom will turn into a bust or not. The reason is that before uncertainty is realized, the data are not informative about which agent is correct.<sup>1</sup>

Our model has three features. First, there is uncertainty about the long-run fundamentals that drive house prices. We assume that in each period, there is a small probability that housing fundamentals will change permanently to a new value. This emphasis on long-run fundamentals is related to the literature on long-run risk (Bansal and Yaron 2004; Hansen, Heaton, and Li 2008).

Second, as in Harrison and Kreps (1978), Scheinkman and Xiong (2003), Acemoglu, Chernozhukov, and Wold (2007), Dumas, Kurshev, and Uppal (2009), Piazzesi and Schneider (2009), and Geanakoplos (2010), agents in our economy have heterogeneous beliefs about fundamentals. Some agents believe that housing fundamentals will improve while others do not. Agents can update their priors in a Bayesian fashion. However, the data do not convey useful information about long-run fundamentals, so agents’ priors stay constant over time. In other words, agents agree to disagree, and this disagreement persists over time. One group of agents is correct in their views about future fundamentals, but there is no way to know *ex ante* which group that is.

The third feature of the model is an element that we refer to as “social dynamics.” Agents meet randomly with each other, and some agents change their priors about long-run fundamentals as a result of these meetings. We use the entropy of an agent’s probability distribution of future fundamentals to measure the uncertainty of his views. We assume that when agent  $i$  meets agent  $j$ , the probability that  $i$  adopts the prior of  $j$  is decreasing (increasing) in the entropy of the prior of  $i$  ( $j$ ). In other words,

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<sup>1</sup> Models in which agents have homogeneous expectations can also generate protracted movements in house prices (see, e.g., Zeira 1999; Chu 2014). But these models generally imply a close relation between house prices and fundamentals that is difficult to see in the data. Glaeser and Gyourko (2006) argue that it is difficult to explain the observed large changes in house prices with changes in incomes, amenities, or interest rates.

agents with tighter priors are more likely to convert other agents to their beliefs. Our model generates dynamics in the fraction of agents who hold different views that are similar to those generated by the infectious-disease models proposed by Bernoulli (1766) and Kermack and McKendrick (1927).<sup>2</sup>

We consider two cases. In the first case, the agents with the tightest priors are those who expect fundamentals to remain the same. In the second case, the agents with the tightest priors are those who expect fundamentals to improve. **In the absence of realization of uncertainty about long-run fundamentals, the model generates fads. In the first case, there is a rise and fall in the number of people who believe that buying a house is a good investment. Here, the model generates a protracted boom-bust cycle. In the second case, there is a rise and fall in the number of people who believe that housing fundamentals will not change. Here, the model generates a protracted boom in housing prices that is not followed by a bust.**

We use the model to compute the price path expected by different agents. These unconditional expected price paths take into account the probability of uncertainty being realized at each point in time. Regardless of which agent happens to be correct, the model has the following implications. Agents who think that fundamentals will improve expect prices to rise and then level off. Agents who think that fundamentals will not change expect prices to rise and then fall. An econometrician taking repeated samples from data generated by the model would see both boom-busts and booms that are not followed by busts. The boom-bust episodes typically occur in economies in which agents who do not expect fundamentals to improve happen to be correct. The episodes in which booms are not followed by busts typically occur in economies in which agents who expect fundamentals to improve happen to be correct. Of course, in any given economy an econometrician would not be able to predict *ex ante* which type of episode would occur.

We first study the implications of social dynamics in a frictionless asset-pricing model of the housing market. While useful for building intuition, the model is too stylized to account for various features of the data. For this reason, we embed our model of social dynamics into a matching model of the housing market of the sort considered by Piazzesi and Schneider (2009). As these authors show, a small number of optimists can have a large impact on housing prices. However, heterogeneity in beliefs *per se* is not enough to generate protracted booms or booms and busts

<sup>2</sup> There is a growing literature that provides evidence on the importance of social dynamics in equity markets. See, e.g., Kelly and Ó Gráda (2000), Duflo and Saez (2002), Hong, Kubik, and Stein (2005), Brown et al. (2008), and Kaustia and Knüpfer (2008).

of the sort observed in the data. Here, social dynamics play a key role by changing the fraction of agents who hold different views about future fundamentals. In our model these changes introduce nontrivial dynamics into house prices.

We calibrate the six parameters of our model that control the distribution of beliefs and their dynamics to match nine moments constructed from micro evidence on agents' expectations of future house prices and self-assessed values of agents' homes. Even though we work with an over-identified system, our model does a good job of accounting for the moments that we target. We choose a separate set of parameters so that the steady state of the model is consistent with long-run properties of the US housing market.

The data on expectations come from Case and Shiller (2010). In each year for which we have the survey data, we include the following moments in the calibration procedure: the mean, across those surveyed, of the 1-year-ahead expected increase in home prices and the difference between the mean and median of the same forecast. The first set of moments is relevant for obvious reasons: We want our model of social dynamics to be consistent with the expected house price appreciation during the recent boom-bust episode. The second set of moments is relevant because, in a model with homogeneous expectations, the difference between the mean and median expected appreciation in house prices is zero. In contrast, our model does well at capturing the average value of this statistic over the boom part of the episode.

The data on self-assessed values of agents' homes come from the American Housing Survey. These data reveal that, as US house prices appreciated, the gap between the mean and median values of what agents reported their homes were worth widened. Social dynamics, which imply a rise in the number of optimistic agents during the boom, provide a natural explanation for this widening gap. Our model does quite well at accounting for the differences between the self-assessed mean minus median home values reported in the American Housing Survey for the 2003–6 period, which are moments targeted by our calibration procedure. Significantly, the model is also consistent with the magnitude and rise in the mean relative to median self-assessed home values before 2003. It does so even though these moments are not targeted by our calibration procedure. Social dynamics are the key to the model's success along this dimension since they generate a cross section of beliefs that evolves over time.

Finally, we present some evidence on three other central implications of our model. First, booms (busts) are marked by increases (decreases) in the number of agents who buy homes only because of large expected capital gains. Second, the probability of selling a home is positively correlated

with house prices. Third, sales volume is positively correlated with house prices. We find support for all three implications in the data. More generally, we argue that the extensive margin of the number of potential home buyers plays a critical role in house price dynamics.

The remainder of this paper is organized as follows. In Section II, we study the implications of social dynamics in a frictionless asset-pricing model of the housing market. Section III presents a simple matching model of the housing market and describes its transition dynamics. Section IV incorporates social dynamics into the matching model and generates our main results. We discuss the model calibration procedure in Section V and the model's quantitative properties in Section VI. In Section VII, we present empirical evidence regarding the key mechanisms at work in the model. Section VIII contains concluding remarks.

## II. Social Dynamics in a Frictionless Model

In this section we consider a simple frictionless model of the housing market. We use this model to describe the role played by social dynamics and the implied movements in the fraction of agents with different beliefs about long-run fundamentals.

### A. *The Model Economy*

The economy is populated by a continuum of agents with measure one. All agents have linear utility and discount utility at rate  $\beta$ . Agents are either homeowners or renters. To simplify, we assume that each agent can own only one house. One characteristic that distinguishes houses from stocks and other assets is that houses cannot be sold short. So, we assume that there is no short selling in our model.<sup>3</sup>

For simplicity, we assume that there is a fixed stock of houses,  $k < 1$ , in the economy. This assumption is motivated by the observation that large booms and busts occur in cities where increases in the supply of houses are limited by zoning laws, land scarcity, or infrastructure constraints (see, e.g., Glaeser, Gyourko, and Saks 2005; Quigley and Raphael 2005; Barlevy and Fisher 2010; Saiz 2010). There is a rental market with  $1 - k$  houses. These units are produced by competitive firms at a cost of  $w$  per period, so the rental rate is constant and equal to  $w$ . The momentary utilities of owning and renting a house are  $\varepsilon^h$  and  $\varepsilon^r$ , respectively. We assume that

<sup>3</sup> We use the conventional meaning of the expression "short sale," which is a transaction in which an investor borrows an asset and sells it with the promise to return it at a later date. In the recent crisis, the term short sale has been used with a different meaning. It refers to a situation in which the house's sale price falls short of the mortgage value and the bank agrees to accept the proceeds of the sale in lieu of the mortgage balance.

the utility of owning a home is higher than the net utility of renting ( $\varepsilon^h > \varepsilon^r - w$ ), so that home prices are positive.

We first consider the equilibrium of a version of the economy with no uncertainty. Agents decide at time  $t$  whether they will be renters or homeowners at time  $t + 1$ . The net utility of being a renter at time  $t + 1$  is  $\varepsilon^r - w$ . If an agent buys a house at time  $t$ , he pays  $P_t$ . At time  $t + 1$ , he lives in the home and receives a utility flow  $\varepsilon^h$ . The agent can sell the house at the end of period  $t + 1$  for a price  $P_{t+1}$ . Since all agents are identical, in equilibrium they must be indifferent between buying and renting a house. So, house prices satisfy the following equation:

$$-P_t + \beta(P_{t+1} + \varepsilon^h) = \beta(\varepsilon^r - w). \quad (1)$$

The stationary solution to this equation is

$$P = \frac{\beta}{1 - \beta} \varepsilon, \quad (2)$$

where  $\varepsilon = \varepsilon^h - (\varepsilon^r - w)$ .<sup>4</sup>

We now consider an experiment that captures the effects of infrequent changes in the value of housing fundamentals. Examples include low-frequency changes in the growth rate of productivity, which affects agents' wealth, and changes in financial regulation or innovations, which make it easier for agents to purchase homes. For concreteness, we focus on the utility of owning a home. Suppose that, before time 0, the economy is in a steady state with no uncertainty, so  $P_t = P$ . At time 0, agents learn that in each period, with small probability  $\phi$ , the value of  $\varepsilon$  changes permanently to a new level,  $\varepsilon^*$ . Agents agree about the value of  $\phi$  but disagree about the probability distribution of  $\varepsilon^*$ . Agents do not receive any information useful to update their priors about the distribution of  $\varepsilon^*$ .<sup>5</sup> As soon as uncertainty is resolved, agents become homogeneous in their beliefs.

Prior to the resolution of uncertainty, agents fall into three categories depending on their priors about  $\varepsilon^*$ . We refer to these agents as "optimistic," "skeptical," and "vulnerable," with the fraction of agents of each type being denoted, respectively, by  $o$ ,  $s$ , and  $v$ . Agents' types are publicly observable, and variables that depend on type are indexed by  $j = o, s, v$ . Priors are common knowledge, so higher-order beliefs play no role in our model. The laws of social dynamics described below are public informa-

<sup>4</sup> It is well known that there are explosive solutions to eq. (1) (see, e.g., Diba and Grossman 1987). We abstract from these solutions in our analysis.

<sup>5</sup> If agents disagreed about the value of  $\phi$ , they would update their priors about  $\phi$  after observing whether a change in fundamentals occurred. We abstract from uncertainty about the value of  $\phi$  to focus our analysis on the importance of social dynamics.

tion. Agents take into account future changes in the fractions of the population that hold different views.

The new value of the flow utility of owning a home,  $\varepsilon^*$ , is drawn from the set  $\Phi$ . For simplicity, we assume that this set contains  $n$  elements. An agent of type  $j$  attaches the probability distribution function (pdf)  $f^j(\varepsilon^*)$  to the elements of  $\Phi$ .

We assume that, at time 0, there is a very small fraction of skeptical and optimistic agents. Almost all agents are vulnerable; that is, they have diffuse priors about future fundamentals. Optimistic agents expect an improvement in fundamentals:

$$E^o(\varepsilon^*) > \varepsilon.$$

Skeptical and vulnerable agents do not expect fundamentals to improve:

$$E^s(\varepsilon^*) = E^v(\varepsilon^*) = \varepsilon.$$

For now, we assume that agents do not internalize the possibility of changing their type as a result of social interactions. This assumption rules out actions that are optimal only because agents might change their type in the future. For example, a skeptical agent might buy a home, even though this action is not optimal given his current priors, because there is a chance he might become optimistic in the future. We return to this issue at the end of this section.

We use the entropy of the pdf  $f^j(\varepsilon^*)$  to measure the uncertainty of an agent's views,

$$e^j = -\sum_{i=1}^n f^j(\varepsilon_i^*) \ln[f^j(\varepsilon_i^*)].$$

The higher is the value of  $e^j$ , the greater is agent  $j$ 's uncertainty about  $\varepsilon^*$ . This uncertainty is maximal when the pdf is uniform, in which case  $e^j = \ln(n)$ .

Agents meet randomly at the beginning of the period. When agent  $l$  meets agent  $j$ ,  $j$  adopts the prior of  $l$  with probability  $\gamma^{lj}$ . The value of  $\gamma^{lj}$  depends on the ratio of the entropies of the agents' pdfs:

$$\gamma^{lj} = \max(1 - e^l/e^j, 0). \quad (3)$$

This equation implies that a low-entropy agent does not adopt the prior of a high-entropy agent. **In addition, it implies that the probability that a high-entropy agent adopts the priors of the low-entropy agent is decreasing in the ratio of the two entropies.** We use this formulation for two reasons. First, it strikes us as plausible. Second, it is consistent with evidence from the psychology literature that people are more persuaded by those who are confident (e.g., Snizek and Van Swol 2001; Price and Stone 2004).

Throughout, we assume that the entropy of vulnerable agents exceeds the entropy of skeptical and optimistic agents:

$$e^s < e^v, \quad e^o < e^v.$$

So, the vulnerable are the most likely to change their views. In addition, we make the natural assumption that most agents are vulnerable at time 0 and that the initial number of optimistic and skeptical agents is small and identical:  $o_0 = s_0$ .

The population dynamics generated by our model are similar to those implied by the infectious-disease models of Bernoulli (1766) and Kermack and McKendrick (1927).<sup>6</sup> We consider two cases. In the first, the prior of the skeptical agents has the lowest entropy. In the second, the prior of the optimistic agents has the lowest entropy. In both cases, if uncertainty is not resolved, the entire population converges to the view of the agent with the lowest entropy. The model generates a fad, in the sense that the fraction of the population with the second-lowest entropy rises and then falls.

### 1. Case 1

In this case, the pdf of the skeptical agents has the lowest entropy:

$$e^s < e^o < e^v.$$

The fractions of optimistic, skeptical, and vulnerable agents in the population evolve according to

$$o_{t+1} = o_t + \gamma^{ov} o_t v_t - \gamma^{so} o_t s_t, \quad (4)$$

$$s_{t+1} = s_t + \gamma^{sv} s_t v_t + \gamma^{so} o_t s_t, \quad (5)$$

$$v_{t+1} = v_t - \gamma^{ov} o_t v_t - \gamma^{sv} s_t v_t. \quad (6)$$

To understand equation (4), note that there are  $o_t v_t$  encounters between optimistic and vulnerable agents.<sup>7</sup> As a result of these encounters,  $\gamma^{ov} o_t v_t$  vulnerable agents become optimistic. Similarly, there are  $s_t o_t$  encounters between skeptical and optimistic agents. As a result of these encounters,  $\gamma^{so} s_t o_t$  optimistic agents become skeptical. These two sets of encounters and the value of  $o_t$  determine  $o_{t+1}$ .

<sup>6</sup> Bernoulli (1766) used his model of the spread of smallpox to show that vaccination would result in a significant increase in life expectancy. When vaccination was introduced, insurance companies used Bernoulli's life expectancy calculations to revise the price of annuity contracts (Dietz and Heesterbeek 2002).

<sup>7</sup> See Duffie and Sun (2007) for a law of large numbers that applies to pairwise random meetings.



Consider next equation (5). There are  $o_t s_t$  encounters between skeptical and optimistic agents, which lead  $\gamma^{so} o_t s_t$  optimistic agents to become skeptical. There are also  $s_t v_t$  encounters between skeptical and vulnerable agents, which lead  $\gamma^{sv} s_t v_t$  vulnerable agents to become skeptical. Finally, equation (6) implies that the fraction of vulnerable agents declines over time because  $\gamma^{ov} o_t v_t$  vulnerable agents become optimistic and  $\gamma^{sv} s_t v_t$  become skeptical.

Consider a path of the economy along which uncertainty is not realized. In case 1, the model can generate a fad in which the number of optimistic agents rises for a while before declining toward zero. To see how this pattern emerges, suppose that initially a large fraction of the population is vulnerable and that  $\gamma^{ov} v_0 > \gamma^{so} s_0$ . In conjunction with equation (4), the latter condition implies that the number of optimistic agents initially rises over time as the number of vulnerable agents who become optimistic is larger than the number of optimistic agents who become skeptical. The number of vulnerable agents declines over time as some of these agents become optimistic and others become skeptical (see eq. [6]). This decline implies that, eventually,  $\gamma^{ov} v_t < \gamma^{so} s_t$ . At this point, the fraction of optimistic agents begins to fall. As  $t \rightarrow \infty$ , all optimistic agents become skeptical (see eq. [5]).

## 2. Case 2

In this case, the pdf of the optimistic agents has the lowest entropy:

$$e^o < e^s < e^v.$$

The fractions of optimistic, skeptical, and vulnerable agents in the population evolve according to

$$o_{t+1} = o_t + \gamma^{ov} o_t v_t + \gamma^{os} o_t s_t, \quad (7)$$

$$s_{t+1} = s_t + \gamma^{sv} s_t v_t - \gamma^{os} o_t s_t, \quad (8)$$

$$v_{t+1} = v_t - \gamma^{ov} o_t v_t - \gamma^{sv} s_t v_t. \quad (9)$$

To understand equation (7), note that the  $o_t v_t$  encounters between optimistic and vulnerable agents lead  $\gamma^{ov} o_t v_t$  vulnerable agents to become optimistic. There are also  $o_t s_t$  encounters between optimistic and skeptical agents, which lead  $\gamma^{os} o_t s_t$  skeptical agents to become optimistic. Equation (8) reflects the fact that the  $o_t s_t$  encounters between skeptical and optimistic agents result in  $\gamma^{os} o_t s_t$  skeptical agents becoming optimistic. The  $s_t v_t$  encounters between skeptical and vulnerable agents result in  $\gamma^{sv} s_t v_t$  vulnerable agents becoming skeptical. Finally, equation (9) implies that  $v_t$  declines, since  $\gamma^{ov} o_t v_t$  vulnerable agents become optimistic and  $\gamma^{sv} s_t v_t$  become skeptical.

This version of the model also generates a fad, but here, it is the number of skeptical agents that rises for a while before declining toward zero. A fad arises when initially a large fraction of the population is vulnerable and  $\gamma^{sv}v_t > \gamma^{os}o_t$ . The basic difference between cases 1 and 2 is that in the latter case skeptics are converted into optimists, so that eventually all agents become optimistic.

### B. Equilibrium in the Frictionless Model

House prices are determined by the marginal buyer. To identify this buyer, we sort agents in declining order of their house valuations. The marginal buyer is the agent who is at the  $k$ th percentile of house valuations. When the fraction of optimistic agents is lower than  $k$  for all  $t$ , the marginal home buyer is always a nonoptimistic agent. Since these agents do not expect changes in the utility of owning a home, the price is constant over time at the value given by equation (2). In order to generate a boom-bust cycle, at least  $k$  agents must be optimistic at some point in time.

It is useful to define the time  $t$  fundamental value of a house before the resolution of uncertainty for a given agent, assuming that this agent is the marginal buyer until uncertainty is resolved. We denote these fundamental values for the optimistic, skeptical, and vulnerable agents by  $P_t^o$ ,  $P_t^v$ , and  $P_t^s$ , respectively. The value of  $P_t^o$  is given by

$$P_t^o = \beta \left\{ \phi \left[ E^o(\varepsilon^*) + \beta \frac{E^o(\varepsilon^*)}{1 - \beta} \right] + (1 - \phi)(\varepsilon + P_{t+1}^o) \right\}. \quad (10)$$

The logic that underlies this equation is as follows. With probability  $\phi$ , uncertainty is resolved. In this case, the expected utility flow and house price at time  $t + 1$  are  $E^o(\varepsilon^*)$  and  $\beta E^o(\varepsilon^*)/(1 - \beta)$ , respectively. With probability  $1 - \phi$ , uncertainty is not resolved. In this case, the agent receives a utility flow,  $\varepsilon$ , and values the house at  $P_{t+1}^o$ . Since we are deriving the fundamental value under the assumption that the optimistic agent is always the marginal home buyer,  $P_t^o = P_{t+1}^o = P^o$ . Solving equation (10) for  $P^o$ , we obtain

$$P^o = \beta \frac{\phi E^o(\varepsilon^*)/(1 - \beta) + (1 - \phi)\varepsilon}{1 - \beta(1 - \phi)}. \quad (11)$$

Vulnerable and skeptical agents expect  $\varepsilon^*$  to equal  $\varepsilon$ , so

$$P^s = P^v = \frac{\beta}{1 - \beta} \varepsilon. \quad (12)$$

We begin by characterizing the equilibrium of the economy in case 1. Recall that in this case, the fraction of optimistic agents first rises and then falls. Suppose that the number of optimistic agents is lower than

$k$  for  $t < t_1$  and exceeds  $k$  for  $t \in [t_1, t_2]$ , where  $t_2 < \infty$ . For  $t > t_2$ , the marginal home buyer is a skeptical agent, so the price is given by

$$P_t = P^s \quad \text{for } t \geq t_2 + 1. \quad (13)$$

Using  $P_{t_2+1}$  as a terminal value, we can compute recursively the prices for  $t \leq t_2$  that obtain if uncertainty is not realized. Since the marginal home buyer between period  $t_1$  and period  $t_2$  is an optimistic agent, we have

$$P_t = \beta\{\phi[E^o(\varepsilon^* + P_{t+1}^*)] + (1 - \phi)(\varepsilon + P_{t+1})\}$$

for  $t_1 \leq t \leq t_2$ . Here,  $P_{t+1}$  and  $P_{t+1}^*$  are the  $t + 1$  prices when uncertainty is not realized and when uncertainty is realized, respectively.

Since the marginal home buyer for  $t < t_1$  is a vulnerable/skeptical agent, we have

$$P_t = \beta\{\phi[E^s(\varepsilon + P_{t+1}^*)] + (1 - \phi)(\varepsilon + P_{t+1})\}$$

for  $t < t_1$ . In writing this equation, we use the fact that  $E^s(\varepsilon^*) = E^v(\varepsilon^*)$ .

The following proposition characterizes the equilibrium in case 1.

**PROPOSITION 1.** The equilibrium price path in case 1 when uncertainty is not realized is given by

$$P_t = \begin{cases} P^s + [\beta(1 - \phi)]^{t_1-t}(P_{t_1} - P^s) & t < t_1 \\ P^o - [\beta(1 - \phi)]^{t_2+1-t}(P^o - P^s) & t_1 \leq t \leq t_2 \\ P^s & t > t_2. \end{cases} \quad (14)$$

The equilibrium price path when uncertainty is realized is given by

$$P_t = \frac{\beta}{1 - \beta} \varepsilon^*. \quad (15)$$

The intuition for this proposition is as follows. Before time  $t_1$  the marginal buyer is a vulnerable agent. If uncertainty is not realized, the marginal buyer at time  $t_1$  is an optimistic agent. The latter agent is willing to buy the house at a value that exceeds  $P^s$  because he realizes a capital gain,  $P_{t_1} - P^s$ , with probability  $(1 - \phi)^{t_1-t}$ . The equilibrium price is equal to  $P^s$  plus the expected discounted capital gain, which is  $[\beta(1 - \phi)]^{t_1-t}(P_{t_1} - P^s)$  (see the first line of eq. [14]). The price jumps at time 0 from  $P^s$  to  $P^s + [\beta(1 - \phi)]^{t_1}(P_{t_1} - P^s)$  because of the expected capital gain associated with the change in the marginal buyer at time  $t_1$ . As long as uncertainty is not realized, the price rises before time  $t_1$  because the expected discounted capital gain increases at the rate  $\beta(1 - \phi)$ .

Between time  $t_1$  and  $t_2$  the marginal buyer is an optimistic agent. However, if uncertainty is not realized, the marginal buyer at time  $t_2 + 1$  is a skeptical agent who is willing to buy the house at a price  $P^s < P^o$ . So, the

equilibrium price is equal to  $P^o$  minus the expected discounted capital loss,  $[\beta(1 - \phi)]^{t_2+1-t}(P^o - P^s)$  (the second line of eq. [14]). As long as uncertainty is not realized, the price falls before  $t_2 + 1$ , because the expected discounted capital loss rises at rate  $\beta(1 - \phi)$ . After time  $t_2 + 1$  there are no more changes in the identity of the marginal buyer. So, unless uncertainty is realized, the price remains constant and equal to the fundamental value of a house to a skeptical agent,  $P^s$ . Finally, once uncertainty is realized, agents have homogeneous expectations about fundamentals and the price of a house is given by equation (15).

Proposition 1 implies that the model generates a boom-bust cycle in house prices as long as uncertainty is not realized. Of course, the model can also generate a boom-bust as well as a protracted boom depending on when uncertainty is realized and the realization of  $\varepsilon^*$ .

The following proposition characterizes the equilibrium in case 2. Recall that, in this case, the fraction of the population that is optimistic converges monotonically to one. We define  $t_1$  as the first time period in which there are more optimistic agents than homes ( $o_t \geq k$ ).

**PROPOSITION 2.** The equilibrium price path in case 2 when uncertainty is not realized is given by

$$P_t = \begin{cases} P^s + [\beta(1 - \phi)]^{t_1-t}(P^o - P^s) & t < t_1 \\ P^o & t \geq t_1. \end{cases} \quad (16)$$

The equilibrium price path when uncertainty is realized is given by

$$P_t = \frac{\beta}{1 - \beta} \varepsilon^*. \quad (17)$$

The intuition for this proposition is as follows. From time  $t_1$  until uncertainty is resolved, the marginal home buyer is an optimistic agent. So, without resolution of uncertainty, the price is equal to  $P^o$  for all  $t \geq t_1$ . Before  $t_1$ , the marginal home buyer is a vulnerable/skeptical agent who has a fundamental house value  $P^s$ . The equilibrium price is equal to  $P^s$  plus the discounted expected value of the capital gain that results from selling the house to an optimistic agent at time  $t_1$ ,  $[\beta(1 - \phi)]^{t_1-t}(P^o - P^s)$ .

### C. A Simple Numerical Example

We now consider a simple numerical example that illustrates the properties of the model summarized in the previous proposition.

We choose the normalization  $\varepsilon = E^v(\varepsilon^*) = E^s(\varepsilon^*) = 1$ . Given this choice, the equilibrium depends on three additional features of agents' priors about future fundamentals:  $E^o(\varepsilon^*)$ ,  $e^o/e^v$ , and  $e^s/e^v$ . In both cases 1 and 2 we assume that

$$E^o(\varepsilon^*) = 2.89.$$

In case 1 we assume that

$$e^o/e^v = 0.894, \quad e^s/e^v = 0.890.$$

In case 2 we assume that

$$e^o/e^v = 0.890, \quad e^s/e^v = 0.894.$$

We think of each time period as representing 1 month and choose  $\beta$  so that the implied annual discount rate is 6 percent. We assume that there is a very small number of optimistic and skeptical natural renters at time 0:  $o_0 = s_0 = 2.87 \times 10^{-6}$ . The remainder of the population is vulnerable. We choose  $\phi$ , the probability that uncertainty is realized in each period, to equal .0038. Without resolution of uncertainty, this value, together with our other assumptions, implies that a boom-bust pattern emerges over the course of roughly 19 years.

### 1. Case 1

Our choices for  $e^o/e^v$  and  $e^s/e^v$  imply

$$\gamma^{so} = 0.00475, \quad \gamma^{ov} = 0.106, \quad \text{and} \quad \gamma^{sv} = 0.110.$$

Given these values, equations (5) and (6) imply that the maximum value of  $o_t$  is 0.345. So, the presence of optimistic agents affects prices only if  $k < 0.345$ . We assume that  $k = 0.275$ .

Figure 1a shows the evolution of the fraction of skeptical, optimistic, and vulnerable agents in the absence of resolution of uncertainty about  $\varepsilon^*$ . Consistent with the intuition above, the fraction of optimistic agents in the population initially increases slowly. The infection then gathers momentum until the fraction of optimistic agents peaks at 0.345 in the middle of year 12. Thereafter, this fraction declines toward zero. Between  $t_1$ , the middle of year 11, and  $t_2$ , the end of year 19, the optimistic agents are the marginal buyers since they exceed  $k = 0.275$  in the population. The fraction of vulnerable agents falls over time and converges to zero as these agents become either skeptical or optimistic. The fraction of skeptical agents rises monotonically over time until everybody in the economy is skeptical.

Consistent with proposition 1, figure 2 shows that the price jumps at time 0 and then continues to rise slowly until optimistic agents become the marginal home buyers at time  $t_1$ . Thereafter, the price drops rapidly, reverting to its initial steady-state value.

The one-period-ahead rate of return that agent  $j$  expects at time  $t$ , conditional on uncertainty not having been realized, is given by

$$r_t^j = \frac{\phi[E^j(\varepsilon^*) + \beta E^j(\varepsilon^*)/(1 - \beta)] + (1 - \phi)(\varepsilon + P_{t+1})}{P_t} - 1. \quad (18)$$

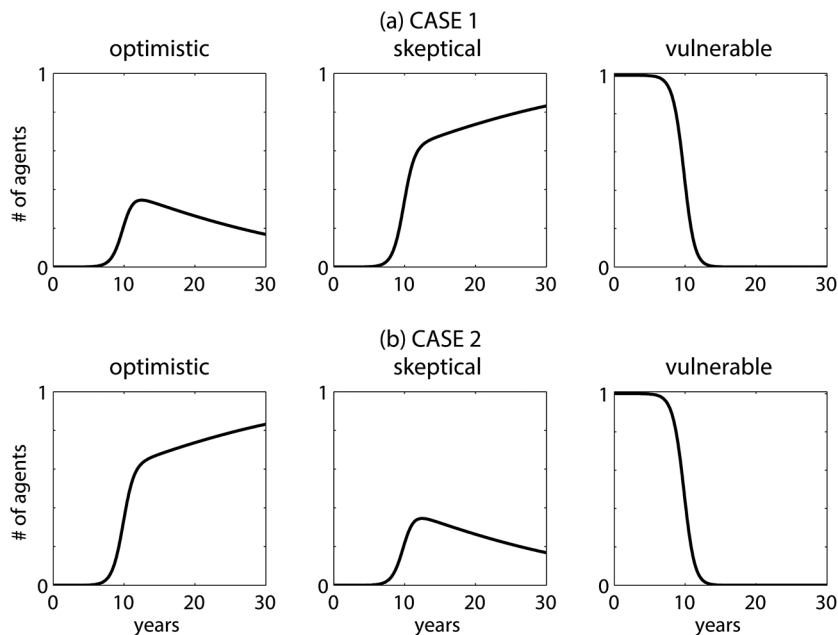


FIG. 1.—Social dynamics. The graphs show the evolution of the populations of each type of agent due to social dynamics. In case 1, the priors of skeptical agents have the lowest entropy, and the priors of the vulnerable agents have the highest entropy. In case 2, the priors of optimistic agents have the lowest entropy, and the priors of the vulnerable agents have the highest entropy.

Figure 2 displays  $r_t^j$  expressed on an annual basis. The figure also displays the volume of transactions implied by the model computed under the assumption that trade occurs only when at least one of the agents has a motive for transacting.

A key feature of figure 2 is that agents have heterogeneous beliefs about the expected rate of return to housing. This basic feature of our model is consistent with the findings of Piazzesi and Schneider (2009), who document this heterogeneity using the Michigan Survey of Consumers.<sup>8</sup>

The annualized real rate of return to the marginal homeowner is constant and equal to 6 percent. Before  $t_1$ , the skeptical/vulnerable agents are the marginal homeowners. Optimistic agents expect very high rates of return, which reflect the high value of  $E^o(\varepsilon^*)$ . So all newly optimistic agents ( $\gamma^{ov}o_i v_i$ ) buy homes.<sup>9</sup> During this period, prices rise and all trans-

<sup>8</sup> Vissing-Jørgensen (2003) provides evidence of substantial heterogeneity of beliefs regarding the returns to other assets, such as stocks.

<sup>9</sup> We assume that the vulnerable agents sell since they are indifferent between holding and selling. The optimistic agents could induce them to sell by offering an arbitrarily small premium. Some optimistic agents become skeptical during this time period. However, for

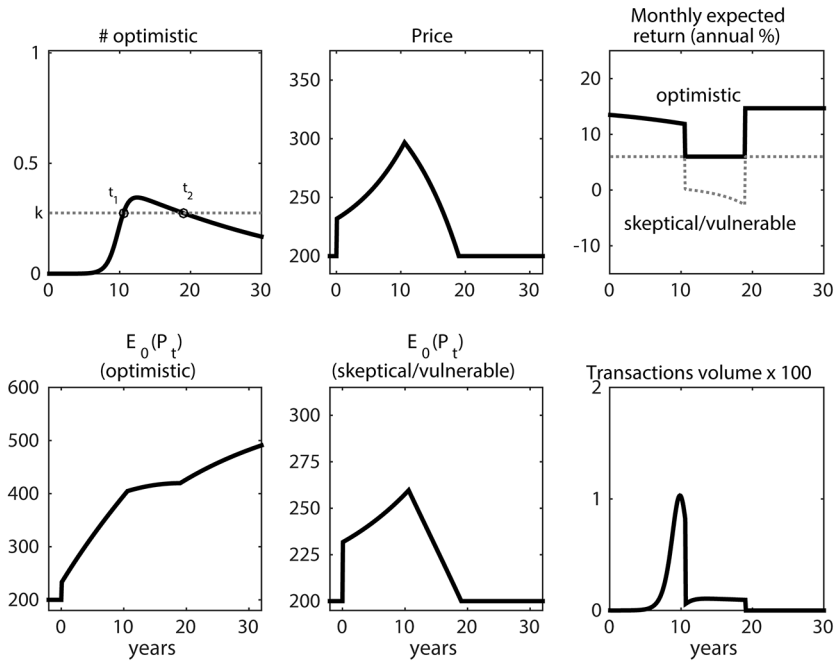


FIG. 2.—Equilibrium of the frictionless model, case 1. The graphs show a variety of paths for the frictionless model with social dynamics in case 1, in which the priors of skeptical agents have the lowest entropy, and the priors of the vulnerable agents have the highest entropy. The number of optimistic agents, the price of a house, the monthly expected rate of return, and transactions volume are all computed under the assumption that uncertainty is not realized. The expected price paths are the expected values of the house price at each date, as of time 0, given the priors of the different agents.

actions are initiated by agents who buy homes. Prices and transaction volume peak simultaneously at time  $t_1$ .

Between time  $t_1$  and  $t_2$ , the marginal buyer is an optimistic agent. During this period, the skeptical/vulnerable agents expect negative rates of return because they have a low expected value of  $\varepsilon^*$ . So, all newly skeptical agents ( $\gamma^{so} s_t o_t$ ) sell their homes to optimistic agents who are indifferent between buying and holding. During this period, prices fall and all transactions are initiated by agents who sell homes. Figure 2 displays the time series of transactions volume. Prices and transactions volume peak simultaneously at time  $t_1$ . Transaction volume collapses once prices start to fall because at this point optimistic agents own all the houses. After time  $t_1$ , the number of transactions recovers as some optimistic agents become skeptical and sell their homes.

$t \leq t_1$ , optimistic agents who become skeptical are indifferent between holding and selling, so we assume that they do not transact.

After time  $t_2$ , the marginal homeowner is, once again, a skeptical/vulnerable agent. Optimistic agents expect very high rates of return that are not reflected in market prices, so all newly optimistic agents ( $\gamma^{ov}, v_t$ ) buy homes. But there are so few vulnerable agents that the number of transactions is close to zero.

From figure 2 we see that, while the identity of the marginal homeowner changes over time, the rate of return to the marginal owner is always 6 percent. Since pricing is determined by the marginal owner, the expectations of inframarginal agents are not reflected in home prices.

Finally, figure 2 displays the price paths expected by optimistic and skeptical/vulnerable agents at time 0. These paths are given by

$$E_0^j(P_t) = (1 - \phi)^{t+1}(\varepsilon + P_{t+1}) + [1 - (1 - \phi)^{t+1}] \times [E^j(\varepsilon^*) + \beta E^j(\varepsilon^*)/(1 - \beta)], \quad (19)$$

for  $j = o, s, v$ . Optimistic agents expect prices to rise very rapidly until time  $t_1$ . Thereafter, expected prices continue to rise but at a lower rate, reflecting the fall in actual market prices that occurs if uncertainty is not realized. This fall is outweighed by the high value of  $\varepsilon^*$  expected by optimistic agents. Finally, expected prices rise at a slightly higher rate after time  $t_2$ , because the price remains constant if uncertainty is not realized.

Consider next the price path expected by skeptical and vulnerable agents at time 0. Equation (19) implies that

$$E_0^o(P_t) - E_0^s(P_t) = [1 - (1 - \phi)^{t+1}] \frac{E^o(\varepsilon^*) - E^s(\varepsilon^*)}{1 - \beta}. \quad (20)$$

So, the difference between  $E_0^o(P_t)$  and  $E_0^s(P_t)$  reflects agents' different expectations about  $\varepsilon^*$ . This difference implies that skeptical/vulnerable agents always expect a lower price than optimistic agents. The skeptical/vulnerable agents expect prices to rise between time 0 and time  $t_1$  because the price appreciation that occurs, as long as uncertainty is not realized, outweighs the fall in price that occurs if uncertainty is realized. Between time  $t_1$  and  $t_2$ , skeptical/vulnerable agents expect prices to fall whether uncertainty is realized or not. After time  $t_2$ , the market price corresponds to the skeptical/vulnerable agent's fundamental price, so expected prices are constant.

## 2. Case 2

As in case 1, we assume that  $k = 0.275$ . Our choices for  $e^o/e^v$  and  $e^s/e^v$  imply

$$\gamma^{os} = 0.00475, \quad \gamma^{ov} = 0.110, \quad \text{and} \quad \gamma^{sv} = 0.106.$$



Figure 1*b* shows the evolution of the fraction of skeptical, optimistic, and vulnerable agents in the absence of resolution of uncertainty about  $\varepsilon^*$ . The dynamics are the same as in figure 1*a*, except that the skeptical and optimistic agents have switched places. Here there is a fad, in the sense that the number of skeptical agents rises for roughly 12.5 years before falling to zero. The fraction of optimistic agents rises monotonically over time until everyone is optimistic.

Consistent with proposition 2, figure 3 shows that the price jumps at time 0 and then continues to rise until the middle of year 10, when all homes are owned by optimistic agents. From this moment on, the price is constant and equal to the optimistic agent's fundamental value.

Figure 3 also shows the volume of transactions implied by the model. At time 0, all homes are owned by vulnerable agents. Between time 0 and time  $t_1$ , all newly optimistic agents ( $\gamma^{ov} o_t v_t$ ) buy homes. At time  $t_1$ , all the

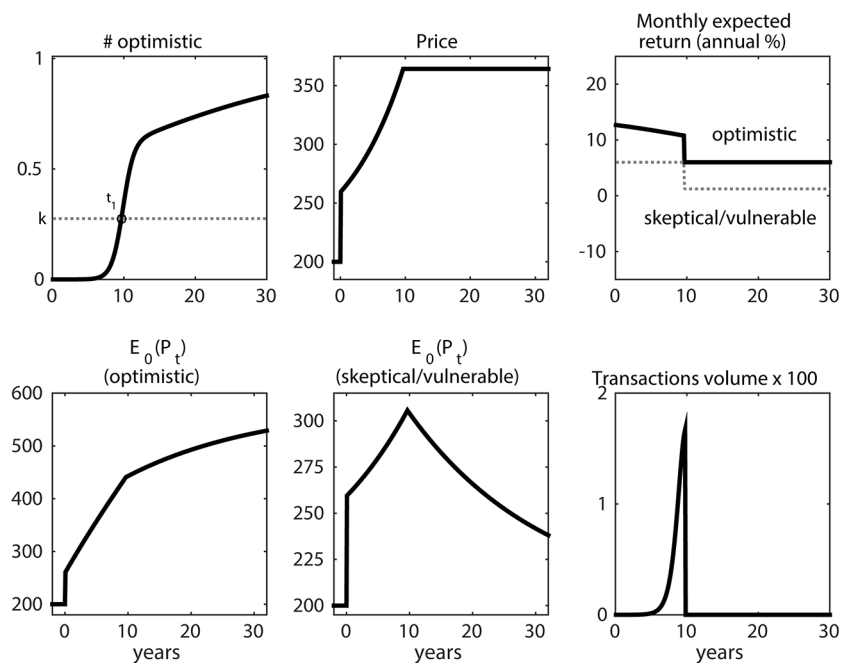


FIG. 3.—Equilibrium of the frictionless model, case 2. The graphs show a variety of paths for the frictionless model with social dynamics in case 2, in which the priors of optimistic agents have the lowest entropy, and the priors of the vulnerable agents have the highest entropy. The number of optimistic agents, the price of a house, the monthly expected rate of return, and transactions volume are all computed under the assumption that uncertainty is not realized. The expected price paths are the expected values of the house price at each date, as of time 0, given the priors of the different agents.

homes are owned by optimistic agents and there are no new transactions because optimistic agents do not become skeptical.

Finally, figure 3 displays the price path expected by optimistic and skeptical/vulnerable agents at time 0. This path is computed using equation (19). Optimistic agents expect prices to rise very rapidly until  $t_1$ . From this point on, the expected price continues to increase because there is a rise over time in the probability that uncertainty is realized and optimistic agents receive a large capital gain. Figure 3 also displays the price path expected by skeptical and vulnerable agents at time 0. As in case 1, the difference between  $E_0^o(P_t)$  and  $E_0^s(P_t)$  is fully accounted for by different expectations about  $\varepsilon^*$  (see eq. [20]).

#### *D. Interpreting Cross-Sectional Data on House Prices*

A well-known property of housing markets is the presence of both boom-bust episodes and episodes in which booms are not followed by busts. Piazzesi and Schneider (2009) document this property using postwar data. A longer perspective is provided by Ambrose, Eichholtz, and Lindenthal (2013), who document this property using four centuries of housing data for Holland. Eitrheim and Erlandsen (2004) provide analogous evidence using two centuries of housing data for Norway.

It is useful to briefly quantify some stylized facts about the postwar episodes. Our results are based on quarterly OECD data on real house prices for 25 countries for the period 1970–2012. An operational definition of a boom or a bust requires that we define turning points in which upturns and downturns in house prices begin. To avoid defining high-frequency movements in the data as upturns or downturns, we first smooth the data. Let  $y_t$  denote the logarithm of an index of real house prices. Also let  $x_t$  denote the centered moving average of  $y_t$ ,

$$x_t = \frac{1}{2n+1} \sum_{j=-n}^n y_{t+j}.$$

We define an upturn as an interval of time in which  $\Delta x_t > 0$  for all  $t$  and a downturn as an interval of time in which  $\Delta x_t < 0$ . A turning point is the last time period within an upturn or downturn. A boom is an upturn for which  $y_T - y_{T-L} > z$ , and a bust is a downturn for which  $y_T - y_{T-L} < -z$ . Here,  $T$  is the date at which the boom or bust ended,  $L$  is the length of the boom or bust, and  $z$  is a positive scalar. The results discussed below are generated assuming that  $n = 5$ , so that  $x_t$  is defined as an 11-month centered moving average of  $y_t$ . In addition, we assume that  $z = 0.15$  so that booms and busts are defined as price moments greater than or equal to

15 percent. Our findings are not sensitive to small changes in the assumed values of  $n$  and  $z$ .

Three key features emerge from our analysis. First, every country in the sample experienced house price booms and busts.<sup>10</sup> The median sizes of booms and busts are 44.7 and  $-28.5$  percent, respectively. Second, booms and busts occur over protracted periods of time. The median lengths of booms and busts in our sample are 5.5 and 5.38 years, respectively. Third, in many cases booms are followed by protracted busts. We identified 62 booms and 38 busts in our sample. Of the 62 booms, 33 were followed within 6 months by a bust. So, roughly half of the booms turned into a bust, while the other half did not.

Our frictionless model is consistent, at least qualitatively, with these three features of the data. Regardless of whether we are in case 1 or case 2, optimistic agents expect prices to rise and eventually level off, while skeptical agents expect prices to rise and then fall. An econometrician taking repeated samples from our data would see both boom-busts and booms that are not followed by busts. The boom-bust episodes would typically occur in economies in which the skeptical agents happen to be correct. The booms that are not followed by busts would typically occur in economies in which the optimistic agents happen to be right. Of course, in any given economy the econometrician cannot predict which type of episode he would see because, by construction, the data are not informative about which agent is correct.

### *E. Robustness*

In our analysis we assume that agents do not take into account the possibility of changing their type as a result of social interactions. In Appendix A, we assess the quantitative impact of this assumption by calculating equilibrium prices when agents do internalize this possibility. We find that internalizing these changes makes virtually no difference to our results because the probability of switching types is small. In Appendix B, we discuss a second type of robustness. There, we describe a Bayesian environment that generates social dynamics that are similar to those of our model.

## **III. A Matching Model**

The frictionless model shows the potential of social dynamics to account for observed house price dynamics. However, this model has three unattractive features. First, to generate a boom-bust cycle in case 1, the frac-

<sup>10</sup> Australia and Austria experienced only booms, while Germany and Slovenia experienced only busts. The data for Austria and Slovenia are available only since 2000 and 2007, respectively.

tion of agents that are optimistic must exceed  $k$  percent of the population for at least some period of time. According to the Bureau of the Census (Housing Vacancy Survey, series H-111 reports), on average, during the period 1965–2011, 65 percent of American households owned homes. So the model requires that a very large fraction of the population become optimistic.<sup>11</sup> Second, the price rise that occurs at time 0 is large relative to the peak rise in prices. Third, the model is too stylized to account for the fact that the volume of transactions and time to sell are highly correlated with average house prices.

To address these shortcomings, we use an extended version of the matching model proposed by Piazzesi and Schneider (2009). In this section, we consider a version of the model in which agents have homogeneous expectations. The basic structure of this model coincides with that of the frictionless model described in Section II. The economy is populated by a continuum of agents with unit measure. All agents have linear utility and discount utility at the rate  $\beta$ . There is a fixed stock of houses,  $k < 1$ , and a rental market with  $1 - k$  houses. Rental units are produced by competitive firms at a cost  $w$  per period, so the rental rate is constant and equal to  $w$ .

There are four types of agents in the economy: homeowners, unhappy homeowners, natural home buyers, and natural renters. We denote the fraction of these agents in the population by  $h_t$ ,  $u_t$ ,  $b_t$ , and  $r_t$ , respectively. Homeowners and unhappy homeowners own homes at time  $t$ . All homes are occupied in equilibrium so that

$$h_t + u_t = k. \quad (21)$$

Both natural buyers and natural renters rent homes at time  $t$  so that

$$b_t + r_t = 1 - k. \quad (22)$$

We describe the state of the economy by  $z_t = (h_t, b_t)'$ . We now discuss the problems faced by the different agents in the economy.

#### A. Homeowners

A homeowner derives momentary utility  $\varepsilon$  from his home. The agent's value function,  $H(z_t)$ , is given by

$$H(z_t) = \varepsilon + \beta[(1 - \eta)H(z_{t+1}) + \eta U(z_{t+1})]. \quad (23)$$

<sup>11</sup> An alternative strategy for remedying this shortcoming is to allow for heterogeneity in the utility of owning a home. For example, suppose that there is a group of agents who would never sell their home because they derive such a high utility from it. The presence of this group is equivalent to a reduction in  $k$ , so that it is easier to generate a boom in the price of homes that are potentially for sale.

With probability  $\eta$ , a homeowner's match with his home goes sour and he becomes an unhappy homeowner. We denote the value function of an unhappy homeowner by  $U(z_t)$ .

### B. Unhappy Homeowners

We normalize the momentary utility that an unhappy homeowner derives from his home to zero. This agent decides whether or not to put his home up for sale. To simplify, we abstract from the transactions costs of selling a home. When a house is up for sale, it sells with probability  $q^s(z_t)$ . Once the sale occurs, the unhappy homeowner becomes a natural renter. The value function of an unhappy homeowner is given by

$$U(z_t) = \max[U^{\text{sell}}(z_t), U^{\text{stay}}(z_t)]. \quad (24)$$

The value function of an unhappy homeowner who puts his house up for sale is

$$\begin{aligned} U^{\text{sell}}(z_t) = & q^s(z_t) \{P(z_t) + \beta[(1 - \lambda)R(z_{t+1}) + \lambda B(z_{t+1})]\} \\ & + [1 - q^s(z_t)]\beta U(z_{t+1}). \end{aligned} \quad (25)$$

Here,  $P(z_t)$  denotes the price that an unhappy homeowner expects to receive, conditional on a sale,  $R(z_t)$  denotes the value function of a natural renter, and  $B(z_t)$  denotes the value function of a natural home buyer. The utility of a natural home buyer appears in equation (25) because any agent who is a natural renter at the beginning of time  $t + 1$  is, with probability  $\lambda$ , subject to a preference shock that turns him into a natural buyer.

The value function of an unhappy homeowner who decides not to put his house up for sale is

$$U^{\text{stay}}(z_t) = \beta U(z_{t+1}) - \psi(z_t). \quad (26)$$

Here  $\psi(z_t)$  denotes a nonpecuniary or regret cost paid by unhappy homeowners who do not put their house up for sale. We find that our algorithm for solving the model is much more stable if we scale the nonpecuniary cost by the expected revenue from selling the house  $\psi(z_t) = \psi q^s(z_t)P(z_t)$ . In addition, this scale factor leads to a particularly simple expression for the reservation price of an unhappy homeowner:

$$\bar{P}^u(z_t) = \frac{\beta}{1 + \psi} \{U(z_{t+1}) - [(1 - \lambda)R(z_{t+1}) + \lambda B(z_{t+1})]\}. \quad (27)$$

This reservation price makes the unhappy homeowner indifferent between putting the house on the market and not trying to sell it. As  $\psi$  goes to infinity, the reservation price becomes exogenous.

### C. Natural Home Buyers

A natural buyer is a renter at time  $t$ . He has to choose between renting at  $t + 1$  and trying to buy a home. His net flow utility from renting is given by  $\bar{\varepsilon} - w$  and his value function is  $B(z_t)$ . If he decides to continue renting, his value function,  $B^{\text{rent}}(z_t)$ , is given by

$$B^{\text{rent}}(z_t) = \bar{\varepsilon} - w + \beta B(z_{t+1}). \quad (28)$$

If he tries to buy a house, he succeeds with probability  $q^b(z_t)$ . In this case, he pays a price  $P^b(z_t)$  and his continuation utility is that of a homeowner:  $(1 - \eta)H(z_{t+1}) + \eta U(z_{t+1})$ . With probability  $1 - q^b(z_t)$ , he does not succeed in buying a house and he remains a renter at time  $t + 1$ . So the value function of being a potential buyer,  $B^{\text{buy}}(z_t)$ , is given by

$$\begin{aligned} B^{\text{buy}}(z_t) = & \bar{\varepsilon} - w + q^b(z_t)\{-P^b(z_t) + \beta[(1 - \eta)H(z_{t+1}) \\ & + \eta U(z_{t+1})]\} + [1 - q^b(z_t)]\beta B(z_{t+1}). \end{aligned} \quad (29)$$

The value function of a natural home buyer is given by

$$B(z_t) = \max[B^{\text{rent}}(z_t), B^{\text{buy}}(z_t)]. \quad (30)$$

The reservation price,  $\bar{P}^b(z_t)$ , is the price that makes a natural buyer indifferent between buying and renting:

$$\bar{P}^b(z_t) = \beta[(1 - \eta)H(z_{t+1}) + \eta U(z_{t+1}) - B(z_{t+1})]. \quad (31)$$

### D. Natural Renters

A natural renter is a renter at time  $t$ . His net flow utility from renting is given by  $\bar{\varepsilon} - w$  and his value function is  $R(z_t)$ . The only difference between natural renters and natural buyers is that the former derive lower utility from owning a home. We model this difference by assuming that whenever natural renters buy a house they pay a fixed cost,  $\kappa\varepsilon$ . This fixed cost represents the expected present value of the difference between their utility from owning a home and the corresponding utility of a natural buyer.<sup>12</sup> We choose the value of  $\kappa$  so that it is not optimal for natural renters to buy a house in the steady state.

In each period, a fraction  $\lambda$  of natural renters receive a preference shock and become natural home buyers. A natural renter can choose whether to continue renting or to try to buy a house. If he continues renting, his value function,  $R^{\text{rent}}(z_t)$ , is given by

<sup>12</sup> Since the fixed cost is paid up-front, all homeowners are identical. It does not matter whether they used to be a natural buyer or a natural renter. This property simplifies our analysis by reducing the number of different agents in the economy.

$$R^{\text{rent}}(z_t) = \bar{e} - w + \beta[(1 - \lambda)R(z_{t+1}) + \lambda B(z_{t+1})]. \quad (32)$$

The continuation utility reflects the fact that a natural renter becomes a natural home buyer with probability  $\lambda$ .

If the natural renter tries to buy a house, he succeeds with probability  $q^b(z_t)$ . In this case, he pays a price  $P^r(z_t)$  and his continuation utility is the same as that of a homeowner,  $(1 - \eta)H(z_{t+1}) + \eta U(z_{t+1})$ , except that he must pay the fixed cost  $\kappa\epsilon$ . With probability  $1 - q^b(z_t)$  the natural renter does not succeed in buying a house. In this case, he continues to be a renter at time  $t + 1$ . The value function of a natural renter who decides to buy a house,  $R^{\text{buy}}(z_t)$ , is given by

$$R^{\text{buy}}(z_t) = \bar{e} - w + q^b(z_t)\{-P^r(z_t) - \kappa\epsilon + \beta[(1 - \eta)H(z_{t+1}) + \eta U(z_{t+1})]\} + [1 - q^b(z_t)]\beta[(1 - \lambda)R(z_{t+1}) + \lambda B(z_{t+1})]. \quad (33)$$

The value function of a natural renter is given by

$$R(z_t) = \max[R^{\text{rent}}(z_t), R^{\text{buy}}(z_t)]. \quad (34)$$

The reservation price,  $\bar{P}^r(z_t)$ , is the price that makes natural renters indifferent between buying and renting:

$$\begin{aligned} \bar{P}^r(z_t) = \beta\{[(1 - \eta)H(z_{t+1}) + \eta U(z_{t+1})] \\ - [(1 - \lambda)R(z_{t+1}) + \lambda B(z_{t+1})]\} - \kappa\epsilon. \end{aligned} \quad (35)$$

It is useful to define a set of indicator functions summarizing the optimal strategy of different types of agents. The indicator function  $J^b(z_t)$  is equal to one if it is optimal for a natural buyer to buy a house when the state of the economy is  $z_t$  and is equal to zero otherwise. The indicator function  $J^r(z_t)$  is equal to one if it is optimal for a natural renter to buy a house when the state of the economy is  $z_t$  and is equal to zero otherwise. The indicator function  $J^u(z_t)$  is equal to one if it is optimal for an unhappy homeowner to put his house up for sale when the state of the economy is  $z_t$  and is equal to zero otherwise.

### E. Timing

The timing of events within a period is as follows. At the beginning of the period, the state variable is  $z_t$ . Then, preference shocks occur. With probability  $\eta$ , homeowners become unhappy homeowners. With probability  $\lambda$ , natural renters become natural buyers. Then agents make decisions.<sup>13</sup>

<sup>13</sup> Given our notation, value functions are evaluated at this point in time.

Transactions occur at the end of the period. A fraction  $q^s(z_t)J^u(z_t)$  of unhappy homeowners sell their homes while a fraction  $q^b(z_t)J^b(z_t)$  of home buyers buy houses.

The laws of motion for the fraction of homeowners, unhappy homeowners, natural home buyers, and natural renters in the population are given by

$$h_{t+1} = (1 - \eta)h_t + q^b(z_t)[(b_t + \lambda r_t)J^b(z_t) + r_t(1 - \lambda)J^r(z_t)], \quad (36)$$

$$u_{t+1} = (u_t + \eta h_t)[1 - q^s(z_t)J^u(z_t)], \quad (37)$$

$$b_{t+1} = (b_t + \lambda r_t)[1 - q^b(z_t)J^b(z_t)], \quad (38)$$

$$r_{t+1} = (1 - \lambda)r_t[1 - q^b(z_t)J^r(z_t)] + q^s(z_t)J^u(z_t)(u_t + \eta h_t). \quad (39)$$

These equations along with equations (21) and (22) define a law of motion for the state vector,  $z_t$ , which we denote  $z_{t+1} = G(z_t)$ .

#### F. The Matching Technology

Since agents can own only one home, only natural renters and natural buyers can potentially buy homes. The total number of potential buyers is given by

$$\text{Buyers}(z_t) = (b_t + \lambda r_t)J^b(z_t) + r_t(1 - \lambda)J^r(z_t). \quad (40)$$

There is no short selling, and homeowners sell only when the match with their home goes sour. The total number of potential sellers is given by

$$\text{Sellers}(z_t) = (u_t + \eta h_t)J^u(z_t). \quad (41)$$

There is a technology that governs matches between buyers and sellers. When a match occurs, the transactions price is determined by generalized Nash bargaining. The bargaining power of sellers and buyers is  $\theta$  and  $1 - \theta$ , respectively. Matches can occur between a seller and a natural buyer or a natural renter. In the first case, the price paid by the natural buyer,  $P^b(z_t)$ , is

$$P^b(z_t) = \theta \bar{P}^b(z_t) + (1 - \theta) \bar{P}^u(z_t). \quad (42)$$

In the second case, the price paid by the natural renter,  $P^r(z_t)$ , is

$$P^r(z_t) = \theta \bar{P}^r(z_t) + (1 - \theta) \bar{P}^u(z_t). \quad (43)$$

The average price received by an unhappy homeowner,  $P(z_t)$ , is given by

$$P(z_t) = \frac{(b_t + \lambda r_t)J^b(z_t)P^b(z_t) + r_t(1 - \lambda)J^r(z_t)P^r(z_t)}{(b_t + \lambda r_t)J^b(z_t) + r_t(1 - \lambda)J^r(z_t)}. \quad (44)$$



The number of homes sold,  $m(z_i)$ , is determined by the matching function

$$m(z_i) = \mu \text{Sellers}(z_i)^\alpha \text{Buyers}(z_i)^{1-\alpha}. \quad (45)$$

The probabilities of selling,  $q^s(z_i)$ , and buying,  $q^b(z_i)$ , a house are given by

$$q^s(z_i) = m(z_i)/\text{Sellers}(z_i), \quad (46)$$

$$q^b(z_i) = m(z_i)/\text{Buyers}(z_i). \quad (47)$$

### G. Solution Algorithm

In this subsection we discuss our algorithm for solving the model. We begin by describing the steady state and then show how to solve the equilibrium of the model, given arbitrary initial conditions.

#### 1. Steady State

It can be shown that the model economy has a unique steady state in which the fraction of the different types of agents is constant. We now solve for the steady-state values of the probabilities of buying and selling a home ( $q^b$  and  $q^s$ ) and the fraction of the different agents in the population ( $h$ ,  $u$ ,  $b$ , and  $r$ ).

We choose a value for  $\eta$  so that the probabilities of buying and selling a house coincide in the steady state:

$$q^s = q^b.$$

Equations (45) and (46) imply that  $q^s = q^b = \mu$ . This property, together with equations (22) and (38), implies that the steady-state number of natural buyers is given by

$$b = \frac{(1 - \mu)\lambda(1 - k)}{\mu + \lambda(1 - \mu)}.$$

Given  $b$ , we solve for  $r$ ,  $u$ , and  $h$  as functions of  $\mu$ ,  $\lambda$ , and  $k$  using equations (22), (37), and (21).

The fact that  $q^s = q^b$  implies that the number of buyers is equal to the number of sellers (eqq. [46] and [47]). Since there are  $u + \eta h$  unhappy homeowners and  $b + \lambda r$  buyers in the steady state, we set  $\eta$  so that

$$u + \eta h = b + \lambda r.$$

Given the values of  $q^s$  and  $q^b$ , we can solve for the steady-state values of the prices,  $P$ ,  $P^b$ , and  $P^r$ ; the reservation prices of unhappy homeowners, natural renters, and sellers,  $\bar{P}^u$ ,  $\bar{P}^r$ , and  $\bar{P}^s$ ; and the value functions of the

different agents evaluated in the steady state:  $H$ ,  $U$ ,  $B$ , and  $R$ . To do so, we use the steady-state versions of equations (23)–(35), (42)–(44), and the fact that, in the steady state,  $B = B^{\text{buy}}$  and  $R = R^{\text{rent}}$ .

## 2. Transitional Dynamics

We assume that at time  $T = 2000$  the system has converged to the steady state. Consequently, we obtain an approximate solution because it takes an infinite number of periods for the model economy to converge to the steady state.

Let the set  $Z$  denote all the values of the state variable  $z_t$  that occur along the transition path. First, guess that  $J^b(z_t) = J^u(z_t) = 1$  and  $J^r(z_t) = 0$  for all  $z_t \in Z$ . Second, using the initial conditions  $z_0 = (h_0, b_0)$  and equations (36)–(39), compute the sequence of values of  $h_t$ ,  $u_t$ ,  $b_t$ , and  $r_t$ . Third, use equations (40), (41), and (45)–(47) to compute the values of  $q^s(z_t)$  and  $q^b(z_t)$  for  $z_t \in Z$ . Fourth, assume that  $H(z_T) = H$ ,  $U(z_T) = U$ ,  $B(z_T) = B$ , and  $R(z_T) = R$ . Then use equations (23)–(35) and (44) to solve backward for  $\{H(z_t), U(z_t), B(z_t), R(z_t), P(z_t)\}$  for  $t = 1$  to  $T$ . Finally, verify whether the guesses for  $J^b(z_t)$ ,  $J^r(z_t)$ , and  $J^u(z_t)$  for  $z_t \in Z$  describe the optimal behavior of buyers and sellers along the proposed transition path. If not, revise the guesses for  $J^b(z_t)$ ,  $J^r(z_t)$ , and  $J^u(z_t)$  until a consistent solution is obtained.

## H. Experiments

We illustrate the properties of the model through a series of experiments.

### 1. An Expected Improvement in Fundamentals

We first consider the same experiment that we study in the frictionless model assuming that agents have homogeneous beliefs. At time 0, agents suddenly anticipate that, with probability  $\phi$ , the utility of owning a home rises from  $\varepsilon$  to  $\varepsilon^* > \varepsilon$ . It is easy to show that there are no transition dynamics and the economy converges immediately to a new steady state with a higher price. So, when beliefs are homogeneous, anticipated future changes in fundamentals are immediately reflected in today's price. Matching frictions per se do not produce interesting price dynamics, at least in the experiment studied here.

### 2. Transitional Dynamics

We now study an experiment that highlights how an exogenous increase in the number of buyers affects home prices. The resulting intuition is useful for understanding the effects of social dynamics that we discuss

in the next section. Suppose that the fraction of natural buyers in the population is initially higher than its steady-state value,  $b_0 > b$ . Since  $r_0 = 1 - k - b_0$ , the fraction of natural renters in the population is initially lower than its steady-state value. The time 0 value of the state variable is  $z_0 = (b_0, h_0)$ , where  $h_0$  is equal to the steady-state value of  $h$ . Equations (45)–(47) imply that the probability of buying a house at time 0 is lower than in the steady state:  $q^b(z_0) < q^b(z)$ . The time 0 probability of selling is higher than it is in the steady state:  $q^s(z_0) > q^s(z)$ .

We illustrate the transition dynamics of the model using the parameter values summarized in table 1. These values are discussed in detail in Section IV, where we consider the quantitative properties of our model.

Figure 4 depicts the model’s transition dynamics assuming that the time 0 number of natural buyers is roughly double its steady-state level. We now discuss the intuition for why the price is initially high and converges to the steady state from above. Along the transition path, only natural buyers want to buy houses, so the transactions price is a weighted

TABLE 1  
PARAMETER VALUES, MATCHING MODEL

Parameter	Value	Description
Parameters calibrated using the steady-state properties of the model:		
$k$	.65	Fraction of homeowners in population
$\beta$	.995	Discount factor
$\varepsilon$	1	Utility of owning a home
$\bar{\varepsilon}$	1	Utility of renting, natural buyer and renter
$w$	1	Rental rate
$\alpha$	.50	Parameter of matching function
$\mu$	.163	Parameter of matching function
$\lambda$	.011	Preference shock, natural renters
$\eta$	.0058	Preference shock, homeowners
$\kappa$	62	Fixed cost of buying, natural renters
$\theta$	.50	Bargaining power of home buyer
Parameters calibrated to survey data:		
$E^o(\varepsilon^*)$	2.89	Mean of optimists’ prior
$\phi$	.0038	Monthly probability that uncertainty is realized
$\psi$	.358	Opportunity cost, unhappy homeowner
$e^s/e^v$	.890	Relative entropies of skeptical and vulnerable agents’ priors
$e^o/e^v$	.894	Relative entropies of optimistic and vulnerable agents’ priors
$\xi$	$2.87 \times 10^{-6}$	Initial number of skeptical and optimistic agents

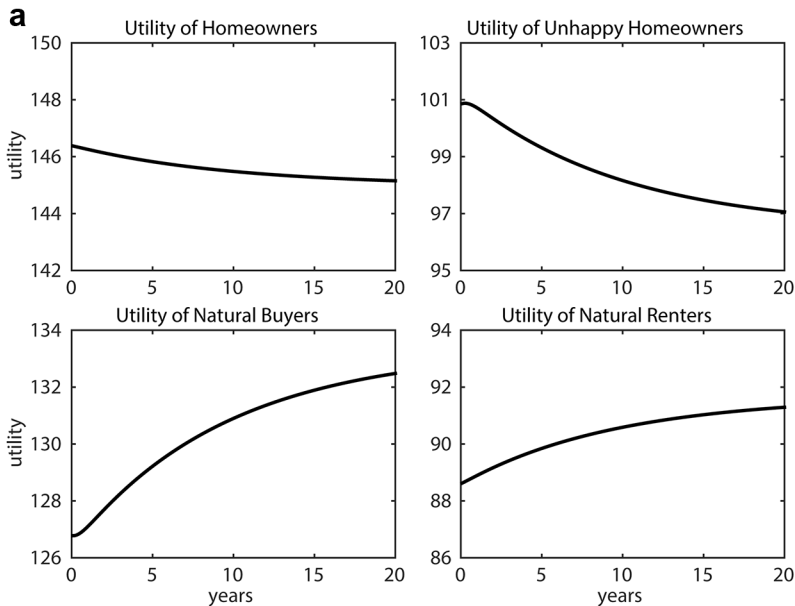


FIG. 4.—Transitional dynamics in a matching model. The figures illustrate the transition dynamics associated with the matching model, when there is an initial increase in the number of natural home buyers. *a*, Utility levels of the different agents. The utility levels of the four types of agents are indicated. *b*, Prices, buyers, sellers, and transaction probabilities. Buyers indicates the number of agents who try to buy a home, while sellers indicates the number of agents who try to sell a home. Price is the average price at which homes are sold. Buyers' reservation price is the reservation price of a natural home buyer. *c*, Agent populations, transactions volume, and transaction probabilities. The four plots on the left show the number of agents of each type across the transition path. Sales indicates the number of transactions.

average of the reservation prices of the natural buyers and the unhappy homeowners:

$$P(z_t) = \theta \bar{P}^b(z_t) + (1 - \theta) \bar{P}^u(z_t). \quad (48)$$

Consider first the determinants of  $\bar{P}^u(z_t)$ . From equation (27),  $\bar{P}^u(z_t)$  is increasing in  $U(z_{t+1})$  and decreasing in  $B(z_{t+1})$  and  $R(z_{t+1})$ . The utility of an unhappy homeowner,  $U(z_{t+1})$ , converges to the steady state from above, a result that reflects two forces. First, because the number of buyers is high during the transition, the probability of selling is higher than in the steady state. Second, the price received by the seller is higher than in the steady state. Next, consider the determinants of  $R(z_{t+1})$ . Along the transition path, it is optimal for natural renters to rent. But, with probability  $\lambda$ , they may become natural buyers. Equation (32) implies that

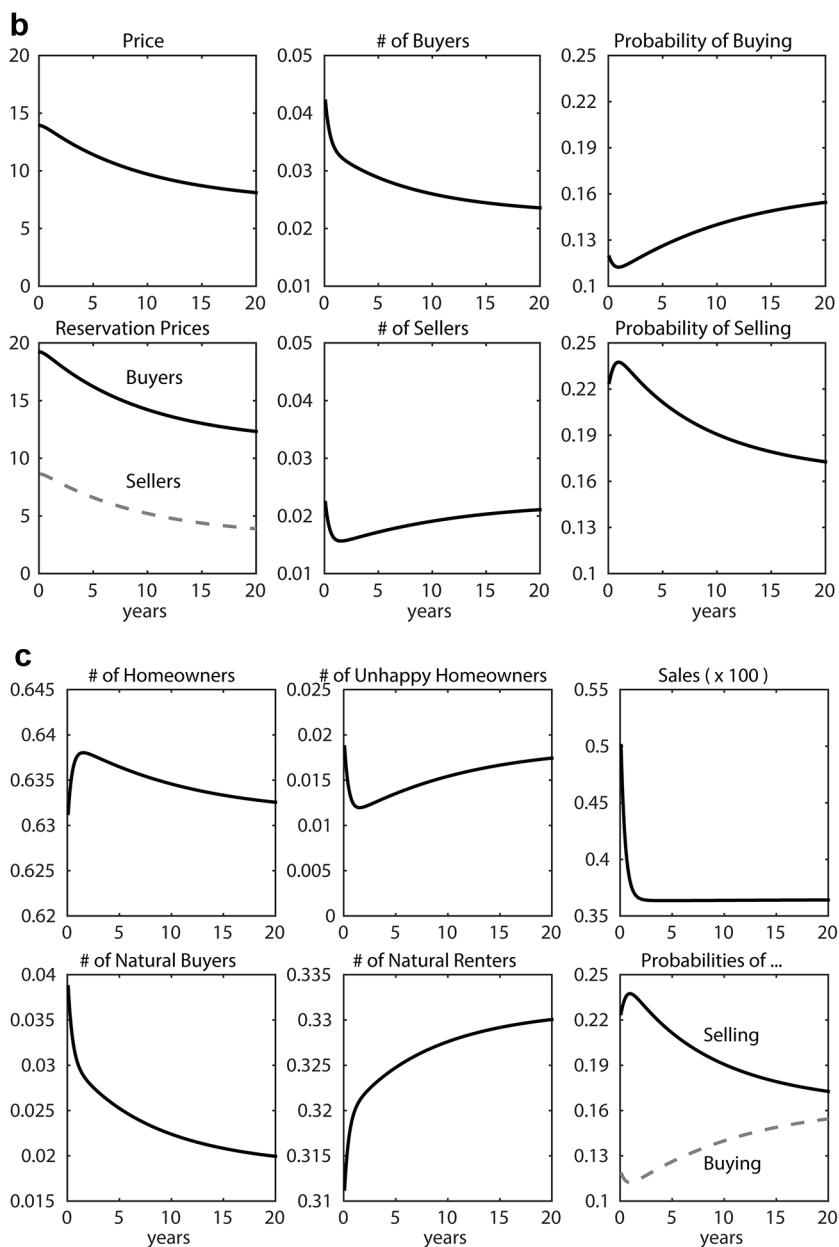


FIG. 4 (Continued)

$R(z_{t+1})$  is an increasing function of the discounted expected present value of  $B(z_{t+2})$ . Since  $B(z_{t+1})$  is low when there is a large number of buyers, so is  $R(z_{t+1})$ . Given that  $U(z_{t+1})$  is high and  $B(z_{t+1})$  and  $R(z_{t+1})$  are low relative to the steady state, the reservation price of an unhappy homeowner,  $\bar{P}^u(z_t)$ , is high.

Consider second the determinants of  $\bar{P}^b(z_t)$ . When a new buyer moves into a home, with probability  $\eta$  he becomes immediately disenchanted and puts the home up for sale. So the reservation price of a natural buyer is an increasing function of  $H(z_{t+1})$  and  $U(z_{t+1})$  (see eq. [31]). Since the opportunity cost to a natural buyer of being a homeowner is  $B(z_{t+1})$ , his reservation price is a decreasing function of  $B(z_{t+1})$ . When the number of buyers is high relative to the steady state, unhappy homeowners can sell their home more quickly and receive a higher price. This property has three implications. First, the value of being an unhappy owner,  $U(z_{t+1})$ , is higher than in the steady state. Second,  $H(z_{t+1})$  is also higher than in the steady state. This result reflects that all homeowners will eventually become disenchanted and sell their homes. Equation (23) implies that  $H(z_{t+1})$  is an increasing function of the discounted expected present value of  $U(z_{t+2})$ , which is high when the number of buyers is unusually high. Third, given our calibration, the value of being a natural buyer,  $B(z_{t+1})$ , falls, reflecting the difficulty in buying a house when there are many buyers. All three forces lead to a rise in  $\bar{P}^b(z_t)$ .

Recall that  $P(z_t)$  is a weighted average of the reservation prices of the unhappy homeowners and the natural buyers (see eq. [48]). Since both of these prices rise, so too does  $P(z_t)$ .

In summary, in this experiment an increase in the initial number of buyers reduces the probability of buying a house and raises the probability of selling a house. In addition, it lowers the utility of buyers, raises the utility of sellers, and generates prices that are above their steady-state values.

These results suggest that a boom-bust episode occurs if, for some reason, there is a persistent increase in the number of buyers followed by a persistent decrease. In the next section we show that social dynamics can generate the required movements in the number of buyers without observable movements in fundamentals.

#### IV. A Matching Model with Social Dynamics

In this section we consider an economy that incorporates the social dynamics described in Section II into the model with matching frictions described in Section III. We use this model to study the same basic experiment considered in Section II. Suppose that before time 0 the economy is in a steady state with no uncertainty. At time 0, agents learn that, with a small probability  $\phi$ , the value of  $\varepsilon$  changes permanently to a new level  $\varepsilon^*$ . Agents agree about the value of  $\phi$  but disagree about the probability dis-

tribution for  $\varepsilon^*$ . Agents do not receive any information that is useful for updating their priors about the distribution of  $\varepsilon^*$ . Once uncertainty is resolved, agents become homogeneous in their beliefs. At that point, the economy coincides with the one studied in the previous section in which the utility of owning a home is  $\varepsilon^*$ . The economy then converges to a steady state from initial conditions that are determined by social dynamics and the timing of the resolution of uncertainty.

Agents' expectations about  $\varepsilon^*$  depend on whether they are optimistic, skeptical, or vulnerable. In addition, agents can be homeowners, unhappy homeowners, natural buyers, or natural renters. So there are 12 different types of agents in the economy. We use the variables  $h_t^j$ ,  $u_t^j$ ,  $b_t^j$ , and  $r_t^j$  to denote the fraction of the population of type  $j$  agents who are homeowners, unhappy homeowners, natural home buyers, and natural renters, respectively. The index  $j$  denotes whether the agent is optimistic, skeptical, or vulnerable:  $j \in \{o, s, v\}$ .

As in Section III, agents are subject to preference shocks that can turn natural renters into natural buyers and homeowners into unhappy homeowners. The timing of events within a period is as follows. First, uncertainty about  $\varepsilon^*$  is realized or not. Second, preference shocks occur. With probability  $\eta$ , homeowners become unhappy homeowners. With probability  $\lambda$ , natural renters become natural buyers. Third, social interactions occur and agents potentially change their views. Fourth, transactions occur.

### A. *Setting Up the Model*

#### 1. Population Dynamics

There are three ways to incorporate social dynamics into the matching model. The first is closest in spirit to Section III. Here, agents meet in the beginning of the period via random matching, at which point social dynamics occur. With this timing, social dynamics affect directly the number of buyers and sellers in the housing market by changing the fraction of agents of different types. The second approach assumes that social interactions occur only when agents transact in the housing market. Under this assumption, transactions drive social dynamics, which later on drive further transactions. The third approach assumes that social dynamics occur at the beginning of the period as well as during market transactions.

We choose the first rather than the second approach because it highlights the role of social dynamics in generating transactions. We choose the first rather than the third approach because it is much simpler and it provides a parsimonious way of generating a gradual increase in the number of optimistic agents (see Sec. II).

To solve the model, we must keep track of the fraction of the different types of agents in the model. Prior to the resolution of uncertainty the number of homeowners adds up to  $k$  and the number of renters to

1 –  $k$ , so we can summarize the state of the economy using a vector of 10 state variables:

$$\mathfrak{z}_t = (h_t, b_t, h_t^v, h_t^s, b_t^v, b_t^s, r_t^v, r_t^s, u_t^v, u_t^s)'$$

To streamline our exposition, we discuss here only the law of motion for the fraction of natural renters who are vulnerable. In Appendix C we describe the population dynamics for the other agents, which are similar. We denote the fraction of vulnerable natural renters at the beginning of the period, after preference shocks occur, after social interactions occur, and after purchases and sales occur, by  $r_t^v$ ,  $(r_t^v)'$ ,  $(r_t^v)''$ , and  $r_{t+1}^v$ , respectively. At the beginning of the period, a fraction  $\lambda$  of the natural renters become natural buyers,

$$(r_t^v)' = r_t^v(1 - \lambda).$$

Next, social interactions occur. A fraction  $\gamma^{sv} s_t$  of the vulnerable natural renters become skeptical and a fraction  $\gamma^{ov} o_t$  become optimistic. Consequently, the fraction of vulnerable natural renters after social interactions is given by

$$(r_t^v)'' = (r_t^v)' - \gamma^{sv} (r_t^v)' s_t - \gamma^{ov} (r_t^v)' o_t.$$

Transactions occur at the end of the period. Let  $(u_t^v)''$  denote the fraction of the vulnerable natural sellers that remain after social interactions occur. Let  $J^{u,v}(\mathfrak{z}_t)$  denote an indicator function that is equal to one if it is optimal for a vulnerable unhappy homeowner to put his house up for sale when the state of the economy at the beginning of the period was  $\mathfrak{z}_t$  and zero otherwise. If these agents put their homes up for sale, a fraction  $q^s(\mathfrak{z}_t)$  succeeds in selling. So, the total number of successful sellers is  $q^s(\mathfrak{z}_t) J^{u,v}(\mathfrak{z}_t) (u_t^v)''$ . These sellers become natural renters. Let  $J^{r,v}(\mathfrak{z}_t)$  denote an indicator function that is equal to one if it is optimal for a vulnerable natural renter to buy a home when the state of the economy is  $\mathfrak{z}_t$  and zero otherwise. The number of vulnerable natural renters who try to purchase a home is equal to  $J^{r,v}(\mathfrak{z}_t) (r_t^v)''$ . A fraction  $q^b(\mathfrak{z}_t)$  of these agents succeed and become natural homeowners. So the number of vulnerable natural renters at the beginning of time  $t + 1$  is given by

$$r_{t+1}^v = (r_t^v)'' - q^b(\mathfrak{z}_t) J^{r,v}(\mathfrak{z}_t) (r_t^v)'' + q^s(\mathfrak{z}_t) J^{u,v}(\mathfrak{z}_t) (u_t^v)''.$$

Using a similar approach for the other population fractions, we can describe the law of motion of  $\mathfrak{z}_t$  as  $\mathfrak{z}_{t+1} = \mathcal{G}(\mathfrak{z}_t)$ , where  $\mathcal{G}$  is a function determined by the deterministic dynamics of the populations of different types.

After uncertainty is realized, of course, agents have homogeneous beliefs and population dynamics are described by the same processes given in Section III.



We now describe the value functions of the different agents in the economy. We begin by displaying the value functions that are relevant after  $\varepsilon^*$  is realized. We then discuss the value functions that are relevant before  $\varepsilon^*$  is realized.

## 2. Value Functions and Price Functions after Realization of Uncertainty

The value functions of the different agents and all the price functions are the same as those defined in Section III with one difference. The momentary utility,  $\varepsilon$ , is replaced in value by  $\varepsilon^*$  when uncertainty is realized. Here, it is useful to explicitly index the value functions  $H$ ,  $U$ ,  $B$ , and  $R$  and the price functions  $P$ ,  $P^b$ ,  $P^r$ ,  $\bar{P}^u$ ,  $\bar{P}^b$ , and  $\bar{P}^r$  by  $\varepsilon^*$ . For example, we define the value function of the homeowner as

$$H(z_t, \varepsilon^*) = \varepsilon^* + \beta[(1 - \eta)H(z_{t+1}, \varepsilon^*) + \eta U(z_{t+1}, \varepsilon^*)].$$

Similarly, the equations we used in Section III to define  $U$ ,  $B$ , and  $R$  and the price functions  $P$ ,  $P^b$ ,  $P^r$ ,  $\bar{P}^u$ ,  $\bar{P}^b$ , and  $\bar{P}^r$  need to be modified only by replacing  $\varepsilon$  with  $\varepsilon^*$ . These functions apply after the resolution of uncertainty because, once uncertainty is resolved, there is no distinction between skeptical, optimistic, and vulnerable agents.

## 3. Value Functions before the Realization of Uncertainty

We can write  $z_t = \Lambda \mathfrak{z}_t$ , where  $\Lambda = (I_2 \ 0_{2 \times 8})$ . In order to solve the model, we need to compute value and price functions for the period before uncertainty is realized. Let  $\mathcal{H}^j(\mathfrak{z}_t)$ ,  $\mathcal{U}^j(\mathfrak{z}_t)$ ,  $\mathcal{B}^j(\mathfrak{z}_t)$ , and  $\mathcal{R}^j(\mathfrak{z}_t)$  denote the value functions before uncertainty is realized of a type  $j$  homeowner, unhappy homeowner, natural buyer, and natural renter, respectively. Also define type  $j$ 's time  $t$  expectation of a generic value function at time  $t + 1$ :

$$\mathcal{V}_e^j(\mathfrak{z}_t) \equiv (1 - \phi)\mathcal{V}^j[\mathcal{G}(\mathfrak{z}_t)] + \phi \sum_{\varepsilon^* \in \Phi} f^j(\varepsilon^*) V[\Lambda \mathcal{G}(\mathfrak{z}_t), \varepsilon^*]. \quad (49)$$

Here  $\mathcal{V}$  represents  $\mathcal{H}$ ,  $\mathcal{U}$ ,  $\mathcal{B}$ , or  $\mathcal{R}$ ;  $V$  represents, correspondingly,  $H$ ,  $U$ ,  $B$ , or  $R$ ;  $\mathcal{G}(\mathfrak{z}_t)$  is the vector of end-of-period  $t$  populations; and  $\Lambda \mathcal{G}(\mathfrak{z}_t)$  represents the relevant subset of these variables if uncertainty is resolved at the beginning of period  $t + 1$ .

Given this notation, prior to the resolution of uncertainty the Bellman equation for a homeowner is

$$\mathcal{H}^j(\mathfrak{z}_t) = \varepsilon + \beta[(1 - \eta)\mathcal{H}_e^j(\mathfrak{z}_t) + \eta \mathcal{U}_e^j(\mathfrak{z}_t)]. \quad (50)$$

The Bellman equation for a type  $j$  unhappy homeowner is

$$\mathcal{U}^j(\mathfrak{z}_t) = \max[\mathcal{U}^{\text{sell},j}(\mathfrak{z}_t), \mathcal{U}^{\text{stay},j}(\mathfrak{z}_t)],$$

with

$$\begin{aligned}\mathcal{U}^{\text{sell},j}(\mathfrak{z}_t) &= \mathfrak{q}^s(\mathfrak{z}_t) \{ \mathcal{P}^j(\mathfrak{z}_t) + \beta[(1 - \lambda)\mathcal{H}_e^j(\mathfrak{z}_t) + \lambda\mathcal{B}_e^j(\mathfrak{z}_t)] \} \\ &\quad + [1 - \mathfrak{q}^s(\mathfrak{z}_t)]\beta\mathcal{U}_e^j(\mathfrak{z}_t), \\ \mathcal{U}^{\text{stay},j}(\mathfrak{z}_t) &= \beta\mathcal{U}_e^j(\mathfrak{z}_t) - \psi\mathfrak{q}^s(\mathfrak{z}_t)\mathcal{P}^j(\mathfrak{z}_t).\end{aligned}$$

Here  $\mathcal{P}^j(\mathfrak{z}_t)$  denotes the average selling price for type  $j$  conditional on a sale, and  $\mathfrak{q}^s(\mathfrak{z}_t)$  is the probability of a sale. The reservation price of a type  $j$  unhappy homeowner is

$$\bar{\mathcal{P}}^{u,j}(\mathfrak{z}_t) = \frac{\beta}{1 + \psi} \{ \mathcal{U}_e^j(\mathfrak{z}_t) - [(1 - \lambda)\mathcal{H}_e^j(\mathfrak{z}_t) + \lambda\mathcal{B}_e^j(\mathfrak{z}_t)] \}.$$

The Bellman equation for a type  $j$  natural buyer,  $\mathcal{B}^j(\mathfrak{z}_t)$ , is given by

$$\mathcal{B}^j(\mathfrak{z}_t) = \max[\mathcal{B}^{\text{rent},j}(\mathfrak{z}_t), \mathcal{B}^{\text{buy},j}(\mathfrak{z}_t)],$$

with

$$\begin{aligned}\mathcal{B}^{\text{rent},j}(\mathfrak{z}_t) &= \bar{\varepsilon} - w + \beta\mathcal{B}_e^j(\mathfrak{z}_t), \\ \mathcal{B}^{\text{buy},j}(\mathfrak{z}_t) &= \bar{\varepsilon} - w + \mathfrak{q}^b(\mathfrak{z}_t) \{ -\mathcal{P}^{b,j}(\mathfrak{z}_t) + \beta[(1 - \eta)\mathcal{H}_e^j(\mathfrak{z}_t) \\ &\quad + \eta\mathcal{U}_e^j(\mathfrak{z}_t)] \} + [1 - \mathfrak{q}^b(\mathfrak{z}_t)]\beta\mathcal{B}_e^j(\mathfrak{z}_t).\end{aligned}\tag{51}$$

Here  $\mathcal{P}^{b,j}(\mathfrak{z}_t)$  denotes the average buying price for a type  $j$  natural buyer, and  $\mathfrak{q}^b(\mathfrak{z}_t)$  is the probability of a purchase. The reservation price of a type  $j$  natural buyer is

$$\bar{\mathcal{P}}^{b,j}(\mathfrak{z}_t) = \beta[(1 - \eta)\mathcal{H}_e^j(\mathfrak{z}_t) + \eta\mathcal{U}_e^j(\mathfrak{z}_t) - \mathcal{B}_e^j(\mathfrak{z}_t)].\tag{52}$$

The Bellman equation for a type  $j$  natural renter,  $\mathcal{B}^j(\mathfrak{z}_t)$ , is given by

$$\mathcal{R}^j(\mathfrak{z}_t) = \max[\mathcal{R}^{\text{rent},j}(\mathfrak{z}_t), \mathcal{R}^{\text{buy},j}(\mathfrak{z}_t)],$$

with

$$\begin{aligned}\mathcal{R}^{\text{rent},j}(\mathfrak{z}_t) &= \bar{\varepsilon} - w + \beta[(1 - \lambda)\mathcal{R}_e^j(\mathfrak{z}_t) + \lambda\mathcal{B}_e^j(\mathfrak{z}_t)], \\ \mathcal{R}^{\text{buy},j}(\mathfrak{z}_t) &= \bar{\varepsilon} - w + \mathfrak{q}^b(\mathfrak{z}_t) \{ -\mathcal{P}^{r,j}(\mathfrak{z}_t) - \kappa\varepsilon + \beta[(1 - \eta)\mathcal{H}_e^j(\mathfrak{z}_t) \\ &\quad + \eta\mathcal{U}_e^j(\mathfrak{z}_t)] \} + [1 - \mathfrak{q}^b(\mathfrak{z}_t)]\beta[(1 - \lambda)\mathcal{R}_e^j(\mathfrak{z}_t) + \lambda\mathcal{B}_e^j(\mathfrak{z}_t)].\end{aligned}\tag{53}$$

Here  $\mathcal{P}^{r,j}(\mathfrak{z}_t)$  denotes the average buying price for a type  $j$  natural renter. The reservation price of a type  $j$  natural renter is

$$\begin{aligned} \bar{\mathcal{P}}^{r,j}(\mathfrak{z}_t) = & \beta[(1 - \eta)\mathcal{H}_e^j(\mathfrak{z}_t) + \eta\mathcal{U}_e^j(\mathfrak{z}_t) - (1 - \lambda)\mathcal{R}_e^j(\mathfrak{z}_t) \\ & - \lambda\mathcal{B}_e^j(\mathfrak{z}_t)] - \kappa\varepsilon. \end{aligned} \quad (54)$$

#### 4. Buyers and Sellers

In a slight abuse of notation (since the state variable is now  $\mathfrak{z}_t$ ), the number of buyers and sellers is given by

$$\text{Buyers}(\mathfrak{z}_t) = \sum_{j=o,s,v} (b_t^j)'' J^{b,j}(\mathfrak{z}_t) + \sum_{j=o,s,v} (r_t^j)'' J^{r,j}(\mathfrak{z}_t), \quad (55)$$

$$\text{Sellers}(\mathfrak{z}_t) = \sum_{j=o,s,v} (u_t^j)'' J^{u,j}(\mathfrak{z}_t). \quad (56)$$

Here  $J^{b,j}(\mathfrak{z}_t)$  ( $J^{r,j}(\mathfrak{z}_t)$ ) is an indicator function that is equal to one if it is optimal for a type  $j$  natural buyer (renter) to buy a home when the state of the economy is  $\mathfrak{z}_t$  and zero otherwise. Similarly,  $J^{u,j}(\mathfrak{z}_t)$  is an indicator function that is equal to one if it is optimal for a type  $j$  unhappy homeowner to put his house up for sale when the state of the economy is  $\mathfrak{z}_t$  and zero otherwise.

The number of homes sold and the probabilities of buying and selling are given by suitably modified versions of equations (45), (46), and (47).

#### 5. Transactions Prices

There are 18 different possible transaction prices arising out of potential transactions between three types of sellers, three types of natural buyers, and three types of natural renters. The average price paid by a type  $j$  natural buyer is

$$\mathcal{P}^{b,j}(\mathfrak{z}_t) = \theta \bar{\mathcal{P}}^{b,j}(\mathfrak{z}_t) + (1 - \theta) \sum_{\ell=o,s,v} \frac{(u_t^\ell)'' J^{u,\ell}(\mathfrak{z}_t)}{\text{Sellers}(\mathfrak{z}_t)} \bar{\mathcal{P}}^{u,\ell}(\mathfrak{z}_t). \quad (57)$$

The average price paid by a type  $j$  natural renter is

$$\mathcal{P}^{r,j}(\mathfrak{z}_t) = \theta \bar{\mathcal{P}}^{r,j}(\mathfrak{z}_t) + (1 - \theta) \sum_{\ell=o,s,v} \frac{(u_t^\ell)'' J^{u,\ell}(\mathfrak{z}_t)}{\text{Sellers}(\mathfrak{z}_t)} \bar{\mathcal{P}}^{u,\ell}(\mathfrak{z}_t). \quad (58)$$

The average price received by a type  $j$  seller is given by

$$\begin{aligned} \mathcal{P}^j(\mathfrak{z}_t) = & \theta \frac{\sum_{\ell=o,s,v} [(b_t^\ell)'' J^{b,\ell}(\mathfrak{z}_t) \bar{\mathcal{P}}^{b,\ell}(\mathfrak{z}_t) + (r_t^\ell)'' J^{r,\ell}(\mathfrak{z}_t) \bar{\mathcal{P}}^{r,\ell}(\mathfrak{z}_t)]}{\text{Buyers}(\mathfrak{z}_t)} \\ & + (1 - \theta) \bar{\mathcal{P}}^{u,j}(\mathfrak{z}_t). \end{aligned} \quad (59)$$

The average price across all transactions can be obtained by averaging across the seller types:

$$\mathcal{P}(\mathfrak{z}_t) = \sum_{\ell=o,s,v} \frac{(u_t^\ell)'' J^{u,\ell}(\mathfrak{z}_t)}{\text{Sellers}(\mathfrak{z}_t)} \mathcal{P}^\ell(\mathfrak{z}_t). \quad (60)$$

### B. Solving the Model

In this subsection, we describe a solution algorithm to compute the equilibrium of the economy along a path on which uncertainty has not been realized.

We begin by considering case 1. In this case, without resolution of uncertainty, all agents eventually become skeptical. Since  $E^s(\varepsilon^*) = \varepsilon$ , if the path under consideration converges, then it converges to the initial steady state of the economy.

We use the algorithm described in Section III to solve for the steady state associated with all possible realizations of  $\varepsilon^*$  and for the values of the value functions along the transition to the steady state for any initial condition  $z_t$  and realized value of  $\varepsilon^*$ :  $H(z_t, \varepsilon^*)$ ,  $U(z_t, \varepsilon^*)$ ,  $B(z_t, \varepsilon^*)$ , and  $R(z_t, \varepsilon^*)$ . As in Section III, we denote by  $Z$  the set of the values of the state variable  $z_t$  that occur along the equilibrium path. We denote by  $\mathcal{Z}$  the set of the values of the state variable  $\mathfrak{z}_t$  that occur along the equilibrium path.

Our solution algorithm is as follows. First, we specify the initial conditions in the economy:  $h_0^j$ ,  $u_0^j$ ,  $b_0^j$ , and  $r_0^j$  for  $j = o, s, v$ . We choose these conditions so that the fractions of homeowners, unhappy homeowners, natural buyers, and natural renters are equal to their initial steady-state values. In addition, we assume that all agents are vulnerable except for a small number,  $\zeta$ , of optimistic and skeptical renters:  $h_0^v = h$ ,  $b_0^v = b$ ,  $u_0^v = u$ ,  $r_0^o = r_0^s = \zeta$ , and  $r_0^v = 1 - k - b - 2\zeta$ .

Second, we guess values of the indicator functions that summarize the optimal decisions of natural buyers, natural renters, and unhappy homeowners  $J^{b,j}(\mathfrak{z}_t)$ ,  $J^{r,j}(\mathfrak{z}_t)$ , and  $J^{u,j}(\mathfrak{z}_t)$  for all  $\mathfrak{z}_t \in \mathcal{Z}$ .

Third, we use equations (C1)–(C20) in Appendix C to compute the path of  $\mathfrak{z}_t$  and the analogues of equations (45)–(47) as well as equations (55) and (56) to compute the values of  $q^s(\mathfrak{z}_t)$  and  $q^b(\mathfrak{z}_t)$  for  $\mathfrak{z}_t \in \mathcal{Z}$ .

Fourth, we compute the limiting values of the value functions of all agents along the path on which uncertainty is not realized. The system of equations that defines these limiting values is given by equations (C22)–(C34) in Appendix C.

Fifth, we solve backward for all the value functions using equations (50)–(54) and (57)–(60). As in Section III, we assume that the economy has reached its steady state at time  $T = 2000$ .

Sixth, we verify that the initial guesses for the indicator functions  $J^{b,j}(\mathfrak{z}_t)$ ,  $J^{r,j}(\mathfrak{z}_t)$ , and  $J^{u,j}(\mathfrak{z}_t)$  describe the optimal behavior of buyers

and sellers along the proposed equilibrium path. If not, we revise the guesses until we obtain a consistent solution. In all the results that we report, the equilibrium values of the indicator functions are  $J^{b,j}(\mathbf{z}_t) = 1$  and  $J^{u,j}(\mathbf{z}_t) = 1$  for all  $j$  and  $J^{r,o}(\mathbf{z}_t) = 1$ ,  $J^{r,s}(\mathbf{z}_t) = J^{r,v}(\mathbf{z}_t) = 0$  for all  $\mathbf{z}_t \in \mathcal{Z}$ .

We use a similar algorithm to solve for the equilibrium in case 2. An important difference between cases 1 and 2 is that, in case 2, without resolution of uncertainty, all agents become optimistic. Given our conjectures about the optimal decisions of the agents, this means the economy does not converge to a steady state equivalent to an economy in which  $\varepsilon^* = E^o(\varepsilon^*)$ . The reason is that in the latter economy, natural renters choose to rent, whereas here, in the limit, all natural renters are optimistic and choose to buy. We provide the detailed solution method for case 2 in Appendix C.

## V. Model Calibration

In this section we discuss our procedure for calibrating the model. In solving the model each period is 1 month long. We choose one set of parameters so that the steady state of the model is consistent with the long-run properties of the US housing market. We choose a second set of parameters, which controls the distribution of beliefs and their dynamics, to match micro evidence on agents' expectations about future house prices and the self-perceived values of their homes during the recent boom-bust episode. Here, we bring to bear new evidence on the evolution of different agents' expectations of home values. Using the Case and Shiller (2010) survey of homeowner expectations and the American Housing Survey, we document that, during the boom episode, there was a sharp increase in the difference between the mean and the median of expected appreciation in house prices and self-assessed home values across agents.

According to the Standard & Poors/Case-Shiller US National Home Price Index, house prices increased from 1994 to 2006 and declined from 2006 to 2012. The value of the inflation-adjusted house price index in 2012 is about the same as in 1994. In light of this observation, we interpret the recent boom-bust episode in the United States as one in which skeptical and vulnerable agents never changed their views about fundamentals (i.e.,  $E^s(\varepsilon^*) = E^v(\varepsilon^*) = \varepsilon$ ) and, ex post, skeptical agents were correct.

In what follows, we want to be agnostic about whether or not the boom ended because uncertainty about future fundamentals was realized. For this reason, we use the quantitative implications of the model in case 1 to guide our calibration. Recall that in this case, a boom-bust pattern occurs both when uncertainty is not realized and when uncertainty is real-

ized and the skeptical agents are correct.<sup>14</sup> In evaluating the model, we think of the US episode as a draw from the skeptical agent's unconditional distribution about future housing fundamentals.

#### A. *Parameters Calibrated Using Steady-State Properties of the Model*

We first describe a set of parameters chosen to render the steady state of the model consistent with selected first moments of the data. We set the stock of houses,  $k$ , to 0.65. Recall that this value is the average fraction of homeowners in the US population. We choose  $\mu$ , the scale parameter in the matching function, so that the average time to sell a house is approximately 6 months. This number is roughly equal to the average time that it takes to sell an existing home, computed using data from the National Association of Realtors for the period 1999–2012. It is also consistent with the calibration in Piazzesi and Schneider (2009), which is based on data from the American Housing Survey. We choose  $\eta$  so that the probabilities of buying and selling coincide in the steady state. We choose  $\lambda$  so that, in conjunction with our other assumptions, households sell their homes, on average, every 15 years. This value is close to the one used in Piazzesi and Schneider (2009). We set both the matching parameter ( $\alpha$ ) and the bargaining parameter ( $\theta$ ) to 0.5 so as to treat buyers and sellers symmetrically.

It is difficult to obtain direct evidence on the parameter  $\kappa$ . In our benchmark calibration we assume that  $\kappa$  is equal to 62. This value implies that the steady-state utility of a natural renter who buys a home is 32 percent lower than that of a natural home buyer. In conjunction with our other assumptions, this value of  $\kappa$  implies that it is not optimal for natural renters to buy homes in the steady state. We find that our results are robust to reasonable perturbations in  $\kappa$ . We choose  $\beta$  to be consistent with an annual discount factor of 6 percent. In addition, we normalize  $\varepsilon$  to one and  $\bar{e} - w$  to zero.

#### B. *Parameters Governing Expectations and Social Dynamics*

We calibrate the six parameters  $E^o(\bar{e}^*)$ ,  $\phi$ ,  $\psi$ ,  $e^s/e^v$ ,  $e^o/e^v$ , and  $\zeta$  to match an equally weighted system of nine features of the data. This procedure is analogous to an overidentified version of generalized method of moments with an identity weighting matrix.

<sup>14</sup> In case 2, a permanent boom occurs when uncertainty is not realized or when the optimistic agents are correct. A boom-bust pattern occurs only when uncertainty is realized and the skeptical are correct.

Our quantitative analysis focuses on the three cities for which Case and Shiller (2010) report expectations data: Boston, Los Angeles, and San Francisco.<sup>15</sup> We assume that the recent US boom-bust episode began in March 1996 when the average real home price in our three cities was at its lowest value in the 1990s. We assume that the episode ended in October 2006, the first month after which there is a sustained, uninterrupted fall in real housing prices for our three cities.<sup>16</sup> We focus on the years 2003, 2005, and 2006, the years during the episode for which we have expectations data (there are no data for 2004).<sup>17</sup>

The first feature of the data that we use in our calibration procedure is the 1-year expected real appreciation. The three observations are reported in table 2.<sup>18</sup>

The next feature of the data that we use is the difference between the mean and the median of the 1-year expected increase in home prices. Again, we have three observations, reported in table 2. To motivate why these statistics are of interest, recall that a central prediction of our model is that, because of social dynamics, a boom in house prices is associated with an increase in the fraction of optimistic agents. This increase generally implies a rise in the difference between the mean and the median expected home price appreciation over the following year. Recall that the fraction of optimistic agents is very small at the start of the boom and rises over time before eventually declining. However, the fraction of optimistic agents never exceeds 50 percent, so the median agent is always a vulnerable or a pessimistic agent. As the fraction of optimistic agents rises, the mean across agents of the expected rate of home price appreciation also rises. Taken together, these observations imply that the difference between the mean and the median expected appreciation rises in the boom phase of the cycle.

Interestingly, a widening gap between mean and median values also shows up in agents' views of what their homes are worth. In the biannual American Housing Survey (AHS), the Bureau of the Census asks homeowners the following question: "How much do you think your house would sell for on today's market?" Our analysis focuses, again, on homes in Boston, Los Angeles, and San Francisco. We compute the percentage difference between the mean and the median valuation for each city at each point in time for the 1997–2009 period. This statistic is roughly zero

<sup>15</sup> The survey also includes results for Milwaukee. We exclude these results because Milwaukee is not included in the S&P/Case-Shiller 20-City Composite Home Price Index.

<sup>16</sup> By sustained, we mean one quarter or longer in duration.

<sup>17</sup> In an updated version of their paper, Case, Shiller, and Thompson (2012) provide summary statistics for additional survey years in Alameda County (CA), Boston, Milwaukee, and Orange County (CA).

<sup>18</sup> These statistics are based on the average forecasts as reported by Case and Shiller (2010, table 6). We use the US survey of professional forecasters to convert expected nominal appreciation into expected real appreciation.

TABLE 2  
HOMEOWNER BELIEFS: STATISTICS FROM SURVEY DATA

	Data	Model
A. Case-Shiller mean expected price appreciation:		
2003*	5.3	7.4
2005*	7.9	7.1
2006*	3.6	7.1
B. Case-Shiller mean minus median expected price appreciation:		
2003*	.6	2.0
2005*	1.9	1.9
2006*	2.0	1.9
C. AHS: mean minus median house valuation:		
1997	.0	−.3
1999	4.3	3.1
2001	10.7	12.7
2003*	14.4	16.8
2005*	20.0	17.9
2006*	19.7	18.3

NOTE.—In panels A and B, the table reports the mean and mean minus median expected house price appreciation from homeowner surveys presented in Case and Shiller (2010). We use data from three cities (Boston, Los Angeles, and San Francisco) and convert nominal forecasts to real as described in the main text. In the column Model, we report the analogue figures from our model treating 2006 as the peak of the house price boom. In panel C, we report statistics based on the biannual American Housing Survey, in which the Bureau of the Census asks homeowners the question “How much do you think your house would sell for on today’s market?” We use responses collected in Boston, Los Angeles, and San Francisco. We report the average percentage difference between the median and the mean valuation for these cities. Figures for 2006 are interpolated from the 2005 and 2007 surveys. In the column “Model” we report the analogue figures from our model when we treat 2006 as the peak of the house price boom. These are based on the mean and median utility levels of homeowners and home sellers in our model.

\* The survey moment is included in our calibration exercise.

in 1997 and remains close to zero until around 2000. Table 2 reports the average of this statistic across the three cities. We use the observations for 2003, 2005, and 2006 in our calibration exercise.

C. *Computing Model Moments*

To compute the analogue to the first three statistics discussed above (expected house price appreciation), we proceed as follows. First, we compute the 1-year-ahead expected appreciation for optimistic, skeptical, and vulnerable homeowners. We then compute the weighted average of these expectations. We also compute, as an analogue to the second group of three statistics, the mean minus median expectations of house price appreciation across homeowners.

A key issue is how to map the AHS question (relevant for the last three statistics) into our model. One possibility is that agents report the average price paid for a house at time  $t$ . All agents in the model know current market prices. So under this interpretation, there should be no disper-



sion in response to the AHS question and the mean and the median responses should coincide. This implication is clearly inconsistent with table 2. We infer that this interpretation of the question is implausible from the perspective of our model.

It is possible that the difference between the mean and median responses reflects systematic changes in the market value of idiosyncratic house characteristics during the boom episode. This interpretation strikes us as implausible because the mean minus the median is close to zero in 1997 and then rises dramatically.

In what follows, we suppose that agents respond to the AHS question by reporting the value that they attach to their home. In our model, the mean value is a weighted average of  $\mathcal{H}_e^j(z_t)$  and  $\mathcal{U}_e^j(z_t)$ , where the weights are the fractions of happy and unhappy homeowners of each type  $j = o, v, s$ . Current market prices have a direct effect on  $\mathcal{U}_e^j(z_t)$  since the agent is trying to sell the house. Market prices affect  $\mathcal{H}_e^j(z_t)$  because happy homeowners might become home sellers in the future. The AHS does not distinguish whether survey respondents currently have their home on the market or not. So we do not make this distinction when we compute the mean and median values implied by our model.

#### *D. Calibrated Parameters*

Table 1 reports the calibrated parameter values. Two key features are worth noting. First, the percentage of the population that are optimistic at time 0 is very small, so a boom-bust episode is triggered by a small number of agents. Second, the entropy ratio  $e^o/e^v$  is slightly larger than  $e^s/e^v$ . Other things equal, this small difference enables the model to generate a gradual boom-bust pattern, even in the absence of resolution of uncertainty.

## **VI. Quantitative Properties of the Model**

In this section we discuss the quantitative properties of our model. The first subsection reports the model's implications for various moments of the data, including those used in the overidentified calibration procedure. In the second subsection we discuss the house price dynamics implied by cases 1 and 2. Finally, we compute and analyze the unconditional expected price paths for the different agents in our economy.

#### *A. Implications for Data Moments*

Table 2 reports the model's implications for various moments of the data. A number of key results emerge with respect to the moments targeted by the calibration procedure. First, the model captures the fact that agents expected substantial appreciation in housing prices in the period 2003–6.

Our model somewhat overstates the average expected appreciation, which is 7.2 percent in our model and 5.6 percent in the data. Second, the model is also consistent with average mean minus median expected rate of home price appreciation over the boom years of the episode. The average value of this statistic over the period 2003–6 is 1.9 percent in the model and 1.5 percent in the data. Third, the model does well at accounting for the difference between the self-assessed mean minus median home values reported in the AHS for the 2003–6 period. The average value of this statistic is 18 percent in both the data and the model.

We now turn to four features that are not targeted by the calibration procedure. First, consider the AHS-based statistics reported in table 2. Notice that in the data the self-assessed mean minus median home value is equal to zero in 1997 and then peaks at 20 percent near the end of the episode. The model succeeds at capturing the magnitude of the rise and the shape of the rise, even though the pre-2003 values were not part of our calibration procedure. This success clearly reflects the presence of heterogeneous expectations and social dynamics. Second, the model does extremely well at accounting for the rise in house prices in the beginning of the episode. A key feature of the data is that housing prices rise very slowly in the initial phases of the boom-bust episode. For example, the Case-Shiller index for the three cities rose by 1.3 percent from March 1996 (the trough) to March 1997. In our model, house prices do not jump in the beginning of the episode. Rather, they slowly start to rise. We view this property as an important success because in standard rational expectations models, asset prices move substantially on impact in response to news about future fundamentals. Third, the length of the boom episode is 10.6 years in the data. According to the model, the time at which the expected price is maximized is 13.1 years from the beginning of the episode. So our model does reasonably well at generating the prolonged nature of the observed boom-bust episode. Finally, the mean value of the maximum percentage rise in house prices implied by the model is 289 percent. In the data this rise is 144 percent. So, judging by these statistics alone, the model overestimates the magnitude of the boom. We can use the model to compute the probability distribution of the maximum rise in prices. We find that a 144 percent boom lies at the 23rd percentile of this distribution. We infer that a boom-bust of the sort observed in the United States is not particularly unlikely from the perspective of our model.

### *B. Analyzing Model Dynamics, Case 1*

We now analyze model dynamics in case 1 at our calibrated parameter levels. In this case, the pdf of the skeptical agents has the lowest entropy ( $e^s < e^o < e^v$ ). The resulting social dynamics are displayed in figure 1a,

while figure 5 describes various features of the model along a path on which uncertainty is not realized. The key features of this path can be summarized as follows. First, average home prices rise and then fall as the infection waxes and wanes. Even though agents have perfect foresight up to the resolution of long-run uncertainty, the initial rise in price is very small. Second, the average transaction price comoves strongly with the number of potential buyers. Third, the number of transactions comoves strongly with the average house price. Fourth, as prices rise, there is a “sellers’ market” in the sense that the probability of selling is high and the probability of buying is low.

Consistent with our discussion in Section III, movements in the number of potential buyers are the key drivers of price dynamics in the model. Over time, the number of potential buyers rises from roughly 1.9 percent to a peak value of roughly 13.6 percent of the population and then declines.

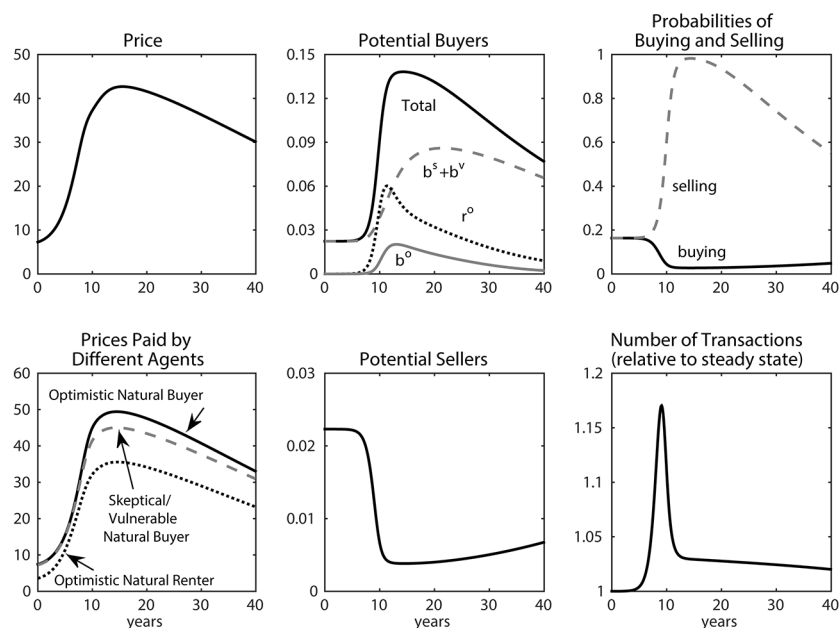


FIG. 5.—Equilibrium of the matching model with social dynamics, case 1. The figures illustrate equilibrium paths when there is no resolution of uncertainty for the matching model with social dynamics in case 1, in which the priors of skeptical agents have the lowest entropy, and the priors of the vulnerable agents have the highest entropy. The number of potential buyers is calculated after preferences shocks have been realized. Here,  $b^s$ ,  $b^v$ , and  $b^o$  represent the populations of skeptical, vulnerable, and optimistic natural buyers, while  $r^o$  is the population of optimistic natural renters.

In the boom phase of the cycle, the number of potential buyers rises for two reasons. First, in contrast to the model without social dynamics, optimistic natural renters want to buy homes. At the peak of the infection, roughly 21 percent of natural renters are optimistic and account for 42 percent of potential buyers (see fig. 5). Second, as more buyers enter the market, the average amount of time to purchase a house rises from 6 to 37 months, while the average time to sell a house drops from 6 months to just over 1 month. To understand these results, recall that the probabilities of buying and selling a home depend on the ratio of buyers to sellers (see eqq. [46] and [47]). Other things equal, the inflow of optimistic natural renters into the housing market increases the number of buyers, thereby lowering the probability of buying a house and raising the probability of selling a house. The latter effect reduces the stock of unhappy homeowners, thus reinforcing the fall in the probability of buying and the rise in the probability of selling a house. As the infection wanes, the number of buyers falls and the number of sellers rises, so the probabilities of buying and selling a house return to their steady-state values.

To understand how changes in the number of buyers and sellers affect prices, we exploit the intuition about transition dynamics discussed in Section IV. The average purchase price is a weighted average of the price paid by four types of agents: optimistic natural renters and optimistic, skeptical, and vulnerable natural buyers.

The price paid by each of these agents depends positively on their reservation price (see eqq. [57] and [58]). Each reservation price is the difference between the value to that agent of being a homeowner and a home buyer (see eqq. [52] and [54]). When the probability of buying is low, the value functions of all potential buyers are low because it is more difficult to realize the utility gains from purchasing a home. When the probability of selling is high, the value functions of unhappy homeowners are high because it takes less time to sell a home. The value functions of homeowners are also high because, with probability  $\eta$ , they become unhappy homeowners.

As more agents become optimistic, the probability of buying falls and the probability of selling rises. As a result, the reservation prices of the different potential buyers rise, leading to a rise in purchase prices.

From figure 5 we see that the optimistic natural buyers pay the highest price. These agents derive a high utility from owning a home and have a high expectation of  $\varepsilon^*$ . The next-highest price is paid by skeptical natural buyers. These agents also derive a high utility from owning a home, but they have a lower expectation of  $\varepsilon^*$  than optimistic natural buyers. Vulnerable and skeptical natural buyers have the same expectation of  $\varepsilon^*$ , so they pay the same price. Optimistic natural renters pay the lowest price. On the one hand, these agents enjoy the house less than natural buyers. On the

other hand, they have a higher expectation of  $\varepsilon^*$  than skeptical and vulnerable natural buyers. For the case being considered the first effect outweighs the second effect.

The presence of optimistic natural renters has two effects. Taking the prices paid by other agents as given, the presence of optimistic natural renters reduces the average price. However, the presence of optimistic renters increases the number of potential buyers, thereby creating a *congestion effect* that reduces the probability of buying a home. As discussed above, this reduction increases the transactions price paid by the other agents in the system. In our example, the second effect dominates the first effect.

### C. Quantifying the Congestion Effect

One way to quantify the importance of the congestion effect is to redo the experiment but not allow optimistic renters to purchase homes. By construction, in this experiment the probability of buying and selling a home is constant, since the number of potential buyers and sellers is unaffected by the infection. It turns out that the average sale price is hardly affected by social dynamics. Average prices go up in this experiment only as a result of a rise in the reservation price of optimistic natural buyers. This price is the difference between the value of a being a new homeowner who is optimistic,  $(1 - \eta)\mathcal{H}^o(\mathfrak{z}_{t+1}) + \eta\mathcal{U}^o(\mathfrak{z}_{t+1})$ , and the value of being an optimistic natural buyer,  $\mathcal{B}^o(\mathfrak{z}_{t+1})$ . The value of becoming a homeowner increases if a vulnerable agent becomes optimistic. But the value of being an optimistic natural buyer also increases because an optimistic agent has a high expected value of  $\varepsilon^*$ . In contrast to the situation in which the congestion effect is operative, here the probability of buying a home remains constant, so there is no countervailing effect on the optimistic natural buyers' value functions. The net result is a small increase in the reservation price of optimistic buyers.

### D. What Happens When Uncertainty Is Resolved?

Figure 6 shows the average behavior of the price if uncertainty is realized in year 15. The solid line depicts the actual house price up to the period when uncertainty is realized. The dashed line shows the average price path that vulnerable/skeptical agents expect after uncertainty is realized. Interestingly, these agents do not expect the price to converge immediately to its steady value after uncertainty is realized. The reason is that, when uncertainty is resolved, the number of natural buyers exceeds its steady-state value. The transition to the steady state is governed by the transition dynamics of the homogeneous expectations model. As emphasized in Section III, when the number of natural buyers exceeds its

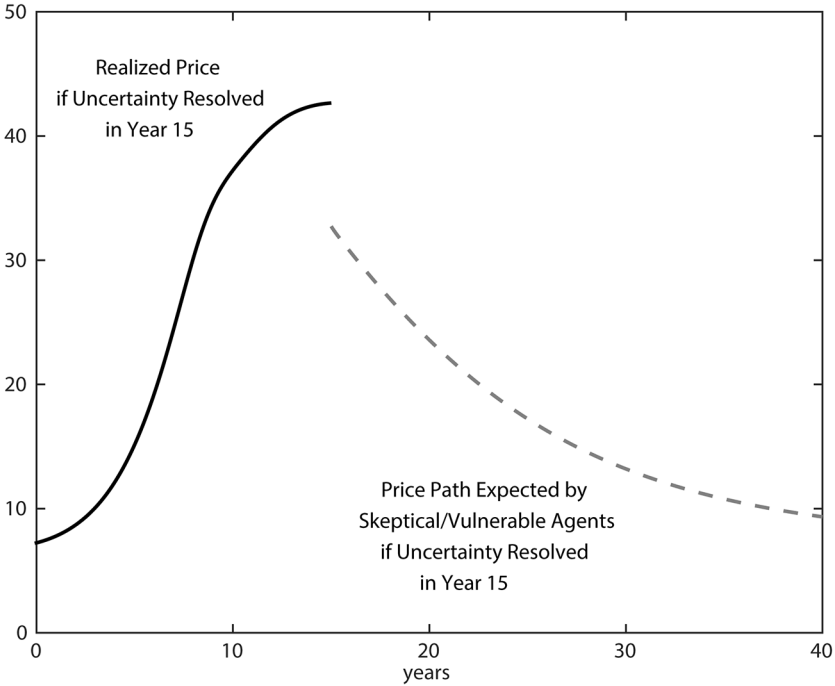


FIG. 6.—Expected prices after the resolution of uncertainty, case 1. The figure illustrates the equilibrium price (solid line) if uncertainty is not realized until the end of year 15. The dashed line indicates the prices the skeptical and vulnerable agents would expect to observe after year 15, if uncertainty were resolved at that date.

steady-state value, the price converges to its steady-state value gradually from above.

Figure 6 helps us understand why a skeptical or vulnerable natural buyer is willing to buy a house even around the peak in housing prices. At this point, the price is much higher than the steady-state price that these agents expect. Even if uncertainty is resolved in the following period, agents expect the fall in the price to be relatively small because the number of potential home buyers is significantly above its steady-state value. Even if a home buyer becomes an unhappy homeowner, the expected capital loss on the house is expected to be relatively small. As a consequence, the gains from living in the house outweigh the expected capital loss.

Optimistic agents expect a large capital gain when uncertainty is realized. The expected gain is so large that it induces natural renters to try to purchase a home. They are willing to do so because the expected gains from speculation outweigh their disposition to rent rather than buy.

Figure 6 shows that there is a discontinuous jump up or down in house prices when uncertainty is realized. We do not observe these types of jumps in the data. The discontinuity reflects the stark nature of how information is revealed in the model. This feature would be eliminated if information about long-run fundamentals gradually percolates throughout the economy as in Duffie, Giroux, and Manso (2010) and Andrei and Cuijean (2013).

### E. Analyzing Model Dynamics, Case 2

We now analyze model dynamics in case 2 at our calibrated parameter levels.<sup>19</sup> In this case, the pdf of the optimistic agents has the lowest entropy ( $e^o < e^s < e^v$ ). The same economic forces discussed above are at work here. The key difference is that, without resolution of uncertainty, the entire population becomes optimistic (see fig. 1*b*). As a consequence, the number of optimistic renters rises and remains high until uncertainty is resolved. So, the number of potential buyers remains high and the congestion effect is operative until then. Not surprisingly, therefore, in case 2 the probability of buying (selling) remains lower (higher) than in case 1, until uncertainty is resolved. Consequently, the volume of transactions does not return to its original steady-state level.

Finally, figure 7 displays the price path in the absence of resolution of uncertainty. As in case 1, the significant boom phase of the price rise takes place before year 15. The boom is larger than in case 1, reflecting the larger number of potential buyers. After year 15, the price continues to rise slowly until uncertainty is resolved.

### F. Expected Price Paths

We now discuss the properties of the time 0 expectations of time  $t$  prices for optimistic and skeptical agents. For  $t > 0$  these are

$$E_0^j(P_t) = (1 - \phi)^t \mathcal{P}[\mathcal{G}^t(\mathfrak{z}_0)] + \sum_{\tau=1}^t \phi(1 - \phi)^{\tau-1} \sum_{\varepsilon^* \in \Phi} f^j(\varepsilon^*) \times P\{G^{t-\tau}[\Lambda \mathcal{G}^\tau(\mathfrak{z}_0)], \varepsilon^*\}. \quad (61)$$

The first term in equation (61) reflects the possibility that uncertainty has not yet been resolved by the end of time  $t$ . The probability of this event,  $(1 - \phi)^t$ , is multiplied by  $\mathcal{P}[\mathcal{G}^t(\mathfrak{z}_0)]$ , the price at time  $t$  in that state of the world. Here  $\mathcal{G}^t(\cdot)$  is the law of motion of the state variables invoked  $t$  times, so it represents  $\mathfrak{z}_t$ . The second term in equation (61) reflects the possibility that uncertainty is resolved at time  $\tau \leq t$ , an event that

<sup>19</sup> For computational reasons, we assume that  $\kappa = 65$  in case 2.

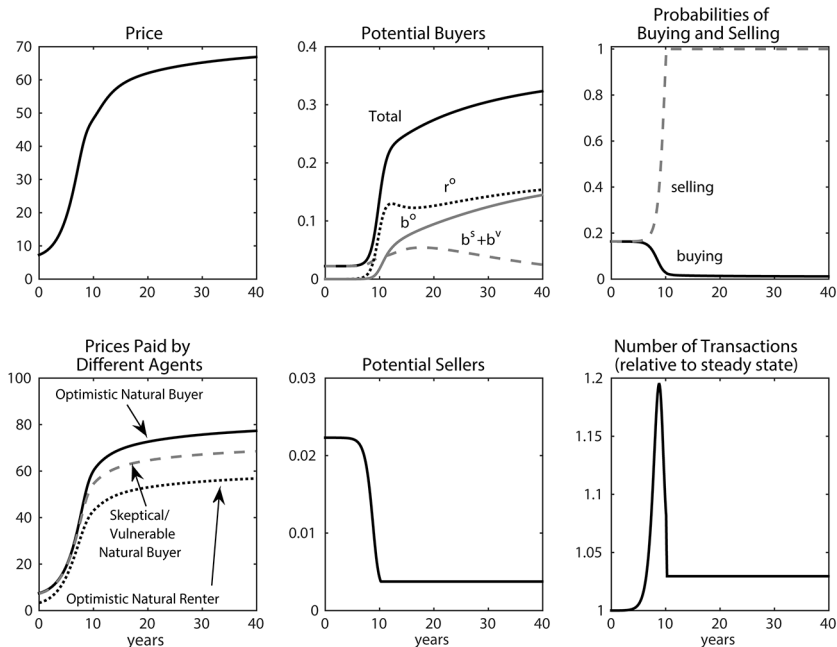


FIG. 7.—Equilibrium of the matching model with social dynamics, case 2. The figures illustrate equilibrium paths when there is no resolution of uncertainty for the matching model with social dynamics in case 2, in which the priors of optimistic agents have the lowest entropy, and the priors of the vulnerable agents have the highest entropy. The number of potential buyers is calculated after preferences shocks have been realized. Here,  $b^s$ ,  $b^v$ , and  $b^o$  represent the populations of skeptical, vulnerable, and optimistic natural buyers, while  $r^o$  is the population of optimistic natural renters.

occurs with probability  $\phi(1 - \phi)^{\tau-1}$ . This probability is multiplied by the price that agent  $j$  expects to occur at time  $t$  if uncertainty is realized at time  $\tau$ . Here,  $G^{t-\tau}[\Lambda \mathcal{G}^{\tau}(\mathbf{z}_0)]$  represents  $z_t$  since  $\mathcal{G}^{\tau}(\mathbf{z}_0)$  represents  $\mathbf{z}_{\tau}$ ,  $\Lambda \mathbf{z}_{\tau}$  represents  $z_{\tau}$ , and  $G^{t-\tau}(\cdot)$  represents the law of motion after the resolution of uncertainty invoked  $t - \tau$  times.

Figure 8a depicts, for case 1, the price paths expected by different agents. Optimistic agents expect prices to rise rapidly until year 17 and to remain relatively high. Skeptical agents expect prices to rise up to year 13, although by less than optimistic agents. Thereafter, skeptical agents expect prices to revert gradually to their old steady-state levels.

Figure 8b depicts, for case 2, the price paths expected by different agents. The key property to notice is that, while there are quantitative differences, the patterns are remarkably similar. Skeptical agents expect a boom that is followed by a bust while optimistic agents expect a boom that is not followed by a bust. Qualitatively this is the same result that we obtained with the frictionless model of Section III. Once again, an



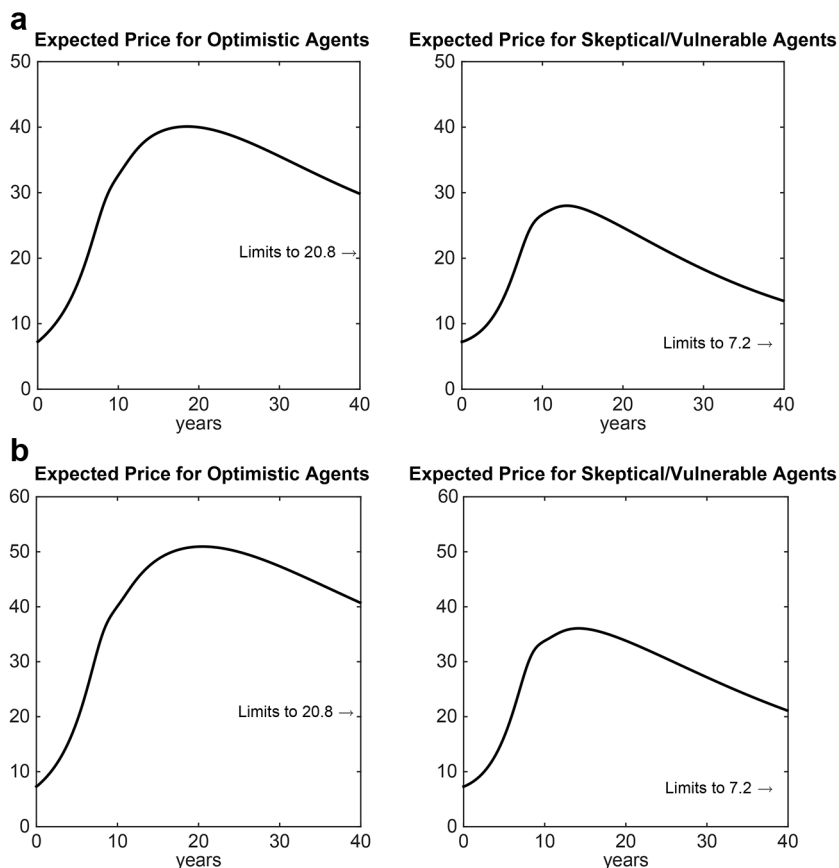


FIG. 8.—Expected price paths, matching model with social dynamics: *a*, case 1; *b*, case 2. The graphs show the price paths expected by different types of agents at time 0. In case 1, the priors of skeptical agents have the lowest entropy, and the priors of the vulnerable agents have the highest entropy. In case 2, the priors of optimistic agents have the lowest entropy, and the priors of the vulnerable agents have the highest entropy.

econometrician taking repeated samples from our data would see both boom-busts and booms that are not followed by busts. The boom-bust episodes typically occur in economies in which the skeptical agents happen to be correct. The booms that are not followed by busts typically occur in economies in which optimistic agents happen to be correct.

## VII. Some Additional Evidence on Key Mechanisms in the Model

In this section, we present some additional evidence on the mechanisms at work in our model. Our model attributes a key role to buyers with

speculative motives. Booms (busts) are marked by increases (decreases) in the number of agents who buy homes primarily because of large expected capital gains (natural renters). It is obviously difficult to measure the importance of such buyers. However, the Michigan Survey of Consumers provides us with some indirect information. The survey includes the question “Is it a good time to buy a home because it is a good investment?” Figure 9 displays the percentage of respondents answering yes to this question from 1996 to 2012, along with the percentage change in

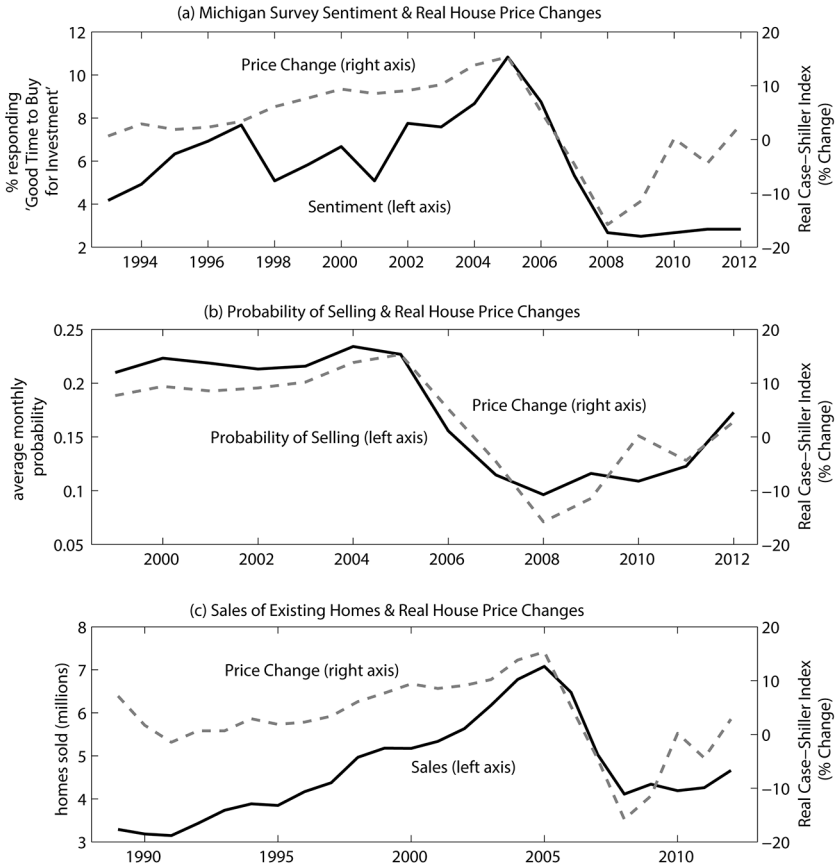


FIG. 9.—Sentiment, housing transactions, and house price changes. In all panels the dashed line is the percentage change in the inflation-adjusted Case-Shiller national house price index. Panel *a* shows survey data from the Michigan Survey of Consumers. The solid line shows the percentage of respondents answering “yes” to the question “Is it a good time to buy a home because it is a good investment?” Panels *b* and *c* show data from the National Association of Realtors. Panel *b* shows the probability of selling (the ratio of sales to inventories for existing homes) as the solid line. Panel *c* shows sales of existing homes as the solid line.

the inflation-adjusted Case-Shiller national price index. There is a clear increase in the number of respondents who thought housing was a good investment during the boom period and a sharp decline during the bust phase.

Suppose we assume that a rise in the number of first-time buyers is likely to come from the pool of natural renters. Then, an additional piece of evidence consistent with our model is that housing booms are accompanied by an increase in the number of first-time buyers. Data from the Current Population Survey show that the number of homes owned by individuals 29 years old and younger increased by 34 percent between 1994 and 2005 and decreased by 20 percent between 2005 and 2012. The numbers are even more dramatic for individuals aged 25 and younger, with the rise and fall equaling 73 and 24 percent, respectively. In a similar vein, Holmans (1995) documents a large rise and fall in the number of first-time buyers during the UK boom-bust episode of the late 1980s and early 1990s. Evidence along the same lines comes from the housing expectations survey data used by Case et al. (2012). From 2003 on, first-time buyers had consistently higher expectations of price appreciation than other buyers. The difference between the 1-year-ahead rate of return expected by first-time buyers and other buyers ranges from 1.1 percent in 2003 to 5.4 percent in 2006. Taken together, the previous evidence is supportive of the important role that our model ascribes to speculative buyers in boom and bust episodes.

A core implication of our model is that a boom (bust) in house prices is associated with an increase (decrease) in the probability of selling a house. To assess this implication, we use data from the National Association of Realtors on inventories and sales of existing homes covering the period 1999–2012. We compute the monthly probability of a sale as the ratio of sales to inventories of existing homes for sale. The annual probability of a sale is the average of the monthly probabilities in a given year. Figure 9 shows that there is a striking comovement between this probability and the rate of change in the inflation-adjusted Case-Shiller price index. Both series rise from 1999 until the end of 2005 and then drop sharply until 2008 before recovering.

Our model also implies that booms (busts) are associated with an increase (decrease) in the volume of transactions. Figure 9 provides empirical evidence on the volume of transactions. Transaction volume rose, reaching a peak in 2005, before falling dramatically through 2009. This pattern is consistent with evidence in Stein (1995).

Recall that, according to our model, an unusually large number of potential buyers enter the market during booms. Their desire to purchase a home is primarily driven by speculative motives. The entry of these agents makes it easier to sell existing homes and increases the overall level of activity in the housing market. During the bust phase, speculative

buyers exit the market, driving down the probability of selling a home and the volume of transactions. So our model implies that the extensive margin plays a critical role in house price dynamics. Taken together, we interpret the evidence in figure 9 as supportive of this implication.

### VIII. Conclusion

Boom-bust episodes are pervasive in housing markets. They occur in different countries and in different time periods. These episodes are hard to understand from the perspective of conventional models in which agents have homogeneous expectations. In this paper we propose a model in which agents have different views about long-run fundamentals. Social interactions can generate temporary increases in the fraction of agents who hold a particular view about long-run fundamentals. The resulting dynamics can produce boom-bust cycles as well as booms that are not followed by busts.

Our model abstracts from financial frictions. It is clear to us that the ability of many young buyers to buy a home is influenced by down payment requirements and credit conditions. An implication of our model is that if young buyers are optimistic but cannot buy a house, say because they are credit constrained, boom-bust cycles in house prices are greatly muted. Indeed, this situation corresponds to the experiment in our model in which we lock out optimistic natural renters from the housing market. In this case there are no congestion effects and there are no pronounced boom-bust cycles. But there is no presumption that a policy of requiring high down payments would be welfare improving because this policy would presumably apply to both natural buyers and natural renters. More generally, policies aimed at curbing rapid price increases are not obviously welfare improving in our model because, in the end, we do not know who is right about the future: the vulnerable, the skeptical, or the optimistic.

### Appendix A

#### Internalizing Changes in Agent Type

In the main text we assume that agents do not take into account the possibility that they may change their type as a result of social interactions. Here we assess the quantitative impact of this assumption by calculating equilibrium prices when agents do internalize the possibility that they may change their type.

In case 1, in the absence of resolution of uncertainty, all agents become skeptical as  $t$  goes to infinity and the terminal price is equal to the fundamental price of a skeptical agent ( $P^s$  in eq. [12]). In case 2, in the absence of resolution of uncertainty, all agents become optimistic as  $t$  goes to infinity and the terminal price is equal to the fundamental price of an optimistic agent ( $P^o$  in eq. [11]). Using

these terminal prices, we can compute the equilibrium price path in a recursive fashion.

When  $o_t \geq k$ , optimistic agents are the marginal homeowners. In this case the equilibrium price is given by

$$P_t = (1 - \gamma^{so} s_t) \beta [\phi E^o(\varepsilon^* + P_{t+1}^*) + (1 - \phi)(\varepsilon + P_{t+1})] \\ + \gamma^{so} s_t \beta [\phi E^s(\varepsilon^* + P_{t+1}^*) + (1 - \phi)(\varepsilon + P_{t+1})].$$

Recall that  $P_{t+1}$  and  $P_{t+1}^*$  are the  $t + 1$  prices when uncertainty is not realized and when uncertainty is realized, respectively. Here an optimistic agent takes into account that with probability  $\gamma^{so} s_t$  he becomes skeptical at time  $t + 1$  and values the house as a skeptical agent. The value of  $\gamma^{so}$  is positive in case 1 but equal to zero in case 2.

When  $o_t < k$  and  $o_t + v_t \geq k$ , vulnerable agents are the marginal homeowners even if  $s_t \geq k$ . Vulnerable agents have higher valuations than skeptical agents because they have a higher probability of becoming optimistic. In this case the equilibrium price is given by

$$P_t = (1 - \gamma^{ov} o_t - \gamma^{sv} s_t) \beta [\phi E^v(\varepsilon^* + P_{t+1}^*) + (1 - \phi)(\varepsilon + P_{t+1})] \\ + \gamma^{ov} o_t \beta [\phi E^o(\varepsilon^* + P_{t+1}^*) + (1 - \phi)(\varepsilon + P_{t+1})] \\ + \gamma^{sv} s_t \beta [\phi E^s(\varepsilon^* + P_{t+1}^*) + (1 - \phi)(\varepsilon + P_{t+1})].$$

Here the vulnerable agent takes into account that with probability  $\gamma^{ov} o_t$  he becomes optimistic and values the house as an optimistic agent. Also, with probability  $\gamma^{sv} s_t$ , he becomes skeptical and values the house as a skeptical agent.

Finally, when  $o_t < k$  and  $o_t + v_t < k$ , the marginal homeowner is a skeptical agent. In this case the equilibrium price is given by

$$P_t = \gamma^{os} o_t \beta [\phi E^o(\varepsilon^* + P_{t+1}^*) + (1 - \phi)(\varepsilon + P_{t+1})] \\ + (1 - \gamma^{os} o_t) \beta [\phi E^s(\varepsilon^* + P_{t+1}^*) + (1 - \phi)(\varepsilon + P_{t+1})].$$

Here the skeptical agent takes into account that, with probability  $\gamma^{os} o_t$ , he becomes optimistic and values the house as an optimistic agent. Recall that  $\gamma^{os}$  is zero in case 1 but is positive in case 2.

We redo the experiment that underlies figure 2 using the same parameter values. The basic finding is that internalizing changes in agent type makes virtually no difference to our results. The basic reason is that the probability of switching types is small. For instance, in case 1, the maximum values of  $\gamma^{ov} o_t$  and  $\gamma^{so} s_t$  in our numerical example are 3 percent and 0.33 percent, respectively. In the main text we abstract from this effect to simplify our computations.

## Appendix B

### An Alternative Interpretation of Social Dynamics

In this appendix we describe an alternative environment that generates social dynamics that are similar to those of our model. In this example agents have heterogeneous priors and receive private signals. Suppose that the agents who are

initially optimistic or skeptical have very sharp priors. Agents who are initially vulnerable have very diffuse priors. All agents receive uninformative private signals. Vulnerable agents have sharp priors that the posteriors of optimistic and skeptical agents are the product of initially diffuse priors and very informative signals. So when a vulnerable agent meets an optimistic (skeptical) agent, his posterior becomes arbitrarily close to that of the optimistic (skeptical) agent. We refer to a vulnerable agent who has a posterior that is very close to that of an optimistic (skeptical) agent as optimistic (skeptical).

We reinterpret  $\gamma^{lj}$  as the probability that agents of type  $l$  meet agents of type  $j$ . We assume that  $\gamma^{ss} = \gamma^{so} = \gamma$  and that  $\gamma^{oo} = 0$ ; that is, skeptical and optimistic agents have no social interactions. Under our assumptions the dynamics of the fraction of the population with different views are similar to those generated by our model of social dynamics. Our assumptions about  $\gamma^{lj}$  eliminate the convergence of posteriors that is a generic property of Bayesian environments. As a result, we preserve the property that different agents agree to disagree.<sup>20</sup> To obtain dynamics similar to cases 1 and 2, we need to introduce a slight asymmetry between skeptical and optimistic agents. A simple, albeit mechanical, way to introduce this asymmetry is to suppose that in case 1 (case 2) a small fraction  $\delta$  of optimistic (skeptical) agents exogenously change their view to those of skeptical (optimistic) agents.

The view of social segmentation embodied in our assumptions about  $\gamma^{lj}$  is consistent with the notion that agents who are strongly committed to a point of view limit their interactions to sources of information and individuals who are likely to confirm their own views. This phenomenon is discussed by Sunstein (2001) and Mullainathan and Shleifer (2005). The latter authors summarize research in psychology, communications, and information theory that is consistent with the social segmentation hypothesis. More recently, Gentzkow and Shapiro (2011) find evidence that people tend to have close social interactions with people who have similar political views. Social segmentation is related to what sociologists call “homophily”: contact between similar people occurs at a higher rate than contact among dissimilar people (McPherson, Smith-Lovin, and Cook 2001).

## Appendix C

In this appendix we describe the laws of motion for the fractions of the population accounted for by the 12 types of agents in the model of Section V. The values of  $\gamma^{lj}$ , which depend on the ratio of the entropies of the pdfs of agents  $l$  and  $j$ , are defined in equation (3). Recall that  $\gamma^{os} = 0$  in case 1 and  $\gamma^{so} = 0$  in case 2.

### A. Homeowners

We denote the fraction of homeowners of type  $j$  ( $j = o, s, v$ ) in the beginning of the period, after preference shocks occur, after social interactions occur, and af-

<sup>20</sup> Acemoglu et al. (2007) provide an alternative environment in which agents agree to disagree because they are uncertain about the interpretation of the signals that they receive.

ter purchases and sales occur by  $h_t^j$ ,  $(h_t^j)'$ ,  $(h_t^j)''$ , and  $h_{t+1}^j$ , respectively. The laws of motion for these variables are given by

$$(h_t^j)' = h_t^j(1 - \eta), \quad j = o, s, v, \quad (C1)$$

$$(h_t^v)'' = (h_t^v)' - \gamma^{sv}(h_t^v)'s_t - \gamma^{ov}(h_t^v)'o_t, \quad (C2)$$

$$(h_t^s)'' = (h_t^s)' + \gamma^{sv}(h_t^s)'s_t - \gamma^{os}(h_t^s)'o_t + \gamma^{so}(h_t^o)'s_t, \quad (C3)$$

$$(h_t^o)'' = (h_t^o)' + \gamma^{ov}(h_t^o)'o_t - \gamma^{so}(h_t^o)'s_t + \gamma^{os}(h_t^s)'o_t, \quad (C4)$$

$$h_{t+1}^j = (h_t^j)'' + q^b(\mathbf{z}_t)J^{bj}(\mathbf{z}_t)(b_t^j)'' + q^b(\mathbf{z}_t)F^{vj}(\mathbf{z}_t)(r_t^j)'', \quad j = o, s, v. \quad (C5)$$

### B. Unhappy Homeowners

We denote the fraction of unhappy homeowners of type  $j$  ( $j = o, s, v$ ) in the beginning of the period, after preference shocks occur, after social interactions occur, and after purchases and sales occur by  $u_t^j$ ,  $(u_t^j)'$ ,  $(u_t^j)''$ , and  $u_{t+1}^j$ , respectively. The laws of motion for these variables are given by

$$(u_t^j)' = u_t^j + \eta h_t^j, \quad j = o, s, v, \quad (C6)$$

$$(u_t^v)'' = (u_t^v)' - \gamma^{sv}(u_t^v)'s_t - \gamma^{ov}(u_t^v)'o_t, \quad (C7)$$

$$(u_t^s)'' = (u_t^s)' + \gamma^{sv}(u_t^s)'s_t - \gamma^{os}(u_t^s)'o_t + \gamma^{so}(u_t^o)'s_t, \quad (C8)$$

$$(u_t^o)'' = (u_t^o)' + \gamma^{ov}(u_t^o)'o_t - \gamma^{so}(u_t^o)'s_t + \gamma^{os}(u_t^s)'o_t, \quad (C9)$$

$$u_{t+1}^j = (u_t^j)'' - q^s(\mathbf{z}_t)F^{uj}(\mathbf{z}_t)(u_t^j)'', \quad j = o, s, v. \quad (C10)$$

### C. Natural Buyers

We denote the fraction of natural buyers of type  $j$  ( $j = o, s, v$ ) in the beginning of the period, after preference shocks occur, after social interactions occur, and after purchases and sales occur by  $b_t^j$ ,  $(b_t^j)'$ ,  $(b_t^j)''$ , and  $b_{t+1}^j$ , respectively. The laws of motion for these variables are given by

$$(b_t^j)' = b_t^j + \lambda r_t^j, \quad j = o, s, v, \quad (C11)$$

$$(b_t^v)'' = (b_t^v)' - \gamma^{sv}(b_t^v)'s_t - \gamma^{ov}(b_t^v)'o_t, \quad (C12)$$

$$(b_t^s)'' = (b_t^s)' + \gamma^{sv}(b_t^s)'s_t - \gamma^{os}(b_t^s)'o_t + \gamma^{so}(b_t^o)'s_t, \quad (C13)$$

$$(b_t^o)'' = (b_t^o)' + \gamma^{ov}(b_t^o)'o_t - \gamma^{so}(b_t^o)'s_t + \gamma^{os}(b_t^s)'o_t, \quad (C14)$$

$$b_{t+1}^j = (b_t^j)'' - q^b(\mathbf{z}_t)J^{bj}(\mathbf{z}_t)(b_t^j)'', \quad j = o, s, v. \quad (C15)$$

### D. Natural Renters

We denote the fraction of natural renters of type  $j$  ( $j = o, s, v$ ) in the beginning of the period, after preference shocks occur, after social interactions occur, and after purchases and sales occur by  $r_t^j$ ,  $(r_t^j)'$ ,  $(r_t^j)''$ , and  $r_{t+1}^j$ , respectively. The laws of motion for these variables are given by

$$(r_t^j)' = r_t^j(1 - \lambda), \quad j = o, s, v, \quad (C16)$$

$$(r_t^v)'' = (r_t^v)' - \gamma^{sv}(r_t^v)'s_t - \gamma^{ov}(r_t^v)'o_t, \quad (C17)$$

$$(r_t^s)'' = (r_t^s)' + \gamma^{sv}(r_t^v)'s_t - \gamma^{os}(r_t^s)'o_t + \gamma^{so}(r_t^o)'s_t, \quad (C18)$$

$$(r_t^o)'' = (r_t^o)' + \gamma^{ov}(r_t^v)'o_t - \gamma^{so}(r_t^o)'s_t + \gamma^{os}(r_t^s)'o_t, \quad (C19)$$

$$r_{t+1}^j = (r_t^j)'' - q^b(\mathbf{z}_t)J^{r,j}(\mathbf{z}_t)(r_t^j)'' + q^s(\mathbf{z}_t)J^{u,j}(\mathbf{z}_t)(u_t^j)'', \quad j = o, s, v. \quad (C20)$$

### E. The Limiting Steady State When Uncertainty Is Not Realized, Case 1

We denote by  $H(\varepsilon^*)$ ,  $U(\varepsilon^*)$ ,  $B(\varepsilon^*)$ , and  $R(\varepsilon^*)$  the steady state of the value functions of different agents in the economy when uncertainty is realized and the realized utility of owning a home is  $\varepsilon^*$ . These values are computed by solving the system of equations (23), (24), (28), (29), (32), (31), and (44), setting  $B = B^{\text{buy}}$  and  $R = R^{\text{rent}}$  and replacing  $\varepsilon$  in equation (23) with the different possible values of  $\varepsilon^*$ . Then let

$$\bar{V}^j = \sum_{\varepsilon^* \in \Phi} f^j(\varepsilon^*) V(z, \varepsilon^*), \quad (C21)$$

where  $V$  represents  $H$ ,  $U$ ,  $B$ , or  $R$ , and  $z = (h, b)'$ , with  $h$  and  $b$  being the steady-state values of  $h$  and  $b$  from Section III. The limiting value functions of different agents along a path in which uncertainty is not resolved can be obtained by solving the following system of equations for  $\mathcal{H}^j$ ,  $\mathcal{U}^j$ ,  $\mathcal{B}^j$ ,  $\mathcal{R}^j$ , and  $\bar{\mathcal{P}}^{b,s}$  and for  $j = o, v, s$ , unless indicated otherwise:

$$\mathcal{H}^j = \varepsilon + \beta\{(1 - \phi)[(1 - \eta)\mathcal{H}^j + \eta\mathcal{U}^j] + \phi[(1 - \eta)\bar{H}^j + \eta\bar{U}^j]\}, \quad (C22)$$

$$\begin{aligned} \mathcal{U}^j &= q^s\mathcal{P}^j + q^s\beta\{(1 - \phi)[(1 - \lambda)\mathcal{R}^j + \lambda\mathcal{B}^j] + \phi[(1 - \lambda)\bar{R}^j + \lambda\bar{B}^j]\} \\ &+ (1 - q^s)\beta[(1 - \phi)\mathcal{U}^j + \phi\bar{U}^j], \end{aligned} \quad (C23)$$

$$\begin{aligned} \bar{\mathcal{P}}^{u,j} &= \frac{\beta}{1 + \psi} \{(1 - \phi)[\mathcal{U}^j - (1 - \lambda)\mathcal{R}^j - \lambda\mathcal{B}^j] \\ &+ \phi[\bar{U}^j - (1 - \lambda)\bar{R}^j - \lambda\bar{B}^j]\}, \end{aligned} \quad (C24)$$

$$\begin{aligned} \mathcal{B}^j &= \bar{\varepsilon} - w - q^b\mathcal{P}^{b,j} + q^b\beta\{(1 - \phi)[(1 - \eta)\mathcal{H}^j + \eta\mathcal{U}^j] \\ &+ \phi[(1 - \eta)\bar{H}^j + \eta\bar{U}^j]\} + (1 - q^b)\beta[(1 - \phi)\mathcal{B}^j + \phi\bar{B}^j], \end{aligned} \quad (C25)$$

$$\begin{aligned} \bar{\mathcal{P}}^{b,j} &= \beta\{(1 - \phi)[(1 - \eta)\mathcal{H}^j + \eta\mathcal{U}^j - \mathcal{B}^j] \\ &+ \phi[(1 - \eta)\bar{H}^j + \eta\bar{U}^j - \bar{B}^j]\}, \end{aligned} \quad (C26)$$

$$\begin{aligned} \mathcal{R}^j &= \bar{\varepsilon} - w + \beta\{(1 - \phi)[(1 - \lambda)\mathcal{R}^j + \lambda\mathcal{B}^j] \\ &+ \phi[(1 - \lambda)\bar{R}^j + \lambda\bar{B}^j]\}, \quad j = s, v, \end{aligned} \quad (C27)$$

$$\begin{aligned} \mathcal{R}^o &= \bar{\varepsilon} - w - q^b(\mathcal{P}^{r,o} + \kappa\varepsilon) + q^b\beta\{(1 - \phi)[(1 - \eta)\mathcal{H}^o + \eta\mathcal{U}^o] \\ &+ \phi[(1 - \eta)\bar{H}^o + \eta\bar{U}^o]\} + (1 - q^b)\beta\{(1 - \phi)[(1 - \lambda)\mathcal{R}^o + \lambda\mathcal{B}^o] \\ &+ \phi[(1 - \lambda)\bar{R}^o + \lambda\bar{B}^o]\}, \end{aligned} \quad (C28)$$



$$\begin{aligned}\bar{\mathcal{P}}^{r,j} &= \beta(1 - \phi)[(1 - \eta)\mathcal{H}^j + \eta\mathcal{U}^j - (1 - \lambda)\mathcal{R}^j - \lambda\mathcal{B}^j] \\ &+ \beta\phi[(1 - \eta)\bar{H}^j + \eta\bar{U}^j - (1 - \lambda)\bar{R}^j - \lambda\bar{B}^j] - \kappa\varepsilon.\end{aligned}\quad (\text{C29})$$

Recall that in the limit all agents are skeptical, and we have conjectured that skeptical natural renters do not choose to buy, thus simplifying expressions for average prices:

$$\mathcal{P}^{b,j} = \theta\bar{\mathcal{P}}^{b,j} + (1 - \theta)\bar{\mathcal{P}}^{u,s}, \quad (\text{C30})$$

$$\mathcal{P}^{r,j} = \theta\bar{\mathcal{P}}^{r,j} + (1 - \theta)\bar{\mathcal{P}}^{u,s}, \quad (\text{C31})$$

$$\mathcal{P}^j = \theta\bar{\mathcal{P}}^{b,s} + (1 - \theta)\bar{\mathcal{P}}^{u,j}, \quad (\text{C32})$$

$$\mathcal{P} = \mathcal{P}^s. \quad (\text{C33})$$

The probabilities of buying and selling are given by

$$q^s = q^b = \mu. \quad (\text{C34})$$

#### F. The Limiting Steady State When Uncertainty Is Not Realized, Case 2

In case 2, all agents become optimistic in the limit when uncertainty is not realized. Given our conjectured optimal decision rules, optimistic natural buyers and natural renters choose to buy homes prior to the resolution of uncertainty. This means that the limiting populations,  $h$ ,  $u$ ,  $b$ , and  $r$ , do not correspond to their initial steady-state values. The reason is that the initial steady state is a constant solution to equations (36)–(41) and (45)–(47) with  $J^r = 0$ , whereas here the limiting case is a constant solution to equations (36)–(41) and (45)–(47) with  $J^r = 1$ . We denote the values of  $h$ ,  $b$ ,  $q^s$ , and  $q^b$  in this limiting case as  $\tilde{h}$ ,  $\tilde{b}$ ,  $\tilde{q}^s$ , and  $\tilde{q}^b$ , and we let  $\tilde{z} = (\tilde{h}, \tilde{b})$ .<sup>21</sup>

Next we denote by  $H(\tilde{z}, \varepsilon^*)$ ,  $U(\tilde{z}, \varepsilon^*)$ ,  $B(\tilde{z}, \varepsilon^*)$ , and  $R(\tilde{z}, \varepsilon^*)$  the value functions of different agents in the economy when uncertainty is realized and the realized utility of owning a home is  $\varepsilon^*$ . These values are computed using the same methods we used to compute utilities for the transitions dynamics case in Section III. Then we define

$$\bar{V}^j = \sum_{\varepsilon^* \in \Phi} f^j(\varepsilon^*) V(\tilde{z}, \varepsilon^*), \quad (\text{C35})$$

where  $V$  represents  $H$ ,  $U$ ,  $B$ , or  $R$ . With this different definition of  $\bar{V}^j$  in place and using  $\tilde{q}^s$  and  $\tilde{q}^b$  in place of  $q^s$  and  $q^b$ , we can solve for the limiting value functions

<sup>21</sup> In solving the model for case 2 we have to make a minor modification to the matching technology and write it as

$$m_t = \min\{\mu \text{Sellers}_t^\alpha \text{Buyers}_t^{1-\alpha}, \text{Sellers}_t, \text{Buyers}_t\}.$$

This ensures that the probabilities of buying and selling are bounded between zero and one. In solving case 1 we found that these constraints never bind. In case 2, in the limiting case,  $\tilde{q}^s = 1$ .

and reservation prices of different agents along a path in which uncertainty is not resolved using equations (C22)–(C29). Since, in the limit, all agents are optimistic, the expressions for average prices are

$$\mathcal{P}^{bj} = \theta \bar{\mathcal{P}}^{bj} + (1 - \theta) \bar{\mathcal{P}}^{u,o}, \quad (\text{C36})$$

$$\mathcal{P}^{rj} = \theta \bar{\mathcal{P}}^{rj} + (1 - \theta) \bar{\mathcal{P}}^{u,o}, \quad (\text{C37})$$

$$\mathcal{P}^i = \theta \frac{[\tilde{b} + \lambda(1 - k - \tilde{b})] \bar{\mathcal{P}}^{b,o} + (1 - \lambda)(1 - k - \tilde{b}) \bar{\mathcal{P}}^{r,o}}{1 - k} + (1 - \theta) \bar{\mathcal{P}}^{u,j}, \quad (\text{C38})$$

$$\mathcal{P} = \mathcal{P}^o. \quad (\text{C39})$$

## References

- Acemoglu, Daron, Victor Chernozhukov, and Muhamet Yildiz. 2007. "Learning and Disagreement in an Uncertain World." Manuscript, Dept. Econ., Massachusetts Inst. Tech.
- Ambrose, Brent W., Piet Eichholtz, and Thies Lindenthal. 2013. "House Prices and Fundamentals: 355 Years of Evidence." *J. Money, Credit, and Banking* 45 (2–3): 477–91.
- Andrei, Daniel, and Julien Cujean. 2013. "Information Percolation in Centralized Markets." Manuscript, Anderson School Management, Univ. California, Los Angeles.
- Bansal, Ravi, and Amir Yaron. 2004. "Risks for the Long Run: A Potential Resolution of Asset Pricing Puzzles." *J. Finance* 59 (4): 1481–1509.
- Barlevy, Gadi, and Jonas D. M. Fisher. 2010. "Mortgage Choices and Housing Speculation." Working Paper no. 2010-12, Fed. Reserve Bank Chicago.
- Bernoulli, Daniel. 1766. "Essai d'une nouvelle analyse de la mortalité causée par la petite vérole, et des avantages de l'inoculation pour la prévenir." In *Mémoires de mathématique et de physique*, 1–45. Paris: Académie Royale des Sciences.
- Brown, Jeffrey R., Zoran Ivković, Paul A. Smith, and Scott Weisbenner. 2008. "Neighbors Matter: Causal Community Effects and Stock Market Participation." *J. Finance* 63 (3): 1509–31.
- Case, Karl E., and Robert J. Shiller. 2010. "What Were They Thinking? Home Buyer Behavior in Hot and Cold Markets." Working paper (May), Yale Univ.
- Case, Karl E., Robert J. Shiller, and Anne K. Thompson. 2012. "What Have They Been Thinking? Home Buyer Behavior in Hot and Cold Markets." *Brookings Papers Econ. Activity* 2012 (2): 265–98.
- Chu, Yongqiang. 2014. "Credit Constraints, Inelastic Supply, and the Housing Boom." *Rev. Econ. Dynamics* 17 (1): 52–69.
- Diba, Behzad T., and Herschel I. Grossman. 1987. "On the Inception of Rational Bubbles." *Q.J.E.* 102 (3): 697–700.
- Dietz, Klaus, and J. A. P. Heesterbeek. 2002. "Daniel Bernoulli's Epidemiological Model Revisited." *Math. Biosciences* 180 (1–2): 1–21.
- Duffie, Darrell, Gaston Giroux, and Gustavo Manso. 2010. "Information Percolation." *American Econ. J.: Microeconomics* 2 (1): 100–111.
- Duffie, Darrell, and Yeneng Sun. 2007. "The Existence of Independent Random Matching." *Ann. Appl. Probability* 17 (1): 386–419.
- Duflo, Esther, and Emmanuel Saez. 2002. "Participation and Investment Decisions in a Retirement Plan: The Influence of Colleagues' Choices." *J. Public Econ.* 85 (1): 121–48.

- Dumas, Bernard, Alexander Kurshev, and Raman Uppal. 2009. "Equilibrium Portfolio Strategies in the Presence of Sentiment Risk and Excess Volatility." *J. Finance* 64 (2): 579–629.
- Eitrheim, Øyvind, and Solveig K. Erlandsen. 2004. "House Price Indices for Norway 1819–2003." In *Historical Monetary Statistics for Norway, 1819–2003*, edited by Øyvind Eitrheim, Jan T. Klovland, and Jan F. Qvigstad. Occasional Paper no. 35/2004. Oslo: Norges Bank.
- Geanakoplos, John. 2010. "The Leverage Cycle." *NBER Macroeconomics Ann.* 24:1–66.
- Gentzkow, Matthew, and Jesse Shapiro. 2011. "Ideological Segregation Online and Offline." *Q.J.E.* 126 (4): 1799–1839.
- Glaeser, Edward L., and Joseph Gyourko. 2006. "Housing Dynamics." Working Paper no. 12787, NBER, Cambridge, MA.
- Glaeser, Edward L., Joseph Gyourko, and Raven E. Saks. 2005. "Why Have Housing Prices Gone Up?" *A.E.R.* 95 (2): 329–33.
- Hansen, Lars Peter, John Heaton, and Nan Li. 2008. "Consumption Strikes Back? Measuring Long-Run Risk." *J.P.E.* 116 (2): 260–302.
- Harrison, J. Michael, and David M. Kreps. 1978. "Speculative Investor Behavior in a Stock Market with Heterogeneous Expectations." *Q.J.E.* 92 (2): 323–36.
- Holmans, Alan. 1995. "Where Have All the First-Time Buyers Gone? Estimating the First-Time Buyer Population in the United Kingdom." *Housing Finance* 25 (February): 7–13.
- Hong, Harrison, Jeffrey D. Kubik, and Jeremy C. Stein. 2005. "Thy Neighbor's Portfolio: Word-of-Mouth Effects in the Holdings and Trades of Money Managers." *J. Finance* 60 (6): 2801–24.
- Kaustia, Markku, and Samuli Knüpfer. 2008. "Do Investors Overweight Personal Experience? Evidence from IPO Subscriptions." *J. Finance* 63 (6): 2679–2702.
- Kelly, Morgan, and Cormac Ó Gráda. 2000. "Market Contagion: Evidence from the Panics of 1854 and 1857." *A.E.R.* 90 (5): 1110–24.
- Kermack, William O., and Anderson G. McKendrick. 1927. "A Contribution to the Mathematical Theory of Epidemics." *Proc. Royal Soc. London, Ser. A, Containing Papers of a Mathematical and Physical Character* 115 (772): 700–721.
- McPherson, Miller, Lynn Smith-Lovin, and James M. Cook. 2001. "Birds of a Feather: Homophily in Social Networks." *Ann. Rev. Sociology* 27:415–44.
- Mullainathan, Sendhil, and Andrei Shleifer. 2005. "The Market for News." *A.E.R.* 95 (4): 1031–53.
- Piazzesi, Monika, and Martin Schneider. 2009. "Momentum Traders in the Housing Market: Survey Evidence and a Search Model." *A.E.R.* 99 (2): 406–11.
- Price, Paul C., and Eric R. Stone. 2004. "Intuitive Evaluation of Likelihood Judgment Producers: Evidence for a Confidence Heuristic." *J. Behavioral Decision Making* 17 (1): 39–57.
- Quigley, John M., and Steven Raphael. 2005. "Regulation and the High Cost of Housing." *A.E.R.* 95 (2): 323–28.
- Saiz, Albert. 2010. "The Geographic Determinants of Housing Supply." *Q.J.E.* 125 (3): 1253–96.
- Scheinkman, José A., and Wei Xiong. 2003. "Overconfidence and Speculative Bubbles." *J.P.E.* 111 (6): 1183–1219.
- Snizekf, Janet A., and Lyn M. Van Swol. 2001. "Trust, Confidence, and Expertise in a Judge-Advisor System." *Org. Behavior and Human Decision Processes* 84 (2): 288–307.
- Stein, Jeremy. 1995. "Prices and Trading Volume in the Housing Market: A Model with Down-Payment Effects." *Q.J.E.* 110 (2): 379–406.

- Sunstein, Cass. 2001. *Republic.com*. Princeton NJ: Princeton Univ. Press.
- Vissing-Jørgensen, Annette. 2003. "Perspectives on Behavioral Finance: Does 'Irrationality' Disappear with Wealth? Evidence from Expectations and Actions." *NBER Macroeconomics Ann.* 18:139–94.
- Zeira, Joseph. 1999. "Informational Overshooting, Booms, and Crashes." *J. Monetary Econ.* 43 (1): 237–57.

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