Understanding Booms and Busts in Housing Markets*

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Abstract

We develop a model of booms and busts in house prices. Agents have heterogeneous expectations about long-run fundamentals. The model allows for "social dynamics" in the sense that agents meet randomly and those with tighter priors are more likely to convert other agents to their beliefs. These dynamics produce a rise an fall in the fraction of the population that believes buying a home is a good investment. The model can account for key features of the recent boom-bust cycle in U.S. housing prices.

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1. Introduction

There are numerous episodes in which real estate prices undergo a protracted boom. In some cases these booms are followed by protracted busts. In other cases, protracted booms lead to seemingly permanently higher house prices. Models in which agents have homogeneous expectations can generate large differences in house prices across steady states with different fundamentals such as borrowing constraints, income growth, demographics, transactions costs, and zoning (see e.g. Chu (2009)). However, it is difficult to generate protracted price movements in models with homogeneous expectations because expected changes in future fundamentals are quickly capitalized into prices. Booms and busts can be generated by assuming that agents first receive increasingly positive signals about future fundamentals and then increasingly negative signals. But the problem with this approach is that for many episodes it is difficult to find *observable* fundamentals that are correlated with house price movements.

In this paper we develop a model that generates protracted booms as well as booms-bust episodes. The model has three key features. First, there is uncertainty about the long-run fundamentals that drive house prices. This feature of the model is related to the literature on long-run risk (Bansal and Yaron (2004), Hansen, Heaton, Li (2008)).

Second, as in Harrison and Kreps (1976), Scheinkman and Xiong (2003), Acemoglu, Chernozhukov, and Yildiz (2007), and Geanakoplos (2010), agents in the economy have heterogenous beliefs about fundamentals. They can update their priors in a Bayesian fashion. But the data do not convey useful information about long-run fundamentals, so the priors of different agents remain constant over time. In other words, agents agree to disagree and this disagreement persists over time. We use the entropy of an agent's probability distribution of future fundamentals to measure the uncertainty of this agent's views.

The third feature of the model is an element which 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 assume that when agent i meets agent j, the probability that agent i adopts the priors of agent j is proportional to the relative entropy of the two priors. 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 diseases models proposed by Bernoulli (1766) and Kermack and McKendrick (1927). By creating a rise and fall in the number of people who believe that buying a house is a good investment, the model generates a boom-bust cycle. Average home prices rise and then fall as the infection waxes and wanes. In addition, the number of transactions is positively correlated with the average home price. 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.

The paper is organized as follows. In Section 2 we provide some empirical background about the nature of housing booms and busts. In Section 3 we describe the social dynamics model and its implications for the behavior of housing prices. We do so in a frictionless model of the housing market. This model illustrates the potential of social dynamics to generate boom-bust patterns. However, the model requires a large number of infected agents to generate a boom-bust pattern in housing prices.

In Section 4 we describe a simple matching model and describe its transition dynamics. In Section 5 we incorporate social dynamics into the matching model. Section 6 concludes.

2. Boom-bust cycles in housing prices: background evidence

In this section we document some key empirical regularities about boom-bust cycles in housing prices using aggregate time series for different countries. Our evidence complements the already extensive literature that uses microeconomic data to analyze particular boom-bust episodes (see e.g. Mian and Sufi (2010) and Barlevy and Fisher (2010)).

An operational definition of a boom or a bust requires that we define turning points where upturns and downturns in housing 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 housing prices. Also let x_t denote the centered-moving average of y_t, $x_t = \sum_{j=-n}^{n} y_{t+j}$. 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 $n = 5$ and $z = 0.15$ but the findings are not sensitive to small changes in these parameters.

We implement our procedure using OECD data on quarterly real house prices for 18 countries from 1970 to 2009.[1] These indices have been normalized so that all countries have a mean value of 100. Figure 1 displays the data. Three features of these data are worth noting. First, every country in our sample experienced housing price booms and busts.[2] The median size of a boom and bust is 54 and 29 percent, respectively. Second, booms and busts occur over protracted periods of time. The median length of booms and busts in our sample is $6\frac{1}{4}$ years and 5 years, respectively. Third, in many cases booms are followed by protracted busts. But not always: in 26 out of 49 boom episodes a boom is *not* followed by a bust.[3] A successful theory should recognize this fact.

3. Social dynamics in a frictionless model

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

The model economy The model economy is populated by a continuum of agents with measure one. All agents have linear utility and discount utility at rate β. Agents are either homeowners or renters. We assume that each agent can only own one house and that there is no short-selling. The first assumption, which we discuss below, is made for simplicity. The second assumption is motivated by the fact that in practice it is not possible to short sell houses. This characteristic of houses distinguishes it from other asset classes, such as stocks, which are easier to short sell.

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.[4] 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.

[1] While our data spans the last four decades, booms-bust episodes in housing prices are a much older phenomenon. Ambrose, Eichholtz, Lindenthal (2010) document the existence of such episodes in Holland over a period of four centuries. Similarly, Eitrheim and Erlandsen (2004) provide analogous evidence for Norway over a period of two centuries.

[2] Australia and Germany only experienced booms and a bust, respectively.

[3] This fraction is almost certainly affected by the fact our sample ends in 2009 and so misses part of the ongoing declines in home prices.

[4] See, e.g. Glaeser, Gyourko, and Saks (2005), Quigley and Raphael (2005), and Barlevy and Fisher (2010).

The momentary utility associated with owning and renting a house is ε^h and ε^r, respectively.

We first consider the equilibrium of the economy when there is no uncertainty. Agents decide at time t whether they will be renters or home owners 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. He lives in the home at time $t+1$ and receives an utility flow ε^h. He can then 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, housing prices must satisfy the following equation:

$$-P_t + \beta\left(P_{t+1} + \varepsilon^h\right) = \beta\left(\varepsilon^r - w\right). \tag{3.1}$$

The stationary solution to this equation is:[5]

$$P = \beta\frac{\varepsilon}{1-\beta}, \tag{3.2}$$

where $\varepsilon = \varepsilon^h - (\varepsilon^r - w)$.

We now consider an experiment that captures the effects of infrequent changes in the value of housing fundamentals. For concreteness we focus on the utility of owning a home, but the analysis could easily be extended to a much broader list of fundamentals. Suppose that before time zero the economy is in a steady state with no uncertainty, so $P_t = P$. At time zero agents learn that, with small probability ϕ, the value of ε will change permanently to a new level ε^*. Agents agree about the value of ϕ but disagree about the probability distribution for ε^*. Agents do not receive information that is useful for updating their priors about the distribution of ε^*.[6] As soon as uncertainty is resolved agents become homogeneous in terms of their beliefs.

Prior to the resolution of uncertainty agents fall into three categories depending on their priors about ε^*. Borrowing from the terminology used in the epidemiology literature we refer to these agents as "infected," "cured," and "vulnerable." We denote by i_t, c_t, and v_t the time t fraction of infected, cured and vulnerable agents, respectively. Agent types are indexed by $j = i, c, v$ and are assumed to be publicly observable. Priors are common knowledge, so higher-order beliefs play no role in our model. The laws of social dynamics described

[5] It is well known that there are explosive rational bubble solutions to equation (3.1) (see e.g. Diba and Grossman (1988)). We abstract from these solutions in our analysis.

[6] If agents disagreed about ϕ they would update their priors about ϕ because they observe whether the event occurs or not. We abstract from this source of uncertainty to focus our analysis on the importance of social dynamics.

below are public information. Agents take into account future changes in the fraction of the population that holds different views.

The new value of the flow utility of owning a home, ε^*, is drawn from the set Φ. 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 Φ.

We assume that at time zero there is a very small fraction of cured and infected agents. Almost all agents are vulnerable, i.e. they have diffuse priors about future fundamentals. Infected agents expect an improvement in fundamentals:

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

Cured and vulnerable agents do not expect fundamentals to improve:

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

For now we assume that agents do not take into account that they might change their views as a result of social interactions. This assumption rules out the possibility that agents might take actions that are optimal only because they might change their type in the future. For example, a cured agent might buy a home even though this action is not optimal given his current priors. Instead, he takes this action in anticipation of the possibility that he might become infected in the future. We return to this issue at the end of this section.

We use the entropy of the probability distribution $f^j(\varepsilon^*)$ to measure the uncertainty of an agents' views,

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

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

Agents meet randomly at the beginning of the period. When agent l meets agent j, the high-entropy agent adopts the priors of the low-entropy agent with probability γ_{lj}. The value of γ_{lj} depends on the ratio of the entropies of the agents' pdfs:

$$\gamma_{lj} = \max(1 - e^l/e^j, 0). \tag{3.3}$$

We adopt this assumption 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. Price and Stone (2004) and Sniezek and Van Swol (2001)).

To simplify, we assume that the pdfs of infected and cured agents are different but have the same entropy, $e^i = e^c$. So, when infected and cured agents meet, neither agent changes his view about long-run fundamentals. We assume that vulnerable agents have uniform priors, so that,

$$e^v > e^c = e^i.$$

When a vulnerable agent meets an infected or cured agent he is converted to their views with probability:

$$\gamma = 1 - e^i/e^v = 1 - e^c/e^v.$$

There are $i_t v_t$ encounters between infected and vulnerables at time t.[7] As a result of these encounters, $\gamma i_t v_t$ vulnerable agents become infected. There are $c_t v_t$ encounters between cured and vulnerables at time t. As a result of these encounters, $\gamma c_t v_t$ vulnerable agents become cured. For now we assume that with a very small probability $\delta_i > 0$, infected agents become cured. This assumption allows us to generate "fads," that is scenarios in which the number of infected agents rises for a period of time but then peaks and declines towards zero.

To see how the model generates a fad, suppose that initially a large fraction of the population is vulnerable, so $\gamma v_t > \delta_i$. Also, consider a path of the economy in which uncertainty is not realized. Along this path the number of infected agents rises over time as more vulnerable agents become infected (see equation (3.4)). The number of vulnerable agents falls over time as some of these agents become infected and others become cured (see equation (3.6)). Eventually, $\gamma v_t < \delta_i$. At this point the fraction of infected agents begins to fall. It follows from equation (3.5) that, when $\delta_i > 0$ all agents in the economy become cured as $t \to \infty$.

The fraction of the population with different views evolves according to:

$$i_{t+1} = i_t + \gamma i_t v_t - \delta_i i_t, \tag{3.4}$$

$$c_{t+1} = c_t + \gamma c_t v_t + \delta_i i_t, \tag{3.5}$$

$$v_{t+1} = v_t - \gamma v_t (c_t + i_t). \tag{3.6}$$

These dynamics are similar to those generated by the models proposed by Bernoulli (1766) and Kermack and McKendrick (1927) to describe the spread of infectious diseases.[8]

[7] See Duffie and Sun (2007) for a law of large numbers that applies to pairwise random meetings.

[8] Bernoulli (1766) used his model of the spread of small pox 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)).

House prices are determined by the marginal buyer. To determine the identity of this buyer we sort agents in declining order of their house valuation. The marginal buyer is the agent who is at the kth percentile of house valuations. When the fraction of infected agents is lower than k for all t, the marginal home buyer is a non-infected 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 (3.2). So, to generate a boom-bust cycle, at least k percent of the agents must be infected at some point in time. We think of k as corresponding to the fraction of agents who own houses. In many industrialized countries k is well above 50 percent. From this perspective the previous model property is clearly a shortcoming in the sense that it requires a massive infection to generate a boom-bust cycle. This shortcoming is one of the prime reasons why we allow for matching frictions in the following sections.

A natural assumption that we use throughout the paper is that the initial number of infected and cured agents is identical: $i_0 = c_0$. To describe the social dynamics associated with these initial conditions it is useful to consider the following two economies. In the 'no exogenous cure economy', $\delta_i = 0$. In the 'exogenous cure economy', $\delta_i > 0$. The number of infected agents in the 'no exogenous cure economy' is always greater than the number of infected agents in the 'exogenous cure economy.' In addition, equations (3.5)-(3.6) imply that, when $\delta_i = 0$, $i_t = c_t$. Since $i_t + c_t + v_t = 1$ and v_t is non-negative, the maximum value of i_t is 50 percent. It follows that in the 'exogenous cure economy' an infected agent is never the marginal buyer if $k > 0.50$.

Suppose that the fraction of infected agents rises above k between time t_1 and $t_2 < \infty$. For $t > t_2$ the cured agents are the marginal traders. So, the price is given by:

$$P_t = \beta\varepsilon/(1-\beta), \quad \text{for } t \geq t_2 + 1. \tag{3.7}$$

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 infected agent is the marginal trader between period t_1 and period t_2 we have:

$$P_t = \beta\{\phi[E^i(\varepsilon^* + P^*_{t+1})] + (1-\phi)(\varepsilon + P_{t+1})\}, \quad \text{for } t_1 \leq t \leq t_2.$$

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 non-infected agents are the marginal traders for $t < t_1$, we have:

$$P_t = \beta\{\phi[E^c(\varepsilon^* + P^*_{t+1})] + (1-\phi)(\varepsilon + P_{t+1})\}, \quad \text{for } t < t_1.$$

The following proposition characterizes the equilibrium price path for this model economy.

Proposition 3.1. *The equilibrium price path when uncertainty is not realized is given by:*

$$P_t = \begin{cases} \frac{\beta\varepsilon}{1-\beta} + [\beta(1-\phi)]^{t_1-t}\left[P_{t_1} - \frac{\beta\varepsilon}{1-\beta}\right], & t < t_1, \\ \frac{\beta\phi E^i(\varepsilon^*)/(1-\beta)+\beta(1-\phi)\varepsilon}{1-\beta(1-\phi)} - [\beta(1-\phi)]^{t_2+1-t}\frac{\beta\phi\left[E^i(\varepsilon^*)-\varepsilon\right]}{[1-\beta(1-\phi)](1-\beta)}, & t_1 \leq t \leq t_2, \\ \beta\varepsilon/(1-\beta), & t > t_2. \end{cases}, \tag{3.8}$$

The equilibrium price path when uncertainty is realized is given by:

$$P_t = \frac{\beta\varepsilon^*}{1-\beta}. \tag{3.9}$$

To understand the intuition underlying this proposition 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 infected, cured and vulnerable agents by P_t^i, P_t^v, and P_t^c, respectively. The value of P_t^i is given by:

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

The logic here is that with probability ϕ uncertainty is resolved and the expected value of the house is $\beta E^i(\varepsilon^*)/(1-\beta)$. With probability $1-\phi$ uncertainty is not resolved. In this case the agent derives a one-period utility flow, ε, and values the house at P_{t+1}^i. Since we are deriving the fundamental value under the assumption that the infected agent is always the marginal trader, $P_t^i = P_{t+1}^i = P^i$. Solving for P_t^i we obtain:

$$P^i = \beta\frac{\phi E^i(\varepsilon^*)/(1-\beta) + (1-\phi)\varepsilon}{1-\beta(1-\phi)}. \tag{3.10}$$

Vulnerable and cured agents expect ε^* to be equal to ε, so:

$$P^c = P^v = \beta\frac{\varepsilon}{1-\beta}.$$

Before t_1 the marginal buyer is a vulnerable agent. However, because of social dynamics, if uncertainty is not realized, the marginal buyer at time t_1 is an infected agent. The latter agent is willing to buy the house at a value that exceeds P^v. So the price of a house must reflect this expected capital gain. The size of the capital gain is $P_{t_1} - P^v$. The probability that the capital gain is realized is $(1-\phi)^{t_1-t}$. Since the capital gain occurs in the future it is discounted by β^{t_1-t}. So the expected, discounted capital gain is given by:

$[\beta(1-\phi)]^{t_1-t}(P_{t_1}-P^v)$. Therefore, the price is equal to P^v plus this capital gain, which coincides with the expression in the first line of equation (3.8). Note that the price jumps at time zero from P^v to $P^v+[\beta(1-\phi)]^{t_1}[P_{t_1}-P^v]$ because of the expected capital gains associated with the change in the marginal buyer at time t_1. As long as uncertainty is not realized, the price rises before t_1 reflecting the fact that the expected, discounted capital gain rises at rate $\beta(1-\phi)$.

Between time t_1 and t_2 the marginal buyer is an infected agent. However, because of social dynamics, if uncertainty is not realized, the marginal buyer at time t_2 is a cured agent. The latter agent is willing to buy the house at a price $P^c<P^i$. So the price of a house must reflect this expected capital loss. The size of the capital loss is: P^i-P^v. The probability that the capital loss is realized is $(1-\phi)^{t_2-t}$. Since the capital loss occurs in the future it is discounted by β^{t_2-t}. So the expected, discounted capital loss is given by: $[\beta(1-\phi)]^{t_2-t}(P^i-P^c)$. The equilibrium price is equal to P^i minus this capital loss, which coincides with the expression in the second line of equation (3.8). As long as uncertainty is not realized, the price falls before t_2+1 reflecting the fact that the expected, discounted capital loss rises at rate $\beta(1-\phi)$.

After time t_2+1 there are no more changes in the marginal buyer. So, unless uncertainty is realized, the price remains constant and equal to the fundamental value of a house to a cured agent, P^c. Once uncertainty is realized, agents have homogeneous expectations so all fundamental values coincide and the price of a house is given by equation (3.9).

The previous proposition 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 boom-boom path depending upon when uncertainty is realized and the realization of ε^*. We view this last result as less interesting because of the difficulty of identifying observable fundamentals that covary with house prices.

So far we emphasized the case in which $\delta_i>0$. Recall that if $\delta_i=0$ and the initial number of infected and cured agents is identical ($i_0=c_0$), the fraction of the populations that is cured and infected grow monotonically to the asymptotic value of 50 percent. So, as long as $k<0.5$, and uncertainty is not realized, house prices

Recall that, in this situation, the fractions of the populations that is cured and infected grow monotonically to the asymptotic value of 50 percent. As long as uncertainty is not realized, house prices jump at time zero and then grow monotonically to the asymptotic value given by (3.10). Of course, if certainty is realized prices would either jump or fall depending on the value of ε^*.

A simple numerical example We now consider a simple numerical example that illustrates the properties of the model summarized in the previous proposition. Recall that, to generate a boom-bust cycle, we need at least k percent of the population to be infected at some point in time. By assumption the pdfs of the cured and the infected agents have the same entropy. Also, the initial fraction of cured and infected agents is identical. Since the fraction of infected agents in the population can never exceed 50 percent, the presence of infected agents affects prices only if $k < 0.5$. In the following example we assume that $k = 0.1$.

We use the beta distribution to guide our choice of pdfs over ε^* for the different agents in the economy. This family of continuous distributions, which depends on two parameters, x and y, is very flexible and includes the uniform distribution as a particular case. We denote by x^j and y^j the parameters of the beta distribution of agent j.[9]

To simplify our computations we work with a discrete approximation to the beta distributions defined on a symmetric grid with six points. To compute the probability of each of these points we divide the support of the distribution into six intervals of equal size and compute the integral of the beta distribution over these intervals. The support of the distribution corresponds to the mid points of the different intervals.[10]

We choose the parameters x^j and y^j so that the discretized beta distribution satisfies two properties. First, the expected value of ε^* is the same for cured and vulnerable agents and it is higher for infected agents. Second, the entropy of the pdf is the same for cured and infected agents and it is higher for vulnerable agents. The expected values and entropies associated with the different pdfs are: $E^v(\varepsilon^*) = E^c(\varepsilon^*) = 2.9$, $E^i(\varepsilon^*) = 8.4$, $e^i = e^c = 0.82$, and $e^v = 0.93$. These values of e^i, e^c, and e^v imply that $\gamma = 0.12$.

We think of the time period as one month and choose β so that the annual discount rate is six percent. We assume that $\delta_i = 0.009$ and that there is a very small number of infected and cured natural renters at time zero: $r_0^i = 10^{-5}$, $r_0^c = 10^{-5}$. The remainder of the population is vulnerable. At time zero agents learn that the utility of owning a home

[9] We assume that the support of the distribution is the interval [0 10]. The pdf of infected, cured and vulnerable agents are parameterized by: $x^i = 2.0$, $y^i = 0.25$, $x^c = 9.15$, $y^c = 21.96$, and $x^v = 7.0$, $y^v = 16.8$.

[10] The support is given by : $\varepsilon^* \in \{0.83, 2.50, 4.17, 5.83, 7.50, 9.17\}$.

will change permanently to a new level ε^* with probability $\phi = 1/120$. As we see below a boom-bust pattern emerges over the course of 15 years. Our assumption about ϕ implies that the probability of observing a boom-bust pattern of this sort conditional on an infection starting is roughly 22 percent.

We focus on the evolution of the economy over a time period when uncertainty has not been resolved, i.e. agents have not learned the new level of ε^*. Figure 2 shows the evolution of the fraction of cured, infected and vulnerable agents as well as the path for the equilibrium house price. The fraction of infected agents in the population initially increases slowly. The infection then gathers momentum until the fraction of infected agents peaks at 21 percent in year eight. Thereafter this fraction declines eventually reaching zero. Between periods six and 16 the infected agents are the marginal buyers since they exceed a fraction k percent of the population. The fraction of vulnerable agents falls over time and converges towards zero as these agents become either cured or infected. The fraction of cured agents rises monotonically over time until everybody in the economy is cured. Consistent with the previous proposition Figure 2 shows that the price jumps at time zero and then continues to slowly rise until the infected agent become the marginal trader. Thereafter prices drop rapidly, reverting to the value of the price in the initial steady state.

This model shows the potential of social dynamics to generate boom-bust patterns. However, this frictionless model has three unattractive features. First, to generate a boom-bust cycle, the fraction of agents that are infected must exceed k for at least some period of time. According to the Housing Vacancy Survey of the Bureau of the Census, the average fraction of American households who own homes is 65.4 percent. So, the model requires that a very large fraction of the population become infected. Second, the price rise that occurs at time zero is large relative to the peak rise in prices (13 percent versus 34 percent). Finally, to generate a substantial rise in prices, the infected agents must be the marginal traders for an extended period of time. In this example they are the marginal traders for roughly ten years. The peak percentage rise in prices relative to the steady state is 34 percent. We can reduce the amount of time during which infected agents are the marginal traders by raising the cure rate. The cost of doing so is that the boom in housing prices becomes smaller. For example, if we raise the cure rate, δ, from 0.009 to 0.015 then the infected agents are the marginal traders for only 3.3 years. In this case the peak percentage rise in prices relative to the steady state is only 16 percent.

An alternative interpretation of social dynamics We conclude this section by describing an alternative environment which 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 infected and cured have very sharp priors. Agents that are initially vulnerable have very diffuse priors. All agents receive uninformative private signals. Vulnerable agents have sharp priors that the posteriors of infected and cured agents are the product of initially diffuse priors and very informative signals. So, when a vulnerable agent meets an infected (cured) agent his posterior becomes arbitrarily close to that of the infected (cured) agent. We refer to a vulnerable agent who has a posterior that is very close to that of an infected (cured) agent as infected (cured).

We reinterpret γ_{lj} as the probability that agents of type l meet agents of type j. We assume that $\gamma_{vc} = \gamma_{vi} = \gamma$ and that $\gamma_{ci} = 0$, i.e. cured and infected agents have no social interactions. Under our assumptions the dynamics of the fraction of population with different views are similar to those generated by our model of social dynamics. Our assumptions about γ_{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. 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.

The view of social segmentation embodied in our assumptions about γ_{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 that are likely to confirm their own views. This view 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 (2010) find evidence that people tend to have close social interactions with people who have similar political views.[11]

Internalizing changes in agent type So far we assumed that agents do not take into account that they may change their type as a result of social interactions. Here we assess the quantitative impact of this assumption. As before we focus on the case in which uncertainty is not realized.

[11] These authors focus their analysis on whether the internet is changing the ideological seggregation of online news. They find that there is little evidence that the internet is becoming more seggregated over time.

For $t > t_2$ the marginal trader is a cured agent so the equilibrium price is given by equation (3.7). For $t_1 \leq t \leq t_2$ the marginal trader is an infected agent, so the price is given by:

$$\begin{aligned} P_t &= (1-\delta)\beta\{\phi[E^i(\varepsilon^* + P^*_{t+1})] + (1-\phi)(\varepsilon + P_{t+1})\} + \\ &\quad \delta\beta\{\phi[E^c(\varepsilon^* + P^*_{t+1})] + (1-\phi)(\varepsilon + P_{t+1})\}. \end{aligned}$$

Here the infected agent takes into into account that with probability δ, he might become cured at time $t+1$ and value the house as a cured agent. For $t < t_1$ the vulnerable agent is the marginal trader, so the price is given by:

$$\begin{aligned} P_t &= (1-\gamma i_i)\beta\{\phi[E^c(\varepsilon^* + P^*_{t+1})] + (1-\phi)(\varepsilon + P_{t+1})\} \\ &\quad +\gamma i_t\beta\{\phi[E^i(\varepsilon^* + P^*_{t+1})] + (1-\phi)(\varepsilon + P_{t+1})\}. \end{aligned}$$

Here the vulnerable agent takes into account that, with probability γi_t, he might become infected and value the house as an infected agent. The vulnerable agent might also become a cured agent. But such a change in identity does not affect the agent's valuation because cured and vulnerable agents have the same expectation of ε^*.

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, the maximum value of γi_t in our numerical example is 1.3 percent. So, the quantitative impact of internalizing changes in agent type is small. In following sections we abstract from this effect to simplify our computations.

4. A matching model

We model the housing market using 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 2. The economy is populated by a continuum of agents with measure one. All agents have linear utility and discount utility at rate β. There is a fixed stock of houses, $k < 1$, in the economy 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, home sellers, 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. Home owners and home sellers own homes at time t. In equilibrium all homes are occupied so that:

$$h_t + u_t = k. \tag{4.1}$$

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

$$b_t + r_t = 1 - k. \tag{4.2}$$

We describe the state of the economy by $s_t = \{h_t, b_t\}$. We now discuss the problems faced by the different agents in the economy.

Homeowners A homeowner derives momentary utility ε from his home. The agent's value function, $H(s_t)$, is given by:

$$H(s_t) = \varepsilon + \beta\left[(1-\eta)H(s_{t+1}) + \eta U(s_{t+1})\right]. \tag{4.3}$$

With probability η a homeowner's match with his home goes sour and he becomes a home seller. We denote the value function of a home seller by $U(s_t)$.

Home sellers A home seller sells his home with probability $p(s_t)$. Once the sale occurs, the home seller becomes a natural renter. The home seller's value function is given by:

$$U(s_t) = p(s_t)[P(s_t) + \beta R(s_{t+1})] + [1 - p(s_t)]U(s_{t+1}). \tag{4.4}$$

Here $P(s_t)$ is the expected price received by a home seller and $R(s_t)$ is the value function of a natural renter.

To simplify, we abstract from the transactions costs of selling a home. In addition, we assume that the reservation price of a home seller, $\bar{P}^u$, is an exogenous constant. To ensure that transactions occur in the steady state we require that $\bar{P}^u$ be lower than the steady state reservation price of natural buyers.

Natural home buyers A natural buyer is a renter at time t. He has to choose between renting at $t+1$ or trying to buy a home. His net flow utility from renting is given by $\varepsilon^b - w$

and his value function is given by $B(s_t)$. If he decides to continue renting his value function, $B^{rent}(s_t)$, is given by:

$$B^{rent}(s_t) = \varepsilon^b - w + \beta B(s_{t+1}). \tag{4.5}$$

If he tries to buy a house, he succeeds with probability $q(s_t)$. In this case, he pays a price $P^b(s_t)$ and his continuation utility is that of a home owner $((1-\eta)H(s_{t+1}) + \eta U(s_{t+1}))$. With probability $1 - q(s_t)$, 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, $B^{buy}(s_t)$, is given by:

$$\begin{aligned} B^{buy}(s_t) \quad = \quad & q(s_t)\left\{\varepsilon^b - w - P^b(s_t) + \beta\left[(1-\eta)H(s_{t+1}) + \eta U(s_{t+1})\right]\right\} \\ & + \left[1 - q(s_t)\right] B^{rent}(s_t). \end{aligned} \tag{4.6}$$

The value function of a natural home buyer is given by:

$$B(s_t) = \max[B^{rent}(s_t), B^{buy}(s_t)]. \tag{4.7}$$

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

$$\bar{P}^b(s_t) = \beta\left[(1-\eta)H(s_{t+1}) + \eta U(s_{t+1}) - B(s_{t+1})\right]. \tag{4.8}$$

Natural renters A natural renter is a renter at time t. His net flow utility from renting is given by $\varepsilon^r - w$ and his value function is $R(s_t)$. 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.[12] We choose the value of κ so that it is not optimal for natural renters to buy a house in the steady state.

In each period a fraction λ of natural renters receives 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, $R^{rent}(s_t)$, is given by:

$$R^{rent}(s_t) = \varepsilon^r - w + \beta\left[(1-\lambda)R(s_{t+1}) + \lambda B(s_{t+1})\right]. \tag{4.9}$$

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

[12] Since the fixed cost is paid upfront all home owners are identical. It does not matter whether they used to be natural buyers or natural renters.

If the natural renter tries to buy a house, he succeeds with probability $q(s_t)$. In this case, he pays a price $P^r(s_t)$ and his continuation utility is the same as that of a home owner $((1-\eta)H(s_{t+1})+\eta U(s_{t+1}))$ except that he must pay the fixed cost $\kappa\varepsilon$. With probability $1-q(s_t)$ 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 potential buyer, $R^{buy}(s_t)$, is given by:

$$\begin{aligned} R^{buy}(s_t) &= q(s_t)\left\{\varepsilon^r - w - P^r(s_t) + \beta\left[(1-\eta)H(s_{t+1}) + \eta U(s_{t+1}) - \kappa\varepsilon\right]\right\} \\ &\quad +(1-q(s_t))R^{rent}(s_t). \end{aligned} \tag{4.10}$$

The value function of a natural home buyer is given by:

$$R(s_t) = \max[R^{rent}(s_t), R^{buy}(s_t)]. \tag{4.11}$$

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

$$\bar{P}^r(s_t) = \beta\left[(1-\eta)H(s_{t+1}) + \eta U(s_{t+1})\right] - \beta\left[(1-\lambda)R(s_{t+1}) + \lambda B(s_{t+1})\right] - \kappa\varepsilon. \tag{4.12}$$

Timing The timing of events within a period is as follows. Preference shocks occur in the beginning of the period. With probability η home owners become home sellers. With probability λ natural renters become natural buyers. Transactions occur at the end of the period. A fraction $p(s_t)$ of home sellers sell their home while a fraction $q(s_t)$ of home buyers buy a house.

The laws of motion for the fraction of home owners, home sellers, natural home buyers and natural renters in the population are given by:

$$h_{t+1} = (1-\eta)h_t + q(s_t)\left[(b_t + \lambda r_t)\, J^b(s_t) + r_t(1-\lambda)J^r(s_t)\right], \tag{4.13}$$

$$u_{t+1} = (u_t + \eta h_t)\,(1-p(s_t))\,, \tag{4.14}$$

$$b_{t+1} = (b_t + \lambda r_t)\,[1 - q(s_t)J^b(s_t)], \tag{4.15}$$

$$r_{t+1} = (1-\lambda)r_t[1-q(s_t)J^r(s_t)] + p(s_t)\,(u_t + \eta h_t)\,. \tag{4.16}$$

The matching technology There is a technology that governs matches between buyers and sellers. We define the indicator function $J^b(s_t)$ which takes the value one if it is optimal for natural buyers to buy a house when the state of the economy is s_t and zero otherwise. The indicator function $J^r(s_t)$ is equal to one if it is optimal for natural renters to buy a house when the state of the economy is s_t and is equal to zero otherwise.

Since agents can only own one home, only natural renters and natural buyers can potentially buy homes:

$$\text{Buyers}(s_t) = (b_t + \lambda r_t)\, J^b(s_t) + r_t(1-\lambda)J^r(s_t). \tag{4.17}$$

There is no short selling and homeowners only sell when the match with their home goes sour. It follows that the fraction of the population that are sellers is given by:

$$\text{Sellers}(s_t) = u_t + \eta h_t. \tag{4.18}$$

When a match occurs, the transactions price is determined by generalized Nash bargaining. The bargaining power of buyers and sellers is θ 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, $P^b(s_t)$, is:

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

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

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

The average price received by a home seller, $P(s_t)$, is given by:

$$P(s_t) = \frac{(b_t + \lambda r_t)\, J^b(s_t)P^b(s_t) + r_t(1-\lambda)J^r(s_t)P^r(s_t)}{(b_t + \lambda r_t)\, J^b(s_t) + r_t(1-\lambda)J^r(s_t)}. \tag{4.19}$$

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

$$m(s_t) = \mu \text{Sellers}(s_t)^{\alpha}\text{Buyers}(s_t)^{1-\alpha}. \tag{4.20}$$

The probability of selling ($p(s_t)$) and buying ($q(s_t)$) a house are given by:

$$p(s_t) = m(s_t)/\text{Sellers}(s_t), \tag{4.21}$$

$$q(s_t) = m(s_t)/\text{Buyers}(s_t). \tag{4.22}$$

4.1. Solution Algorithm

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

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 probability of buying and selling and home and the fraction of the different agents in the population, p, q, h, u, b, and r.

We choose the parameter η so that the probability of buying and selling a house coincide in the steady state:

$$p = q.$$

Equations (4.21) and (4.20) imply that $p = \mu$. This fact in conjunction with equations (4.2) and (4.15) imply that the steady state number of natural buyers is given by:

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

The fact that $p = q$ implies that the number of buyers is equal to the number of sellers. Since the only sellers are unhappy home owners and the only buyers in steady state are natural buyers it follows that:

$$u = b.$$

Equations (4.1) and (4.2) imply:

$$h = k - u.$$

$$r = 1 - k - b.$$

The steady state version of equation (4.14) implies that the value of η consistent with $p = q$ is given by:

$$\eta = \frac{\mu u}{(1-\mu)h}.$$

Given the values of p and q we can now solve for the steady-state values of the purchase price, the reservation price of a buyer, and the value functions of the different agents evaluated in the steady state: P, P^b, H, U, B and R. To do so we use the steady state versions of equations (4.3), (4.4), (4.5), (4.6), (4.9), (4.8), and (4.19) and the fact that in the steady state $B = B^{buy}$ and $R = R^{rent}$.

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 S denote all the values of the state variable s_t that occur along the transition path. First, guess that $J^b(s_t) = 1$ and $J^r(s_t) = 0$ for all $s_t \in S$. Second, using the initial conditions $s_0 = \{h_0, b_0\}$ and equations (4.13) through (4.16), compute the sequence of values of h_t, u_t, b_t, and r_t. Third, use equations (4.17), (4.18), (4.21), and (4.22) to compute the values of $p(s_t)$ and $q(s_t)$ for $s_t \in S$. Fourth, assume that: $H(s_T) = H$, $U(s_T) = U$, $B(s_T) = B$, and $R(s_T) = R$. Then use equations (4.3) to (4.12) and (4.19) to solve backwards for $\{H(s_t), U(s_t), B(s_t), R(s_t), P(s_t)\}$ for $t = 1$ to T. Finally, verify whether $J^b(s_t) = 1$ and $J^r(s_t) = 0$ describe the optimal behavior of buyers and sellers along the proposed transition path.

4.2. Experiments

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

An expected improvement in fundamentals We now consider the same experiment that we study in the frictionless model but with homogeneous beliefs. At time zero agents suddenly anticipate that, with probability ϕ, the utility of owning a home rises from ε 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.

Transitional dynamics We now study an experiment that highlights the effect of an exogenous increase in the number of buyers on home prices. The resulting intuition is useful for understanding the results that we obtain when we incorporate social dynamics into the model. 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. We denote by s the steady state value of the state variables: $s = \{b, h\}$ and by $s_0 = \{b_0, h\}$ the time-zero value of the state variables. Equations (4.20), (4.21) and (4.22) imply that the time-zero probability of buying a house is lower than it is in steady state: $p(s_0) < p(s)$. The time-zero probability of selling is higher than it is in steady state: $q(s_0) > q(s)$.

To illustrate the transition dynamics of the model we consider a numerical example based on parameter values summarized in Table 1. We use the same values for β, ω, and ε used in Section 2. We set the stock of houses, k equal to 0.65, which coincides with the average fraction of homeowners in the United States over the period 1965 to 2010. We set ε^r, ε^b, and ω to one. We set η, the probability that a home owner becomes a home seller, to 0.008. This value implies that home owners sell their house on average every 10 years. We choose λ, the probability that a natural renter becomes a natural buyer, so that probability of buying and selling a home are the same in the steady state. The resulting value of λ is 0.02. We set the matching function parameter μ to 1/6. This value implies that the average time to sell a house in the steady state is six months. We set the matching parameter α and the bargaining parameter θ to 0.5 so as to treat buyers and sellers symmetrically. We set the reservation price of the seller to $\bar{P}^u = 1$. This value is lower than the steady state reservation price of natural buyers, so that it is optimal for natural buyers to buy in the steady state. Finally, we set $\kappa = 40$, a value which implies that the steady state utility of a natural renter who buys a home is 28 percent lower than that of a natural home buyer. Our assumptions imply that it is not optimal for natural renters to buy homes in the steady state.

Figure 3 depicts the model's transition dynamics. Home prices are initially high and converge to the steady state from above. In addition, the path for prices and for the number of buyers mirror each other closely. To understand these properties notice that the utility of a home seller converges to the steady state from above ($U(s_{t+1}) > U(s)$), 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.

We now discuss the intuition for why $P(s_t) > P(s)$. Along the transition path only natural buyers want to buy houses, so the transactions price, $P(s_t)$ is given by:

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

Since $\bar{P}^u$ is exogenous, movements in $P(s_t)$ are determined by movements in $\bar{P}^b(s_t)$. Equation (4.8) implies that $\bar{P}^b(s_t)$ is an increasing function of $H(s_{t+1})$ and $U(s_{t+1})$ and a decreasing function of $B(s_{t+1})$. Since $U(s_{t+1})$ is greater than $U(s)$, equation (4.3) implies that $H(s_{t+1}) > H(s)$. In addition, the value function of a natural buyer approaches the steady state from below. The basic reason for why $B(s_{t+1}) < B(s)$ is that the probability of realizing the surplus from buying a home is low along the transition to the steady state $(q(s_t) < q(s))$. Since $H(s_{t+1})$ and $U(s_{t+1})$ are above the steady state and $B(s_{t+1})$ is below its steady state value, it follows from equation (4.8) that the reservation price must be above its steady state value, $\bar{P}^b(s_t) > \bar{P}^b(s)$.

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 value.

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.

5. A matching model with social dynamics

In this section we consider an economy that incorporates the social dynamics described in Section 3 into the model with matching frictions described in Section 4. We use this model to study the same basic experiment considered in Section 3. Suppose that before time zero the economy is in a steady state with no uncertainty. At time zero agents learn that, with a small probability ϕ, the value of ε will change permanently to a new level ε^*. Agents agree about the value of ϕ but disagree about the probability distribution for ε^*. Agents receive no information that is useful for updating their priors about the distribution of ε^*. Once uncertainty is resolved agents become homogeneous in terms of their beliefs. At that point the economy coincides with the one studied in the previous section where the utility of owning a home is ε^*. 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 ε^* depend on whether they are infected, cured or vulnerable. In addition agents can be home owners, home sellers, natural buyers, or natural renters. So, all told there are twelve 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, home sellers, natural home buyers, and natural renters, respectively. The index j denotes whether the agent is infected, cured or vulnerable: $j \in \{i, c, v\}$.

As in Section 3, agents are subject to preference shocks which can turn natural renters into natural buyers and home owners into home sellers. The timing of events within a period is as follows. First, uncertainty about ε^* is realized or not. Second, preference shocks occur. With probability η home owners become home sellers. With probability λ natural renters become natural buyers. Third, social interactions occur and agents potentially change their views. Fourth, transactions occur.

Population dynamics To solve the model we must keep track of the fraction of the different types of agents in the model. To streamline our exposition we focus here on the law of motion for the fraction of natural renters who are vulnerable. In the appendix we describe the population dynamics for the other agents in the economy. The mechanics of these dynamics are similar to those which we now describe.

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 λ of the natural renters become natural buyers,

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

Next, social interactions occur. Recall that the pdf of cured and infected agents have the same entropy. So, conditional on meeting an agent with different views, the probability of an agent becoming infected or cured is the same (γ). It follows that a fraction γc_t of the vulnerable natural renters become cured and a fraction γi_t become infected. Consequently, the fraction of vulnerable natural renters after social interactions is given by:

$$(r_t^v)'' = (r_t^v)' - \gamma\,(r_t^v)'\,c_t - \gamma\,(r_t^v)'\,i_t.$$

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. All of these agents put their homes up for sale but only a fraction $p(s_t)$ succeed in actually selling their home. So the total number of sellers is $p(s_t)\,(u_t^v)''$. These sellers become natural renters. Let $J^{r,v}(s_t)$ 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 s_t and zero otherwise. The number of vulnerable natural renters who try to purchase a home is equal to: $J^{r,v}(s_t)\,(r_t^v)''$. A fraction

$q(s_t)$ of these agents succeed and become natural home owners. So, the number of vulnerable natural renters at the beginning of time $t+1$ is given by:

$$r_{t+1}^v = (r_t^v)'' - q(s_t) J^{r,v}(s_t) \, (r_t^v)'' + p(s_t) \, (u_t^v)'' \, .$$

We now describe the value functions of the different agents in the economy. We begin by displaying the value functions that are relevant after uncertainty about ε^* is realized. We then work backwards and discuss the value functions that are relevant before ε^* is realized.

Value functions after the realization of uncertainty We use upper bars to denote the value functions that apply after the resolution of uncertainty. These value functions depend on the realized value of ε^* and on the state of the economy, s_t. Since the number of home owners adds up to k and the number of renters to $1-k$, we can summarize the state of the economy by using ten of the 12 population fractions:

$$s_t = \{b_t^v, b_t^c, b_t^i, r_t^v, r_t^c, h_t^v, h_t^c, h_t^i, u_t^v, u_t^c\}.$$

Let $\bar{H}(\varepsilon^*, s_t)$, $\bar{U}(\varepsilon^*, s_t)$, $\bar{B}(\varepsilon^*, s_t)$, and $\bar{R}(\varepsilon^*, s_t)$ denote the value function of a home owner, home seller, a natural buyer and a natural renter, respectively. In addition, $P(\varepsilon^*, s_t)$, $P^b(\varepsilon^*, s_t)$, and $P^r(\varepsilon^*, s_t)$ denote the average price received by home sellers, the average price paid by natural home buyers and the average price paid by natural renters, respectively.

The value functions of home owners and home sellers are given by:

$$\bar{H}(\varepsilon^*, s_t) = \varepsilon^* + \beta \left[(1-\eta) \bar{H}(\varepsilon^*, s_{t+1}) + \eta \bar{U}(\varepsilon^*, s_{t+1}) \right] .$$

$$\bar{U}(\varepsilon^*, s_t) = p(s_t)[P(\varepsilon^*, s_t) + \beta \bar{R}(\varepsilon^*, s_{t+1})] + [1 - p(s_t)] \beta \bar{U}(\varepsilon^*, s_{t+1}).$$

We denote by $\bar{B}^{rent}(\varepsilon^*, s_t)$ and $\bar{B}^{buy}(\varepsilon^*, s_t)$ the value function of a natural buyer who rents and buys, respectively. These functions can be written as:

$$\begin{aligned}
\bar{B}^{rent}(\varepsilon^*, s_t) &= \varepsilon^b - w + \beta \bar{B}(\varepsilon^*, s_{t+1}), \\
\bar{B}^{buy}(\varepsilon^*, s_t) &= q(s_t) \{ \varepsilon^b - w - P^b(\varepsilon^*, s_t) + \beta \left[(1-\eta) \bar{H}(\varepsilon^*, s_{t+1}) + \eta \bar{U}(\varepsilon^*, s_{t+1}) \right] \} \\
&\quad + [1 - q(s_t)] \bar{B}^{rent}(\varepsilon^*, s_t).
\end{aligned}$$

The value function $\bar{B}(\varepsilon^*, s_t)$ is given by:

$$\bar{B}(\varepsilon^*, s_t) = \max[\bar{B}^{rent}(\varepsilon^*, s_t), \bar{B}^{buy}(\varepsilon^*, s_t)].$$

We denote by $\bar{R}^{rent}(\varepsilon^*, s_t)$ and $\bar{R}^{buy}(\varepsilon^*, s_t)$ the value function of a natural buyer associated with renting and buying, respectively. These functions can be written as:

$$
\begin{aligned}
\bar{R}^{rent}(\varepsilon^*, s_t) &= \varepsilon^r - w + \beta[(1-\lambda)\bar{R}(\varepsilon^*, s_{t+1}) + \lambda \bar{B}(\varepsilon^*, s_{t+1})], \\
R^{buy}(\varepsilon^*, s_t) &= q(s_t)\{\varepsilon^r - w - P^r(\varepsilon^*, s_t) + \beta\left[(1-\eta)\bar{H}(\varepsilon^*, s_{t+1}) + \eta \bar{U}(\varepsilon^*, s_{t+1}) - \kappa\varepsilon^*\right]\} \\
&\quad + [1-q(s_t)]\bar{R}^{rent}(\varepsilon^*, s_t).
\end{aligned}
$$

In the previous equation we assume that the fixed cost ($k\varepsilon^*$) paid by the natural renter for buying a home is proportional to the realized vale of ε^*. This assumption insures that it is optimal for a natural renter to rent a home in the steady state of the economy regardless of the realized value of ε.

The value function $\bar{R}(\varepsilon^*, s_t)$ is given by:

$$
\bar{R}(\varepsilon^*, s_t) = \max[\bar{R}^{rent}(\varepsilon^*, s_t), \bar{R}^{buy}(\varepsilon^*, s_t)].
$$

Value functions before the realization of uncertainty Let $H^j(s_t)$, $U^j(s_t)$, $B^j(s_t)$, and $R^j(s_t)$ denote the value functions of a type j home owner, home seller, natural buyer and natural renter, respectively. In addition, $P(s_t)$, $P^{b,j}(s_t)$, and $P^{r,j}(s_t)$ denote the average price received by home sellers, the average price paid by natural home buyers and the average price paid by natural renters, respectively.

The expectations operation $E^j\left[V^j\left(s_{t+1}\right)\right]$ denotes the expectation of a generic value function $V^j(s_{t+1})$ based on the pdf of a type j agent:

$$
E^j[V^j(s_{t+1})] = (1-\phi)V^j(s_{t+1}) + \phi \sum_{\varepsilon^* \in \Phi} f^j(\varepsilon^*)\bar{V}(\varepsilon^*, s_{t+1}). \tag{5.1}
$$

Here $\bar{V}(\varepsilon^*, s_{t+1})$ denotes the value function after the realization of uncertainty.

The value functions of a type j home owner and home seller are given by:

$$
H^j(s_t) = \varepsilon + \beta\{(1-\eta)E^j[H^j(s_{t+1})] + \eta E^j[U^j(s_{t+1})]\}, \tag{5.2}
$$

$$
U^j(s_t) = p(s_t)\{P(s_t) + \beta E^j[R^j(s_{t+1})]\} + [1-p(s_t)]\beta E^j[U^j(s_{t+1})]. \tag{5.3}
$$

We denote by $B^{rent,j}(s_t)$ and $B^{buy,j}(s_t)$ the value function of a natural buyer of type j associated with renting and buying, respectively. These functions can be written as:

$$
\begin{aligned}
B^{rent,j}(s_t) &= \varepsilon^b - w + \beta E^j[B^j(s_{t+1})], \qquad (5.4)\\
B^{buy,j}(s_t) &= q(s_t)\{\varepsilon^b - w - P^{b,j}(s_t) + \beta E^j[(1-\eta)H^j(s_{t+1}) + \eta U^j(s_{t+1})]\} \\
&\quad + [1-q(s_t)]B^{rent,j}(s_t).
\end{aligned}
$$

The value function of a type j natural buyer, $B^j(s_t)$, is given by:

$$B^j(s_t) = \max[B^{rent,j}(s_t), B^{buy,j}(s_t)].$$

The reservation price of a natural buyer of type j, $\bar{P}^{b,j}(s_t)$, is given by:

$$\bar{P}^{b,j}(s_t) = E^j \beta[(1-\eta)H^j(s_{t+1}) + \eta U^j(s_{t+1}) - B^j(s_{t+1})]. \tag{5.5}$$

Recall that this price makes the agent indifferent between buying and renting.

We denote by $R^{rent,j}(s_t)$ and $R^{buy,j}(s_t)$ the value function of a type j natural renter who rents and buys, respectively. These functions can be written as:

$$\begin{aligned} R^{rent,j}(s_t) &= \varepsilon^r - w + \beta E^j\{(1-\lambda)R^j(s_{t+1}) + \lambda B^j(s_{t+1})\}, \quad (5.6) \\ R^{buy,j}(s_t) &= q(s_t)\{\varepsilon^r - w - P^{r,j}(s_t) + \beta E^j[(1-\eta)H^j(s_{t+1}) + \eta U^j(s_{t+1}) - \kappa\varepsilon]\} \\ &\quad +[1-q(s_t)]B^{rent,j}(s_t). \end{aligned}$$

The value function of a type j natural renter, $R^j(s_t)$, is given by:

$$R^j(s_t) = \max[R^{rent,j}(s_t), R^{buy,j}(s_t)].$$

The reservation price of a natural buyer of type j, $\bar{P}^{r,j}(s_t)$, is given by:

$$\begin{aligned} \bar{P}^{r,j}(s_t) &= E^j\beta\{(1-\eta)H^j(s_{t+1}) + \eta U^j(s_{t+1}) - \kappa\varepsilon \quad (5.7) \\ &\quad -(1-\lambda)R^j(s_{t+1}) - \lambda B^j(s_{t+1})\}. \end{aligned}$$

Buyers and sellers The number of buyers and sellers is given by:

$$\text{Buyers}(s_t) = \sum_{j=i,c,v} \left(b_t^j + \lambda r_t^j\right) J^{b,j}(s_t) + \sum_{j=i,c,v} r_t^j (1-\lambda) J^{r,j}(s_t). \tag{5.8}$$

$$\text{Sellers}(s_t) = u_t + \eta h_t. \tag{5.9}$$

The number of homes sold is given by equation (4.20). The probability of buying and selling is given by equations (4.21) and (4.22), respectively.

Transactions prices There are six different possible transaction prices. The first three prices arise from a match between a home seller and the three different types of natural buyers:

$$P^{b,j}(s_t) = \theta \bar{P}^{b,j}(s_t) + (1-\theta)\bar{P}^u. \tag{5.10}$$

The remaining three prices arise from a match between a home seller and the three different types of natural renters:

$$P^{r,j}(s_t) = \theta \bar{P}^{r,j}(s_t) + (1-\theta)\bar{P}^{u}. \tag{5.11}$$

The expected price received by a seller, $P(s_t)$ is given by:

$$P(s_t) = \frac{\sum_{j=i,v,c} (b_t^j)'' J^{b,j}(s_t) P^{b,j}(s_t) + \sum_{j=i,v,c} (r_t^j)'' J^{r,j}(s_t) P^{r,j}(s_t)}{\sum_{j=i,v,c} (b_t^j)'' J^{b,j}(s_t) + \sum_{j=i,v,c} (r_t^j)'' J^{r,j}(s_t)}. \tag{5.12}$$

Here $J^{b,j}(s_t)$ is an indicator function that is equal to one if it is optimal for a type j natural buyer to buy a home when the state of the economy is s_t and zero otherwise. Similarly, $J^{r,j}(s_t)$ is an indicator function that is equal to one if it is optimal for a type j natural renter to buy a home when the state of the economy is s_t and zero otherwise.

5.1. Solving the model

In this subsection we describe a solution algorithm to compute the equilibrium of the economy along a path in which uncertainty has not been realized. Given our assumptions about social dynamics all agents eventually become cured. Since $E^c(\varepsilon^*) = \varepsilon$, if the path under consideration converges then it converges to the initial steady of the economy.

We can use that algorithm described in Section 4 to solve for the steady state associated with all possible realizations of ε^* and for the values of the value functions along the transition to the steady state for any initial condition s_t and realized value of ε^*: $\bar{H}(\varepsilon^*, s_t)$, $\bar{U}(\varepsilon^*, s_t)$, $\bar{B}(\varepsilon^*, s_t)$, and $\bar{R}(\varepsilon^*, s_t)$. As in Section 4 we denote by S the set of the values of the state variable s_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 $j = i, c, v$. We choose these conditions so that the fractions of homeowners, home sellers, natural buyers and natural renters are equal to their steady state values. In addition, we assume that all agents are vulnerable except for a small number, ζ, of infected and cured renters: $h_0^v = h$ and $b_0^v = b$, $u_0^v = u$, $r_0^i = r_0^c = \zeta$, and $r_0^v = 1 - 2\zeta$.

Second, we guess values of the indicator functions that summarize the optimal decisions of natural buyers and natural renters, $J^{b,j}(s_t)$ and $J^{r,j}(s_t)$ for all $s_t \in S$. For example, $J^{b,j}(s_t) = 1$ for all j, $J^{r,i}(s_t) = 1$, $J^{r,c}(s_t) = J^{r,v}(s_t) = 0$ for all $s_t \in S$.

Third, we use equations (8.1) through (8.20) in the appendix to compute the path for the fractions of different agents in the population: h_t^v, h_t^c, h_t^i, u_t^v, u_t^c, u_t^i, b_t^v, b_t^c, b_t^i, r_t^v, r_t^c, and

r_t^i.

Fourth, we use equations (4.21), (4.22), (5.8), and (5.9), to compute the values of $p(s_t)$ and $q(s_t)$ for $s_t \in S$.

Fifth, we compute the limiting value of the value function of all agents along the path in which uncertainty is not realized. The system of equations that defines these limiting values is given by equation (8.21)-(8.26) in the appendix.

Sixth, we solve backwards for all the value functions using equations (5.2) to (5.7) and (5.10) to (5.12). As in Section 4 we assume that the economy has reached its steady state at time $T = 2000$. To compute $E^j[V^j(s_{t+1})]$, defined in equation (5.1), where V^j is a generic value function, requires solving the steady state that obtains when uncertainty is realized for each possible value of ε^* and solving backwards from the steady state to obtain $\bar{V}(\varepsilon^*, s_{t+1})$. for each possible value of ε^*. We then use the pdf of agent j over ε^* to compute the expected value of $\bar{V}(\varepsilon^*, s_{t+1})$: $\sum_{\varepsilon^* \in \Phi} f^j(\varepsilon^*)\bar{V}(\varepsilon^*, s_{t+1})$.

Seventh, verify that the initial guesses for the indicator functions $J^{b,j}(s_t)$ and $J^{r,i}(s_t)$ describe the optimal behavior of buyers and sellers along the proposed equilibrium path.

5.2. Quantitative properties of the model

We illustrate the properties of the model using a numerical example based on the same parameters used in Section 4. These parameters are summarized in Table 1. Figure 4 depicts the evolution of the economy along a path in which uncertainty about ε^* is not realized. The first row of Figure 4 depicts the fraction of the total population that is infected, cured and vulnerable. Since the parameters that control social dynamics are the same used in Section 3, the social dynamics are also the same.

The other key features of Figure 4 can be summarized as follows. First, average home prices rise and then fall as the infection waxes and wanes. Strikingly, even though agents have perfect foresight up to the resolution of long-run uncertainty, the initial rise in price is very small (less than one percent). Second, the average price is highly correlated with the total number of potential buyers. Third, the number of transactions is positively correlated with the average home 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 4, movements in the number of potential buyers are the key driver of price dynamics in the model. Over time the total number of these buyers rises from 3.8 percent to a peak value of 9.7 percent of the population. Thereafter the number of potential buyers declines.

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, some natural renters, those who have become infected, want to buy homes. At the peak of the infection roughly nine percent of natural renters are infected and account for thirty percent of potential buyers (see Figure 4). Second, as more buyers enter the market, the average amount of time to purchase a home rises from six to 15 months. At the same time, the average time to sell a home drops from 6 months to 2.5 months. To understand these last results, recall that the probability of buying and selling a home depends on the ratio of buyers to sellers (see equations (4.21)-(4.22)). Other things equal, the inflow of infected 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 home sellers, 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 probability 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 4. The average purchase price is a weighted average of the price paid by four types of agents: infected natural renters and infected, cured and vulnerable natural buyers.

The price paid by each of these agents depends positively on their reservation price (see equations (5.10) and (5.11)). These reservation prices are the difference between the value to that agent of being a home owner and a home buyer (see equations (5.5) and (5.7)). 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 home sellers are high because it takes less time to sell a home. The value functions of home owners are also high because with probability η they become a home seller.

As the infection takes hold 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 4 we see that the highest price is paid by infected natural buyers. These agents derive a high utility from owning a home and have a high expectation of ε^*. The next highest price is paid by cured natural renters. These agents also derive a high utility from owning a home but they have a lower expectation of ε^* than infected natural buyers. Vulnerable and cured natural buyers have the same expectation of ε^* so they pay the same price. Infected natural renters pay the lowest price. On one hand these renters enjoy the house less than the natural buyers. On the other hand they have a higher expectation of ε^* than cured and vulnerable natural buyers. For the case being considered the first effect outweighs the second effect.

The presence of infected natural renters has two effects. Taking the prices paid by other agents as given, the presence of infected natural renters reduces the average price. However, the presence of infected renters increases the number of potential buyers 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.

One way to quantify the importance of the congestion effect is to redo the experiment but not allow infected renters to purchase homes. By construction, in this experiment the probability of buying and selling a home are constant, since the number of potential buyers and sellers are unaffected by the infection. It turns out that the average sale price is virtually unaffected by the infection. The only reason for average prices to go up in this experiment is a rise in the reservation price of infected natural buyers. Recall that this price is the difference between the value of a being a new home owner who is infected $((1-\eta)H^i(s_{t+1})+\eta U^i(s_{t+1}))$ and the value of being an infected natural buyer $(B^i(s_{t+1}))$. The value of becoming a home owner increases if a vulnerable agent becomes infected. But the value of being an infected natural buyer also increases because he has a high expected value of ε^*. In contrast to the situation where the congestion effect is operative, here the probability of buying a home remains constant, so there is no countervailing effect on the infected natural buyers value function. The net result is a small increase in the reservation price of the infected buyer.

What happens when uncertainty is resolved? We now discuss the evolution of prices after uncertainty is resolved. The two graphs in Figure 6 show the average behavior of the price if uncertainty is realized in period five and ten respectively. The blue line depicts the actual house price up to the period when uncertainty is realized. When uncertainty is realized there are six possible price paths that can occur, one for each of the possible realized values of ε^*. The green (red) line shows the average price path that infected (vulnerable/cured) agents expect to occur after uncertainty is realized.

On average infected agents expect prices to rise and cured/vulnerable agents expect prices to fall. Neither agent expects the price to converge immediately to its steady value. The reason is that, when uncertainty is resolved, the number of buyers exceeds its steady state value. For every value of ε^* the transition to the steady state is governed by the transition dynamics of the homogeneous expectations model when the number of potential buyers exceeds its steady state value. As emphasized in Section 4, in that scenario the price converges to its steady state value from above.

If uncertainty is realized in period five, the number of infected natural renters is small and the number of potential buyers is close to its steady state value. As a result, there is only a modest role for transition dynamics and the expected initial price is close to its expected steady state value. If uncertainty is realized in period ten, the number of infected natural renters is large and the number of potential buyers is substantially above its steady state value. As a result, the expected initial price is substantially above its expected steady-state value.

The second graph in Figure 6 helps us understand why a cured or vulnerable natural buyer is willing to buy a house even at the peak of the infection (period ten) when the price of a house 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 a home seller, 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.

Infected agents expect a large capital gain when uncertainty is realized. This expected gain is so large that it induces not only natural buyers but also natural renters to try to purchase a home. Under normal circumstances natural renters would not buy a home. They are willing to engage in speculative behavior because the expected gains from speculation outweigh their disposition to rent rather than buy.

Finally, Figure 6 shows that there is a discontinuous jump up or down in housing 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 can be eliminated if information about long-run fundamentals is gradually revealed.

Interpreting U.S. housing price data We now use our model to interpret the recent housing boom-bust episode in the United States. In the first interpretation we assume that uncertainty about fundamentals is not realized. In the second interpretation we assume that uncertainty is realized in 2007 and agents learn that housing fundamentals will not improve (i.e. $\varepsilon^* = \varepsilon$).

The blue line in Figure 7 displays the inflation-adjusted Case-Shiller house price index (U.S. National Values) normalized to one in the first quarter of 1997. From 1997 to 2006 housing prices rose and at an increasing rate. The percentage logarithmic change in real housing prices over this entire period is 66 percent. The annual logarithmic growth rate of real housing prices rises steadily from three 3 percent in 1998 to 12 percent in 2005. Real house prices start to decline in the second quarter of 2006. By the second quarter of 2010 these prices fall by a total of 41 percent in log-percentage terms.

The solid red line in Figure 7 depicts the implications of the model assuming that the infection begins in the first quarter of 1997 and there is no resolution of uncertainty. The model does quite well at matching the cumulative rise in house prices as well as the increase in growth rates during the boom phase of the cycle. However, the model greatly understates the sharp drop in housing prices that occurs after the peak. No doubt this shortcoming reflects the fact that our model abstracts from financial frictions. As a result the model cannot generate phenomena such as personal bankruptcies, short sales of homes, and foreclosures. Undoubtedly these phenomena played an important role in the bust phase of the recent episode. In fact, the Case-Shiller index includes foreclosure prices as well as regular sales prices. Using data for the state of Massachusetts for the period 1987 to 2008, Campbell, Giglio, and Pathak (2010) estimate that the average discount associated with foreclosures is 27 percent. Sufi (2010) estimates that foreclosures account for 1/3 of the decline in U.S. house prices since 2006. This source of decline in home values is simply not present in our model.

We can generate a substantially larger fall in home prices if we assume that uncertainty about housing fundamentals is resolved at the peak of the housing boom. The dashed red line depicts the model's implication for housing prices after resolution of uncertainty. Now the model only understates the level of real housing in the second quarter of 2010 by nine percent. In light of the results in Campbell et al. (2010) and Sufi (2010) this shortcoming can easily be accounted for the presence of foreclosures in the data.

We are somewhat uncomfortable relying on the assumption that uncertainty is realized at the peak of the boom-bust cycle. Instead, we think that a fully convincing explanation of the rapid decline in housing prices requires a model that incorporates financial frictions into the analysis.

6. 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 with social dynamics. In this model agents have different views about long-run fundamentals. Social interactions can generate temporary increases in the fraction of agents who believe that buying a home is a good investment. The resulting dynamics produce boom-bust cycles in housing prices.

At the core of our model is the notion that booms are associated with new entrants into the market who drive up housing prices. In the model these entrants are renters who would normally not be disposed to buy a house. They do so because they expect large capital gains. This core feature of our model is consistent with evidence that housing booms are accompanied by an influx of new buyers. Data from the American Housing Survey compiled by the U.S. Census Bureau shows that the fraction of homes owned by individuals 25 years old and younger increased from 18 percent in 1997 to 25 percent in 2005. This rise surely reflects an influx of new buyers. Similarly, Ortalo-Magne and Rady (1999) document that there was an influx of first-time buyers during the 1990 housing boom in the U.K.

Our model abstracts from financial frictions. But it is clear to us that the ability of many young buyers to buy a home by downpayment requirements and credit conditions. An implication of our model is that if young buyers are infected but cannot buy a house, say because they are credit constrained, boom-bust cycles in housing prices are greatly muted. Indeed, this situation corresponds to the experiment in our model where we locked out infected natural renters from the housing market. Absent congestion effects there are no pronounced boom-bust cycles. Of course, in our model we cannot say that eliminating boom bust cycles is welfare improving. In the end we do not know who is right about the future, the vulnerable, the cured, or the infected.

7. References

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8. Appendix

In this appendix we describe the laws of motion for the fraction of the population accounted for by the twelve types of agents in the model of Section 4.

Homeowners We denote the fraction of home owners of type j ($j = c, i, v$) in the beginning of the period, after preference shocks occur, after social interactions occur, and after 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:

$$(h_t^j)' = h_t^j(1-\eta), \qquad j = i, c, v, \tag{8.1}$$

$$(h_t^v)'' = (h_t^v)' - \gamma\,(h_t^v)'\,c_t - \gamma(h_t^v)' i_t, \tag{8.2}$$

$$(h_t^c)'' = (h_t^c)' + \gamma\,(h_t^v)'\,c_t + \delta_i h_t^i, \tag{8.3}$$

$$(h_t^i)'' = (h_t^i)' + \gamma\,(h_t^v)'\,i_t - \delta_i h_t^i, \tag{8.4}$$

$$h_{t+1}^j = (h_t^j)'' + q(s_t)J^{b,j}(s_t)(b_t^j)'' + q(s_t)J^{r,j}(s_t)(r_t^j)'', \qquad j = i, c, v. \tag{8.5}$$

Home sellers We denote the fraction of home sellers of type j ($j = c, i, v$) 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:

$$(u_t^j)' = u_t^j + \eta h_t^j, \qquad j = i, c, v, \tag{8.6}$$

$$(u_t^v)'' = (u_t^v)' - \gamma\,(u_t^v)'\,c_t - \gamma(u_t^v)' i_t, \tag{8.7}$$

$$(u_t^c)'' = (u_t^c)' + \gamma\,(u_t^v)'\,c_t + \delta_i u_t^i, \tag{8.8}$$

$$(u_t^i)'' = (u_t^i)' + \gamma\,(u_t^v)'\,i_t - \delta_i u_t^i, \tag{8.9}$$

$$u_{t+1}^j = (u_t^j)'' - p(s_t)(u_t^j)'', \qquad j = i, c, v. \tag{8.10}$$

Natural buyers We denote the fraction of natural buyers of type j ($j = c, i, v$) 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:

$$(b_t^j)' = b_t^j + \lambda r_t^j, \qquad j = i, c, v, \tag{8.11}$$

$$(b_t^v)'' = (b_t^v)' - \gamma\,(b_t^v)'\,c_t - \gamma(b_t^v)' i_t, \tag{8.12}$$

$$(b_t^c)'' = (b_t^c)' + \gamma\,(b_t^v)'\,c_t + \delta_i b_t^i, \tag{8.13}$$

$$(b_t^i)'' = (b_t^i)' + \gamma\,(b_t^v)'\,i_t - \delta_i b_t^i, \tag{8.14}$$

$$b_{t+1}^j = (b_t^j)'' - q(s_t)J^{b,j}(s_t)(b_t^j)'', \qquad j = i, c, v. \tag{8.15}$$

Natural renters We denote the fraction of natural renters of type j ($j = c, i, v$) 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:

$$(r_t^j)' = r_t^j(1 - \lambda), \qquad j = i, c, v. \tag{8.16}$$

$$(r_t^v)'' = (r_t^v)' - \gamma\,(r_t^v)'\,c_t - \gamma(r_t^v)' i_t. \tag{8.17}$$

$$(r_t^c)'' = (r_t^c)' + \gamma\,(r_t^v)'\,c_t + \delta_i r_t^i. \tag{8.18}$$

$$(r_t^i)'' = (r_t^i)' + \gamma\,(r_t^v)'\,i_t - \delta_i r_t^i. \tag{8.19}$$

$$r_{t+1}^j = (r_t^j)'' - q(s_t)J^{r,j}(s_t)(r_t^j)'' + p(s_t)(u_t^j)'', \qquad j = i, c, v. \tag{8.20}$$

Limiting steady state when uncertainty is not realized We denote by $\bar{H}(\varepsilon^*)$, $\bar{U}(\varepsilon^*)$, $\bar{B}(\varepsilon^*)$ and $\bar{R}(\varepsilon^*)$ the steady state of the values function of different agents in the economy when uncertainty is realized and the realized utility of owning a home is ε^*. These values are computed by solving the system of equations (4.3), (4.4), (4.5), (4.6), (4.9), (4.8), and (4.19), setting $B = B^{buy}$ and $R = R^{rent}$ and replacing ε in equation (4.3) with the different possible values of ε^*.

The limiting values of the 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 H^j, U^j, B^j, R^j for $j = i, v, c$ and $\bar{P}^{b,c}$ and P:

$$H^j = \varepsilon + \beta\{(1-\phi)\left[(1-\eta)H^j + \eta U^j\right]) + \phi E^i[(1-\eta)\bar{H}(\varepsilon^*) + \eta\bar{U}(\varepsilon^*)]\}, \tag{8.21}$$

$$U^j = p\{P + \beta[(1-\phi)R^j + \phi E^j\bar{R}(\varepsilon^*)]\} + (1-p)\beta[(1-\phi)U^j + E^j\bar{U}(\varepsilon^*)], \tag{8.22}$$

$$R^j = \varepsilon^r - \omega + \beta(1-\phi)\left[(1-\lambda)R^j + \lambda B^j\right] + \beta\phi E^j\left[(1-\lambda)\bar{R}(\varepsilon^*) + \lambda\bar{B}(\varepsilon^*)\right], \tag{8.23}$$

Recall that in the limit all agents are cured so the price of a home is determined by the reservation price of the natural buyer:

$$\bar{P}^{b,c} = \beta(1-\phi)\left[(1-\eta)H^c + \eta U^c - B^c\right] + \beta\phi E^c\left[(1-\eta)\bar{H}(\varepsilon^*) + \eta\bar{U}(\varepsilon^*) - \bar{B}(\varepsilon^*)\right], \tag{8.24}$$

$$P = \theta\bar{P}^{b,c} + (1-\theta)\bar{P}^u. \tag{8.25}$$

The probability of buying and selling are given by:

$$p = q = \mu. \tag{8.26}$$

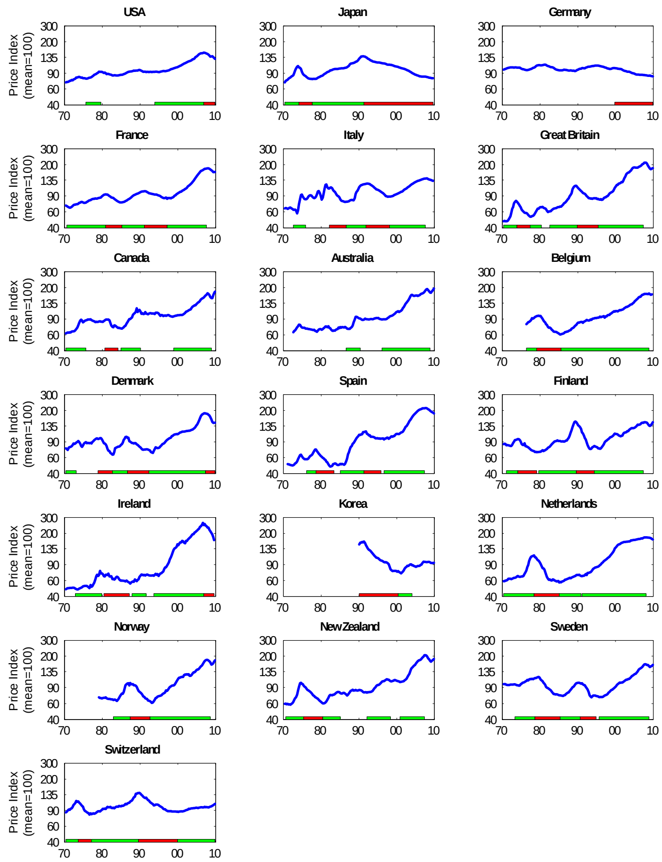


FIGURE 1: Real Home Prices in 18 OECD Countries

Note: Log scale. Mean=100. Green bars indicate real estate booms, red bars indicate real estate busts, as defined in the text.

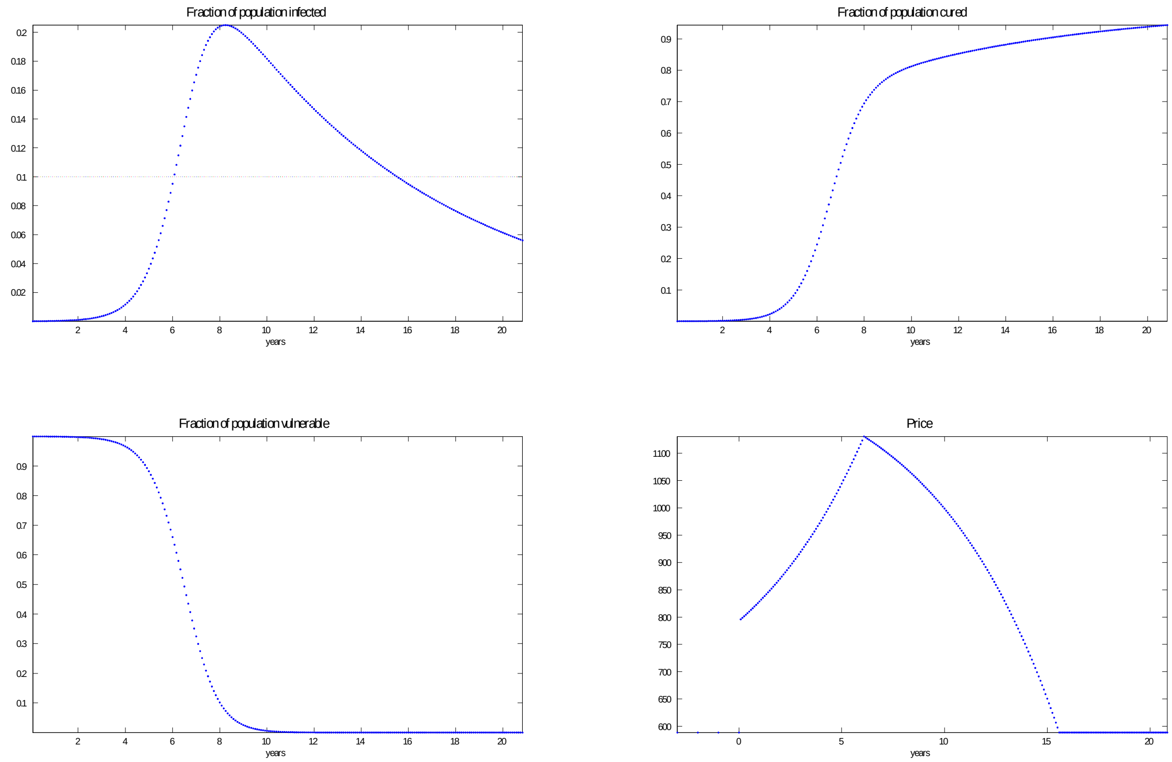


FIGURE 2: Social Dynamics in a frictionless model

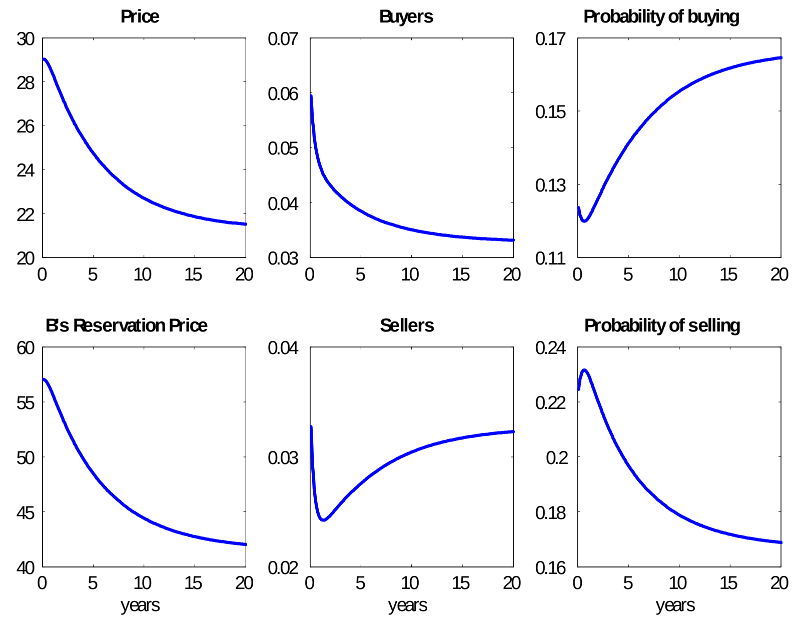
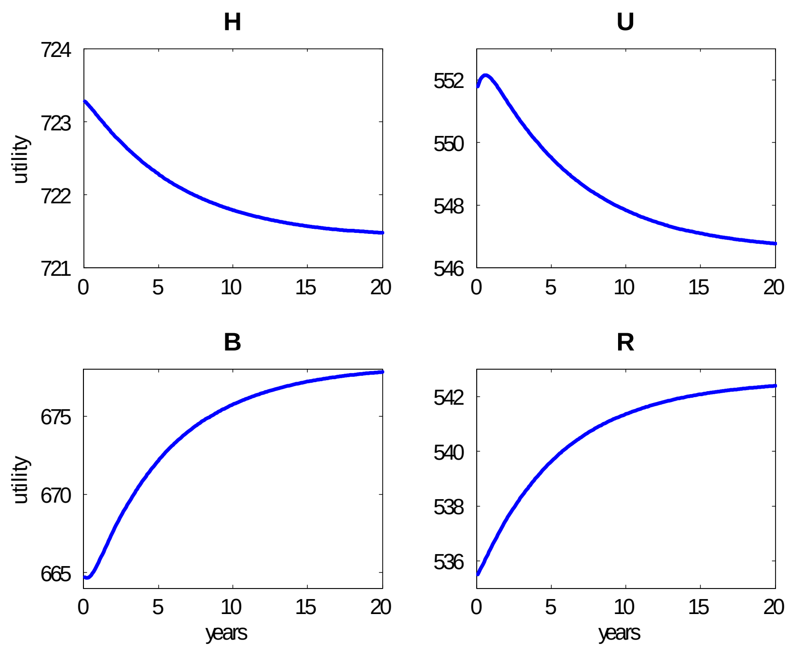


FIGURE 3: Transitional Dynamics in a Matching Model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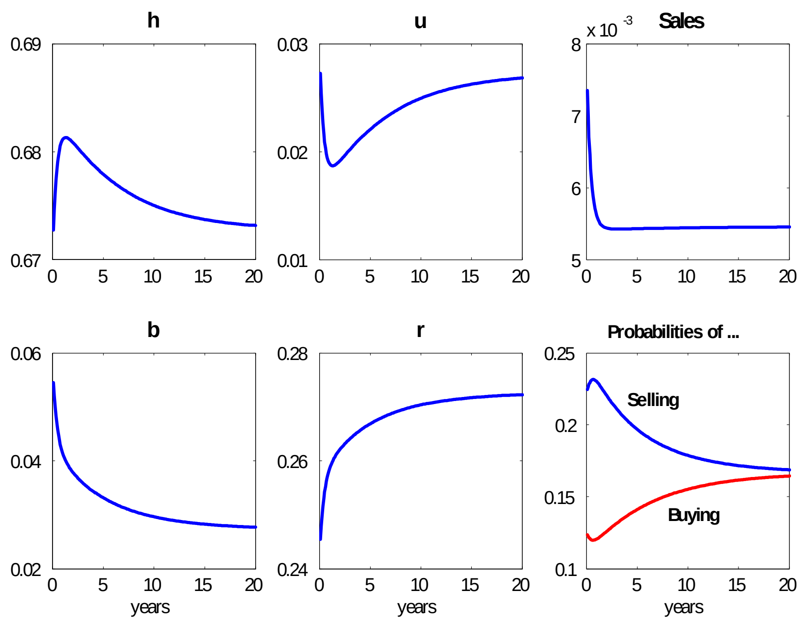
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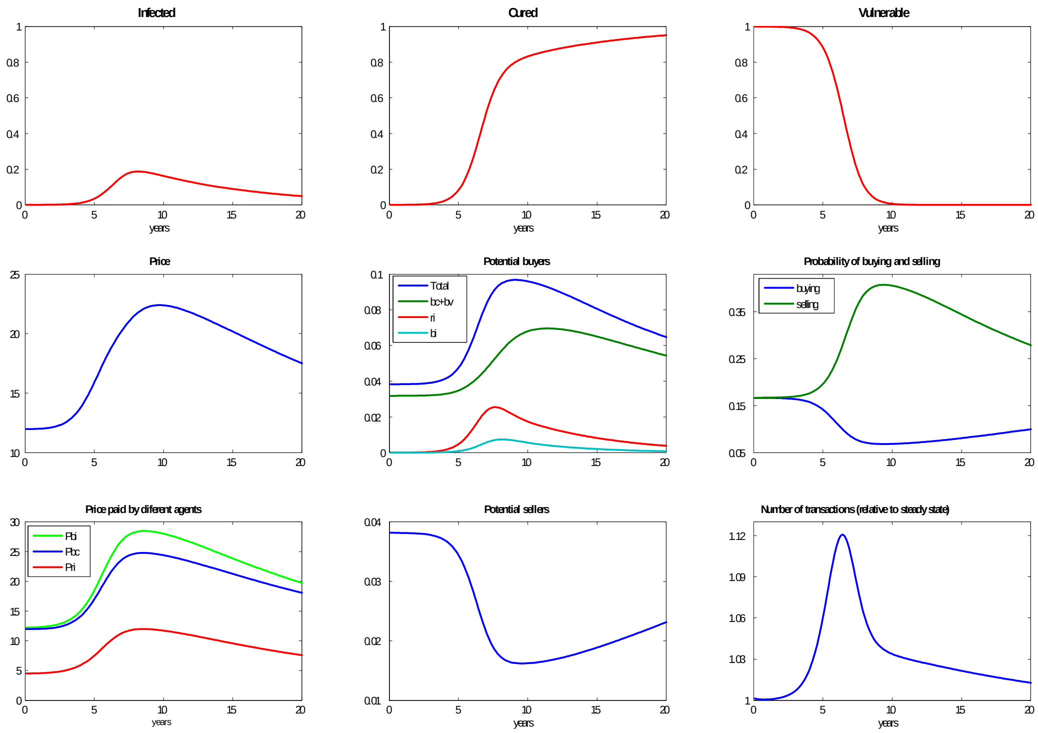

FIGURE 4: A Boom and Bust Cycle in the Model with Social Dynamics

Note: The graphs in the top row show the total populations of infected, cured and vulnerable agents in the model with social dynamics, when there is a shock at date 0 to agents' beliefs. The total population is normalized to 1. The graphs labeled "Buyers" and "Sellers" indicate the populations of agents who attempt to buy or sell in each period. The graphs to the right of these indicate the probabilities with which buyers and sellers meet a match. The graph labeled "Price" shows the average price at which homes sell, while the graph labeled "Different prices" shows the prices at which sellers and buyers of specific types transact.

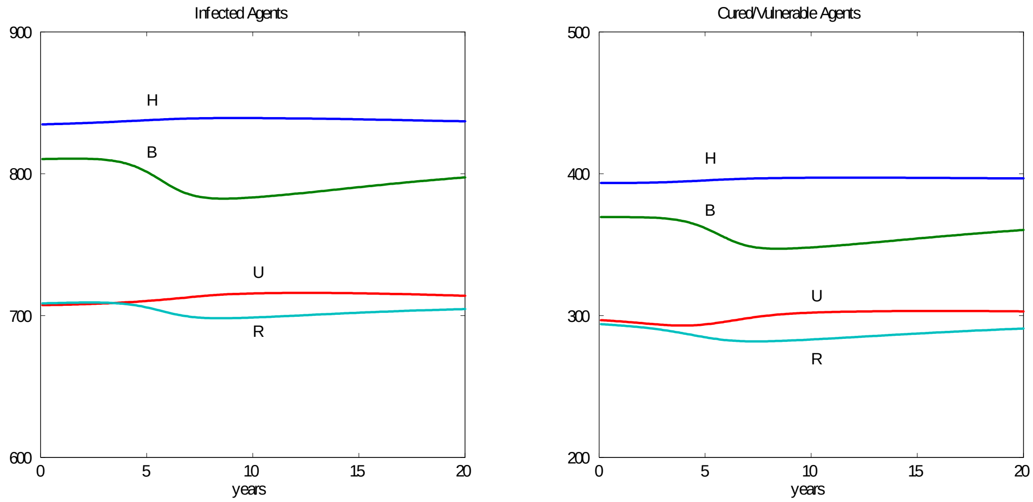

FIGURE 5: Value Functions

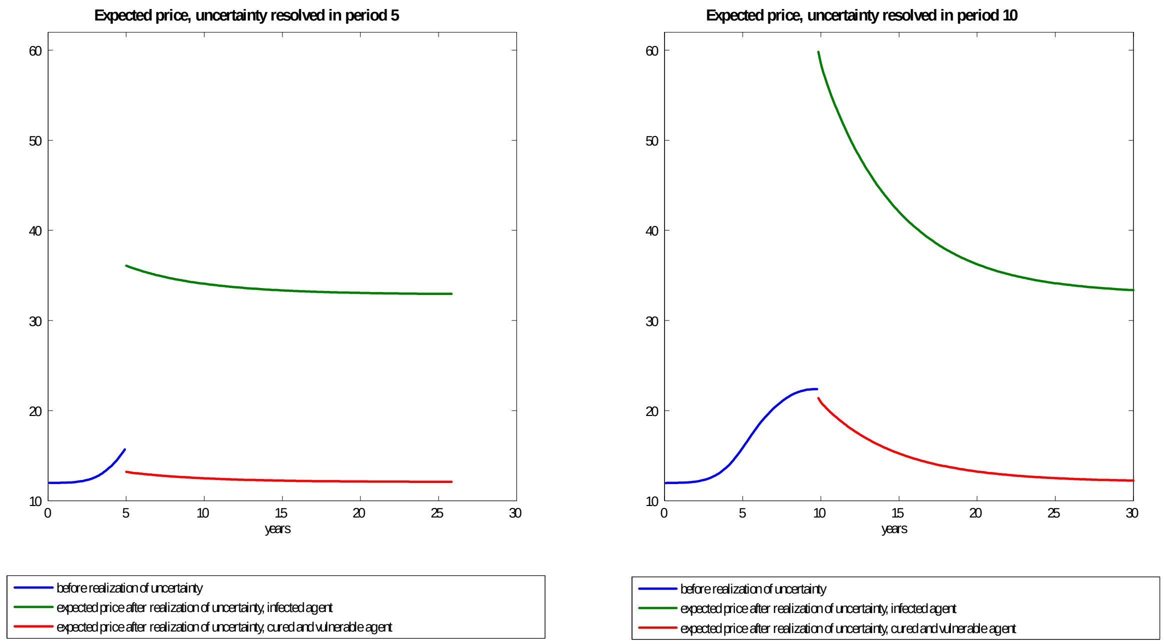

FIGURE 6: Resolution of Uncertainty

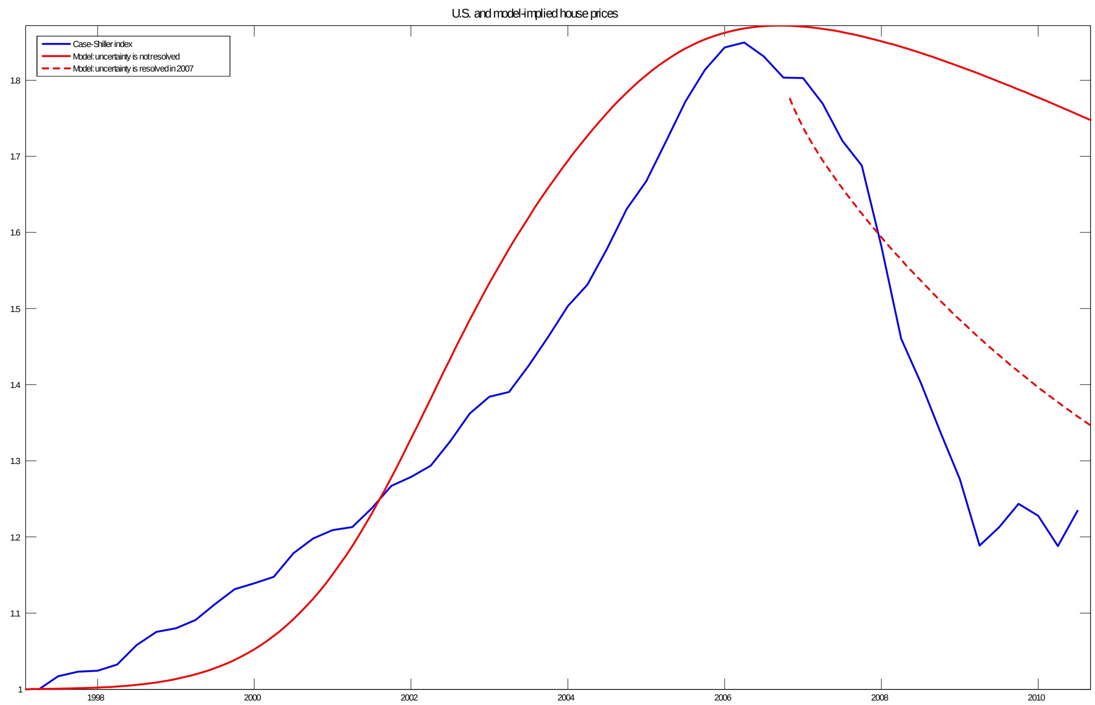

FIGURE 7: Model Experiment and U.S. Data