# House Price Rigidity*

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**Abstract**

This paper develops a novel search-based model of the housing market with price posting by sellers. The approach generates price dispersion and price stickiness – i.e., it is consistent with the observation that some sellers do not adjust their prices when market conditions change, something previous commentators say is puzzling and challenging for standard economic theory. The paper also contributes to the literature on general price dispersion by considering durable goods. The framework is tractable, and parametric cases can be solved explicitly. We also consider variations with bargaining rather than price posting, and directed rather than random search,

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"I don't think anyone wants to argue that house prices are sticky." Stephen Williamson *Sticky Prices and the Keynesian Narrative* (New Monetarist Economics blog, May 8, 2011).

"Home prices are subject to inertia and are sticky downward." Karl E. Case *The Central Role of Home Prices in the Current Financial Crisis: How Will the Market Clear?* (BPEA Fall 2008).

# 1 Introduction

This is an economic theory paper on house prices. It seems to be commonly believed (with exceptions, like Williamson in the epigraph) that they are *sticky*. Genesove and Mayer (2001), e.g., examine data that lead them to conclude that reservation prices are inflexible downward. As they say, "sellers may be unable or unwilling to accept market prices for property in the down part of the cycle." They find this puzzling, and propose that loss aversion can help explain the behavior of list prices, along the lines of Tversky and Kahneman (1991). When house prices fall, they say, "Owners who are averse to losses will have an incentive to attenuate that loss by deciding upon a reservation price that exceeds the level they would set in the absence of a loss, and so set a higher asking price, spend a longer time on the market, and receive a higher transaction price upon a sale," and suggest that sellers are "overly optimistic" in their behavior.[1]

Others make similar comments. Emmerling et al. (2015) suggest that seller behavior is in line with "regret theory" (the utility derived from accepting an offer depends upon the past as well as future forgone offers). Case et al. (2003) say that sellers are reluctant to sell at a price below the "psychological price" at which the property was purchased, even when demand falls drastically. Fabozzi et al. (2009) propose an explanation based on "unrealistic expectations," influenced

[1] To give some details, data from Boston between 1990 and 1997 show that sellers subject to losses set prices that are higher by 25% to 35% of the difference between the expected selling price and their purchase price, and end up with selling at prices 3% to 18% of this difference.

by the most recent observations of prices. See also Eyster et al. (2015) and Levitt and Syverson (2005). In general, these papers can be described as saying house prices look sticky, this is a puzzle, and to understand it we need to deviate from the path provided by standard economic theory using rational expectations and expected utility maximization.

The goal of this paper is to provide a counterpoint. We take it as given that house prices look sticky, and argue that this is *not* inconsistent with the discipline imposed by rational expectations and expected utility maximization, at least once one builds in the realistic frictions captured by rudimentary search theory.

We do this without resort to menu costs, which we think should not be big enough to significantly influence the pricing of such a big-ticket item, even if others think differently. Merlo et al. (2015), e.g., use transaction records for residential property in England to estimate a model with a fixed menu cost of changing price. As they say, "One of the most striking features of the Merlo and Ortalo-Magne [2004] data is that housing list prices appear to be highly (though not completely) sticky."[2] Moreover, "this finding presents a challenge, since the conventional wisdom is that traditional, rational, forward-looking economic theories are unable to explain extreme price stickiness of this sort, unless there are large menu costs associated with price revisions ... [but] this cost is unlikely to be large." Yet they go on to claim "a very small menu cost ... approximately £10 for a home worth £100,000, is sufficient to generate the high degree of list price stickiness observed in the data." Whether one is convinced by their conclusions, it is surely interesting to explore alternative explanations.[3]

[2] To given some more details, 77% of sellers in the UK sample never changed their listed price prior to selling, 18% changed only once, 4% twice, and 1% thrice. Knight (2002) finds something similar for US data.

[3] Merlo et al. (2015) acknowledge that listed prices might be just a starting point for bargaining – i.e., they might be cheap talk – but they do not model this explicitly. However, it better be the case that posted prices mean something – otherwise it would not be much of a puzzle that they are sticky.

Another candidate explanation is learning. However, an analysis of learning in labor markets by Burdett and Vishwanath (1988), where workers do not know the distribution of potential offers in the market, implies reservation wages fall over time, due to selection, rather than stay rigid. So it is not clear that learning really helps here. Taylor (1999) also models information frictions, but instead of sellers, buyers make inferences about houses on the market and sellers try to manipulate this process by pricing strategically.[4] While this is clearly interesting, we are not sure how much it contributes to our understanding of sticky prices. At the same time, we agree with Taylor that modeling the sale of single big durable like a house differs in interesting ways from producers selling repeatedly in the same market.

To summarize the motivation, here is the issue: While loss aversion, regret theory, psychological prices and unrealistic expectations may or may not be features of reality, do we *need* them to explain the facts? An alternative that should be part of the conversation is search theory, which has been successful in accounting for price dispersion and sluggishness in other applications. However, our setup differs from many search-based housing models (see Emmerling et al. 2015 for references), where sellers of houses, like workers in job search theory, sample offers sequentially and decide when to stop. In one version of the model, sellers are more like the firms in Burdett and Judd (1993) or Burdett and Mortensen (1998), posting prices and waiting for random buyers to accept. In another version, they post prices to attract buyers, who use directed search. Both versions capture

[4]Suppose buyers see the history of the house on the market. "A prospective buyer who walks away from a high-priced house conveys little information concerning quality to subsequent consumers who may be interested in it, but a prospective buyer who walks away from a low-priced house transmits a very strong signal regarding his assessment of quality." However, when the price history is unobservable, "high initial prices promote rather than discourages herding. In this case, the seller's optimal policy is to post a low initial price in an effort to sell the house quickly, i.e. before herding commences." This is somewhat related to, e.g., Wolinsky (1983), or Bagwell and Riordan (1991), where pricing behavior in general sends a signal.

some features of housing markets, but to focus on essentials, for the issues at hand, we abstract from many institutional features, including real estate agents, bargaining, etc. – even if we provide some discussion of these below.

A key result the baseline random search model is that there is an endogenous distribution of listed prices, $F(p)$, with support $\mathcal{F} = [\underline{p}, \bar{p}]$, without gaps or mass points, and the expected discounted payoff is the same $\forall p \in \mathcal{F}$. This is not a knife-edge case – it is the unique equilibrium in the pricing game, with $F(p)$ determined so that a seller posting higher $p$ gets a greater surplus from sale, but makes a sale with a lower probability. This then leads to price stickiness. When market conditions change, $F(p)$ and $\mathcal{F}$ respond, but as long as the new and old support overlap, some sellers can leave $p$ the same without sacrificing expected payoff. If, e.g., $\mathcal{F}_t$ shifts down to $\mathcal{F}_{t+1}$, a seller that was low in the support $\mathcal{F}_t$ can stick to the same $p$, even though it is high in the new $\mathcal{F}_{t+1}$, because while the probability of a sale falls, *there is no profitable deviation to a different price.* Something similar happens in the version with directed search.[5]

This proves sticky house prices do not require deviations from rational expectations or expected utility maximization, nor do they require menu costs. This is also discussed, in other contexts, by Head et al. (2013), Liu et al. (2015) and Burdett et al. (2015).[6] While the point here is similar, one needs to amend the standard Burdett-Judd model in several ways to apply it to housing markets, as opposed to retailers repeatedly selling to customers, as in previous applications.

[5] Continuous price distribution is the key to generate sticky prices. Maury and Tripier (2014) show how to generate housing price dispersion with bargaining. Their model leads to discrete price distribution and hence can be difficult to produce price stickiness.

[6] Like our baseline model, those papers use random search as in Burdett-Judd; they do not consider the directed search. Their focus in on generating sticky nominal prices in monetary models without menu costs (somewhat related to earlier work by Caplin and Spulber 1987 and Eden 1994). See Head et al. (2013) for quotations from famous economists from different camps saying that menu costs must be empirically important because many individual prices remain fixed despite continuously changing economic conditions, and that this means money is not neutral. Some of those papers also show the models can account for details in the price change data, as discussed, e.g., by Klenow and Kryvtsov (2008).

When one sells a house in our model, one takes oneself off the market; so there is an opportunity cost to a sale, which is giving up the search for other buyers. Similarly, when one buys a house, there is an opportunity cost of giving up search for a better deal. While reminiscent of the idea in Emmerling et al. (2015), that the utility derived from trading depends upon future forgone offers, we do not need "regret theory" – it is the standard opportunity cost going back to the earliest job search models.

Having buyers and sellers as trade rather infrequently complicates the standard Burdett-Judd models, where sellers can supply as many units as demanded each period, and all agents continue in the same way next period. We want our model to capture the opportunity cost of trade, which is realistic, in that while people who buy or sell a house are not literally off the market forever, they are typically off the market for quite a while. Our setup captures this better than textbook Burdett-Judd theory, yet is still relatively tractable. We also discuss some alternative specifications, including one with bargaining instead of posting, and one with directed rather than random search. The latter, if not the former, also delivers disperse and sticky house prices, although for somewhat different reasons. In that version, ex ante homogeneous sellers coose to cater to different types of buyers, who have different trade-offs between price and the probability of trade. When market conditions change, the distribution of prices changes, but as in the baseline model some sellers can stick to their prices.

The rest of the presentation is organized as follows. Section 2 describes the baseline environment and defines equilibrium. Section 3 works out some examples and describes the effects of parameter changes on the equilibrium. Section 4 takes up the alternative specifications. Section 6 concludes. Some technical results are relegated to the Appendix.

# 2 Model

Time is discrete and continues forever. There is a continuum of buyers with measure $B$ and a continuum of sellers with measure $S$, both of which are fixed, for now. What matters is the seller-buyer ratio, or market tightness for the buyer, $\tau = S/B$. All agents discount the future with factor $\beta = 1/(1+r)$, $r > 0$. Each seller has a single house on the market, while each buyer wants to buy one house. Not all houses are considered the same for a buyer. For simplicity, assume that a buyer either likes a house or does not; in the former case he would get a payoff (expected discounted utility) $u$ if he bought it; in the latter case he would get a payoff of 0. Note that these are idiosyncratic tastes – it is not the case that some houses are better than others; it is simply that one some buyers like house 1 but not house 2, while others like house 2 but not house 1. We realistically assume that after a trade, the buyer and seller exit the market, to be replaced by clones.[7]

At each date $t$, a seller lists a prices $p_t$ for his house. Buyers do not observe all the listings but instead sample from the price distribution, with the CDF denoted $F_t(p)$. In the spirit of Burdett-Judd, each period, a buyer observes $n$ prices of houses that he likes with probability $b_n$, with $\Sigma_{n=0}^{\infty} b_n = 1$ and $\Sigma_{n=0}^{\infty} b_n n = \mathbb{E}n < \infty$. If $n > 1$, he of course prefers the lowest price. Although in principle he may find even the lowest price too high, in equilibrium no seller posts a $p$ that any buyer would refuse. For simplicity, although a buyer can sample more than one seller, we assume a seller is not sampled by more than one buyer at any $t$. This means we do not have to worry about multiple buyers trying to get the same house, in

[7] By way of analogy to a related model, Rubinstein and Wolinsky (1987) develop a search-and-bargaining theory of middlemen in a market where buyers and sellers exit after trade. Nosal et al. (2015) extend that framework, in various ways, but in particular consider the case where buyers and sellers stay on the market forever. This is much easier than the original specification, because the continuation values and outside options cancel (i.e., there is no opportunity cost of trade). It is true here, too, that the model is easier if buyers and sellers stay on the market forever, but that would not be reasonable in a theory of housing markets.

which case it is not clear that the seller should or could commit to the posted price, as discussed in different contexts by, e.g., Julien et al. (2000,2008). Or course, we have the restriction $\mathbb{E}n \leq \tau$, since the LHS is the average number of sellers sampled by a buyer.

With probability $s_n$ a given seller has a buyer that sees $n$ houses he likes that period, including the one of the given seller. It is not hard to see that $\tau s_n = nb_n$. The seller gets a flow utility normalized to 0 from his house while it is on the market, and gets a surplus $p - c$ in the period after a sale, where $c \geq 0$ is a transaction cost, e.g., transfer taxes, realtor fees or the cost of a moving van. In fact, we could alternatively impose this cost on buyers, or on both, but as in elementary tax-incidence theory, that would not change the allocation of payoffs. A buyer gets a flow utility normalized to 0 while searching, and gets a surplus $u - p$ after a purchase. A buyer chooses to accept the lowest offer he has only if it at least make him indifferent from waiting for the next period. Therefore, his value function is

$$V_t^B = \beta \sum_{n=1}^{\infty} b_n \int \max(u - p, V_{t+1}^B) dF_{n,t}(p) + b_0 \beta V_{t+1}^B \tag{1}$$

where $F_{n,t}(p) = 1 - [1 - F_t(p)]^n$ is the distribution of the lowest price among $n$ independent draws from $F_t(p)$, the distribution of listed prices that buyers face in period $t$.

Notice that the max operator in (1) indicates a buyer only buys if the best prices sampled satisfies $u - p \geq V_{t+1}^B$, which defines his reservation price

$$R_t = u - V_{t+1}^B. \tag{2}$$

This illustrates a key difference between standard Burdett-Judd models and our setup. In standard models, a seller has no opportunity cost, since he can sell as much as demand permits this period, and do the same thing next period. In this model, once he sells he is off the market. Similarly, once a buyer buys he is off the market. Hence, $R_t = u - V^B_{t+1} < u$, because agreeing to a price has the opportunity cost of continued search. In standard Burdett-Judd models, a buyer would actually pay $p = u$, and a seller would actually accept $p = c$.

While buyers would reject $p > R$, as mentioned above, in equilibrium no seller posts $p > R_t$. Indeed, the highest listed price is $\bar{p}_t = R_t$ (if $\bar{p}_t < R_t$ the highest price seller can profitably deviate to $\bar{p}_t = R_t$). Indeed, sellers choose prices to maximize their payoff, as described by

$$V^S_t = \beta \max_{p \in [c, R_t]} \left\{ \sum_{n=1}^{\infty} s_n [1 - F_t(p)]^{n-1} (p - c - V^S_{t+1}) \right\} + \beta V^S_{t+1}, \tag{3}$$

where $[1 - F_t(p)]^{n-1}$ in the summation is the probably that $p$ beats the other $n - 1$ prices seen by a buyer with $n$ observations. Notice that sellers can change their price next period at no cost.[8] Also, clearly, all the prices in the support $\mathcal{F}_t$ must yield the same profit, including the highest $\bar{p}_t = R_t$. Since $\bar{p}_t = R_t$ never beats another price,

$$V^S_t = s_1 (R_t - c - V^S_{t+1}) + V^S_{t+1}. \tag{4}$$

Equating (3) and (4) and rearranging, we arrive at

$$\frac{s_1 (R_t - c - V^S_{t+1})}{p - c - V^S_{t+1}} = \sum_{n=1}^{\infty} s_n \left[1 - F_t(p)\right]^{n-1}. \tag{5}$$

Using $R_t = u - V^B_{t+1}$ and $F_t(\underline{p}_t)$, this further implies that we can write the lower bound of the support $\mathcal{F}_t$ as a weighted average of the surpluses,

$$\underline{p}_t = \frac{s_1}{\sum_{n=1}^{\infty} s_n} \left(u - V^B_{t+1}\right) + \frac{\sum_{n=2}^{\infty} s_n}{\sum_{n=1}^{\infty} s_n} (c + V^S_{t+1}). \tag{6}$$

[8] Burdett and Menzio (2014) study a version of Burdett-Judd where sellers have a cost of changing $p$. The result is complicated, and thus we ignore menu costs for this exercise – indeed, the main point is to show how stickiness can emerge without such costs.

Given all this, the following results are standard in this class of models. Note in particular that $\mathcal{F}_t$ is an interval with no gaps or mass points.[9]

**Lemma 1** *If $b_0 + b_1 = 1$, there is one price and it gives all the surplus to sellers; if $b_1 = 0$, there is one price and it gives all the surplus to buyers; otherwise there is price dispersion.*

**Lemma 2** *Given $R_t$ and $V_{t+1}^S$, there is a unique solution to (5), $F_t(p)$, which is in continuous on $\mathcal{F}_t = [\underline{p}_t, \bar{p}_t]$ and differentiable on $(\underline{p}_t, \bar{p}_t)$.*

The Appendix reduces the above equations to the following forward-looking dynamical system in $\left(V_t^B, V_t^S\right)$:

$$\begin{aligned} V_t^B &= \beta\left(1 - b_0 - b_1\right)\left(u - c - V_{t+1}^B - V_{t+1}^S\right) + \beta V_{t+1}^B \\ V_t^S &= b_1 \beta / \tau (u - c - V_{t+1}^B - V_{t+1}^S) + \beta V_{t+1}^S \end{aligned}$$

Notice that $F_t\left(p\right)$ has been eliminated. Any sequence $(V_t^B, V_t^S)$ solving this system constitutes an equilibrium, from which we can construct sequences for $F_t\left(p\right)$ and the other endogenous variables using the above conditions, as long as $(V_t^B, V_t^S)$ is nonnegative and $\lim_{T\to\infty} \beta^T V_T^j = 0$.[10] A stationary equilibrium (or a steady state) is one where the variables are constant over time. The Appendix also verifies the following results.

**Proposition 1** *There is a unique equilibrium. It is stationary. Ruling out the extreme cases in Lemma 1, it entails nondegenerate price dispersion. The en-*

[9] We do not give a formal proof because these results are all standard, going back to Burdett and Judd (1983); for for a recent presentation see Burdett et al. (2015). Intuitively, if there were a gap between $p'$ and $p''$, a seller posting $p'$ could profitably deviate to $p' + \varepsilon$, as this does not lower the probability of a sale. Also, if there were a mass point at $p'$, a seller posting $p'$ could profitably deviate to $p' - \varepsilon$, as this increases the probablity of a sale discretely while only losing $\varepsilon$ on the price.

[10] This limiting condition is standard in dynamic models; see Rocheteau and Wright (2013) for a recent discussion of the technical issues, but it is intuitively obvious that discounted payoffs must be bounded.

*dogenous variables are given by:*

$$\sum_{n=1}^{\infty} nb_n \left[1-F(p)\right]^{n-1} = \frac{b_1 r\left(u-c\right)}{\left(r+1-b_0-b_1+b_1/\tau\right)\left(p-c\right)-b_1\left(u-c\right)/\tau} \quad (7)$$

$$\bar{p} = R = \frac{\left(r+b_1/\tau\right)u+\left(1-b_0-b_1\right)c}{r+1-b_0-b_1+b_1/\tau} \quad (8)$$

$$\underline{p} = \frac{b_1\left(\mathbb{E}n/\tau+r\right)u+\left[\mathbb{E}n\left(r+1-b_0-b_1\right)-rb_1\right]c}{\mathbb{E}n\left(r+1-b_0-b_1+b_1/\tau\right)} \quad (9)$$

$$V^B = \frac{\left(1-b_0-b_1\right)\left(u-c\right)}{r+1-b_0-b_1+b_1/\tau} \quad (10)$$

$$V^S = \frac{b_1\left(u-c\right)/\tau}{r+1-b_0-b_1+b_1/\tau} \quad (11)$$

**Remark 1** *There are closed-form solutions for all variables except $F(p)$. In general, $F(p)$ is characterized as the solution to an infinite polynomial by (7), but note that the LHS is simply the probability a house listed at $p$ gets sold each period. However, it is possible to solve for $F(p)$ explicitly for parametric specifications of the matching probabilities $b_n$ discussed below.*

# 3 Results

We begin by showing how the model simplifies in parametric cases. Consider first a minimal case that avoids the degenerate outcomes in Lemma 1, with $b_0 \geq 0$, $b_1 > 0$, $b_2 = 1-b_0-b_1 > 0$. Then (7) becomes linear in $F(p)$, and is easily solved for

$$F(p) = 1-\frac{b_1}{2b_2}\left[\frac{r\left(u-c\right)}{\left(r+b_1/\tau+b_2\right)p-b_1 u/\tau-\left(r+b_2\right)c}-1\right].$$

Notice $F(p) \in [0,1]$ $\forall p \in [\underline{p},\bar{p}]$, where $\underline{p}$ and $\bar{p}$ are given by (8) and (9). In particular, given $\mathbb{E}n = b_1+2b_2$, the lowest price is

$$\underline{p} = \frac{b_1\left(r+b_1/\tau+2b_2/\tau\right)u+\left[\left(b_1+2b_2\right)\left(r+b_2\right)-rb_1\right]c}{\left(b_1+2b_2\right)\left(r+b_1/\tau+b_2\right)}.$$

One can also check $F'(p) > 0$ and $F''(0) < 0$ $\forall p \in (\underline{p},\bar{p})$, and so the density is decreasing.

As special case of this specification, suppose $b_1 = \pi$ and $b_2 = 1 - \pi$. Here $\pi$ captures market power by sellers: $\pi = 1$ implies $p = u$ with probability 1, so sellers get all the surplus; $\pi = 0$ implies $p = c$ with probability 1 so buyers get all the surplus; and $\pi \in (0,1)$ implies price dispersion so both sides get positive expected surplus. Of course, this is simply an illustration or Lemma 1. Below we describe more generally how the equilibrium depends on $\pi$.

Next consider a Poisson distribution, $b_n = \lambda^n e^{-\lambda}/n! \ \forall n$, for some $\lambda > 0$. In this example, the mean number of houses that a buyer sees and likes each period is $\mathbb{E}n = \lambda$. One can show

$$\begin{aligned} F_t(p) &= 1 - \frac{1}{\lambda} \log \frac{r\,(u-c)}{\left[r + 1 - e^{-\lambda}(1+\lambda) + \lambda e^{-\lambda}/\tau\right](p-c) - \lambda e^{-\lambda}(u-c)/\tau} \\ \underline{p} &= \frac{e^{-\lambda}(r + \lambda/\tau)\,u + \left[r + 1 - e^{-\lambda}(r+1+\lambda)\right] c}{r + 1 - e^{-\lambda}(1+\lambda) + \lambda e^{-\lambda}/\tau}. \end{aligned}$$

Again one can easily check that $F''(p) < 0 \ \forall p \in (\underline{p}, \bar{p})$, and so the density is also decreasing in this example. This example is interesting because, in other applications of Burdett-Judd models, it makes it relatively easy to endogenize search intensity (e.g., Mortensen 2015).

Finally, consider a logarithmic distribution, $b_0 = 0$ and $b_n = -(\omega^n/n)\log(1-\omega) \ \forall n > 0$, for some $\omega \in (0,1)$. Now the mean number of houses that a buyer see and likes is $\mathbb{E}n = -\omega/(1-\omega)\log(1-\omega)$, although the mode is simply 1, and an increase in $\omega$ puts higher probabilities on bigger $n$. One can solve for

$$\begin{aligned} F(p) &= 1 - \frac{\left[r + 1 - b_1(1-\tau)\right] p - \left[(r + \tau b_1)\,u + (1-b_1)\,c\right]}{r\omega\,(u-c)} \\ \underline{p} &= \frac{\left[r + \tau b_1 - r\omega\right] u + \left[1 - b_1 + r\omega\right] c}{r + 1 - b_1(1-\tau)}. \end{aligned}$$

Notice that $F(p)$ is now linear – i.e., the $p$ distribution in this example is actually uniform. We conclude from all these examples that, at least after some routine algebra, the theory delivers rather simple results.

Table 1 reports the effects of exogenous variables on the endogenous variables for the general model, as well as the effects of the parameters in the above examples. These accord well with intuition. For instance, an increase in demand along the extensive margin, captured by a higher buyer-seller ratio $\tau$, reduces $F(p)$ while increasing $\underline{p}$ and $\bar{p}$. In other words, is results in a rightward shift of the density $F'(p)$. Notice it decreases the spread $\bar{p}-\underline{p}$ and $V^B$ while increasing $V^S$. Similarly, an increase in demand along the intensive margin, captured by higher $u$, also results in a rightward shift of $F'(p)$, but in this case it increases the spread $\bar{p}-\underline{p}$ and $V^B$ while decreasing $V^S$. An increase in the transaction costs $c$, naturally, results in a rightward shift of $F'(p)$, while decreasing $\bar{p}-\underline{p}$, $V^B$ and $V^S$.[11]

| | $\tau$ | $u$ | $c$ | $r$ | $\pi$ | $\omega$ |
|---|---|---|---|---|---|---|
| $F(p)$ | + | − | − | − | − | + |
| $\bar{p}$ | − | + | + | + | + | − |
| $\underline{p}$ | − | + | + | + | + | − |
| $\bar{p}-\underline{p}$ | + | + | − | + | ± | − |
| $V^B$ | + | + | − | − | − | + |
| $V^S$ | − | + | − | − | + | − |

Table 1: Effects of Parameters in Baseline Model.

We emphasize that the above results are for the general model. In terms of the examples, recall that when $b_1 = \pi$ and $b_2 = 1-\pi$, higher $\pi$ captures more market power for sellers. As Table 1 shows, a higher $\pi$ shifts the density $F'(p)$ rightward, has an ambiguous impact on the spread, and decreases $V^B$ while increasing $V^S$. The effect on the spread is ambiguous, with $\partial(\bar{p}-\underline{p})/\partial\pi > 0$ iff $r < (1-/\tau)(1-\pi)^2 - 1/\tau$. Also recall that when $n$ has a logarithmic distribution,

[11]Note that while the payoff $V^j$ decreases with $r$, it is easy to check that the flow payoff $rV^j$ increases with $r$.

higher $\omega$ makes it more likely that a buyer likes a higher number of houses. Hence, higher $\omega$ corresponds to more market power for buyers, similar to but note quite the same as lower $\pi$ in the first example. As Table 1 shows, higher $\omega$ shifts $F'(p)$ to the left, and naturally increases $V^B$ while decreasing $V^S$. Again, all of these results accord fairly well with intuition.

# 4 Variations

We now sketch a version of the model with bargaining, as opposed to price posting, for the sake of comparison. To begin, we keep the same matching technology: a buyer can still meet one or more sellers, but a seller can meet at most one buyer each period. When a buyer meets a single seller with a house that he likes, he pays a price denoted $\bar{p}$ and gets a share $\theta$ of the total surplus; and when he meets multiple sellers with houses that he likes, he picks one at random, pays a price denoted $\underline{p}$ and gets all the surplus.[12] This means $u-\bar{p}-V^B = \theta\left(u-c-V^B-V^S\right)$ with probability $b_1$ and $u-\underline{p}-V^B = u-c-V^B-V^S$ with probability $1-b_0-b_1$, since $u-c-V^B-V^S$ is the total surplus.

Hence there is a two-point price distribution. In steady state, the value functions satisfy

$$\begin{aligned} rV^B &= (1-b_0-b_1+b_1\theta)\left(u-c-V^B-V^S\right) \\ rV^S &= s_1(1-\theta)\left(u-c-V^B-V^S\right), \end{aligned}$$

where as in the baseline model $s_1 = b_1\tau$. It is now routine to solve for the

[12] Clearly $\bar{p}$ follows from standard bargaining solutions, including generalized Nash, Kalai or various strategic models, while $\underline{p} < \bar{p}$ is the usual outcome of Betrand competition, again related to Julien et al. (2000,2008).

equilibrium prices

$$\bar{p} = \frac{(1-\theta)(r+b_1/\tau)u + [\theta(r+b_1)+1-b_0-b_1]c}{r+b_1\theta+1-b_0-b_1+(1-\theta)b_1/\tau}$$
$$\underline{p} = \frac{(1-\theta)b_1u/\tau + (r+\theta b_1+1-b_0-b_1)}{r+b_1\theta+1-b_0-b_1+b_1\tau(1-\theta)},$$

as well as the spread $p_1 - p_2$, and payoffs $V^B$ and $V^S$. Table 2 gives the effects of parameters. The substantive results are similar to the baseline posting model, and again accord well with intuition.[13] This version generate discrete price distribution like in Maury and Tripier (2014). Because prices can be sticky only if the new support overlaps with the old support, models with discrete price distribution can generate sticky prices only if parameter changes in a particular way.

We can also introduce a standard, constant-returns, bilateral matching technology, as in the large labor literature following Pissarides (2000). Suppose the total number of buyer-seller contacts is $\mu = \mu(B,S)$. Then, for a seller, the probability of being contacted a relevant counterparty (a buyer that likes his house) is $\mu(B,S)/S = \mu(B/S,1) = \alpha(\tau)$. Similarly, for a buyer, the probability of being contacted a relevant counterparty (a seller with a house he likes) is $\mu(B,S)/B = \alpha(\tau)/\tau$. In this version buyers are never in similultaneous contact with multiple sellers, so they always pay the same price. The only other difference is the arrival rates are pinned down by the population $\tau = B/S$, which we take to be endogenous, although in pricinple one can now introduce entry, e.g., by sellers who decide endogenously to put their house on the market, or by even by builders (e.g., see He et al. 2015 and references therein).

We conclude that bargaining works well in this environment, although it does

[13] One difference from the baseline model is that $\partial\bar{p}/\partial r$ is now ambiguous, depending on market tightness: $\partial\bar{p}/\partial r > 0$ iff $\tau < (1-b_0-b_1+b_1\theta)/b_1\theta$. This is because higher $r$ reduces the outside option in bargaining, but reduces it by less for agents on the short side of the market.

not deliver continuous price dispersion, as in the baseline model. Of course, if agents were heterogeneous, bargaining would result in match-specific prices. If there were a distribution of buyer types with density $g(u)$ on $\mathcal{G} = [\underline{u}, \bar{u}]$, e.g., there would obtain a wide variety of transaction prices in equilibrium. Still, it would be hard to say that prices are sticky in that model, given the terms are negotiated in every single transaction (perhaps this is what Williamson had in mind in the quotation in the epigraph). We do not pursue bargaining further, but presented this formulation as a step toward models that ultimately have some posting and some bargaining in equilibrium.[14]

| | $\tau$ | $u$ | $c$ | $r$ | $\theta$ |
|---|---|---|---|---|---|
| $\bar{p}$ | $-$ | $+$ | $+$ | ? | $-$ |
| $\underline{p}$ | $-$ | $+$ | $+$ | $-$ | $-$ |
| $\bar{p} - \underline{p}$ | $+$ | $+$ | $-$ | $+$ | $-$ |
| $V^B$ | $+$ | $+$ | $-$ | $-$ | $+$ |
| $V^S$ | $-$ | $+$ | $-$ | $-$ | $+$ |

Table 2: Effects of Parameters in Bargaining Model.

The next step is to consider a version where we revert to price posting, but assume directed rather than random search. The solution concept, called competitive search equilibrium, going back to Moen (1997), assumes that buyer see the posted prices of all the sellers, and can direct their search to the ones that post attractive terms. We main the heterogeneity in $u$ across buyers mentioned above – i.e., a distribution of types with density $g(u)$ on $\mathcal{G} = [\underline{u}, \bar{u}]$. Then, as in Mortensen and Wright (2002), the market segments into submarkets with

[14]Bethune et al. (2015) have a model with both posting and bargaining, plus some directed and some random search, based on heterogeneously informed buyers as in Lester (2011). That seup is not especially relevant for housing markets however.

different prices catering to different buyer types (see also Shi 19xx and Shimer 19xx).[15]

One way to describe this is to say that different sellers post different $p = p_u$ to cater to particular buyer types, then buyers see the distribution of prices and direct their search to a preferred listing. There are still frictions in the meeting process, however, and as in the bargaining model we take $\alpha(\tau_u)$ to be the probablity a seller is in contact a buyer earch period, except now $\tau_u$ is the seller-buyer ratio in a particular submarket with price $p_u$. Similarly, $\alpha(\tau_u)/\tau_u$ is the probablity a seller is in contact with a buyer. As in that version, buyers cannot contact multiple sellers simultaneously, but here sellers still compete ex ante by posting a favorable $p_u$, with the understanding that $\tau_u$ is endogenous, and that buyers trade off price versus the probability of trade when deciding where search.[16]

Let $\Sigma^S$ denote the expected surplus for a seller, $\Sigma^u$ the expected surplus for a buyer of type $u$, and $V^u$ the value function for a buyer of type $u$. As is standard, in a submarket catering to type $u$, $(p_u, \tau_u)$ can be determined by maximizing $\Sigma^B_u$ holding $\Sigma^S$ equal to its market value, which is taken as given in that submarket, but determined in general equilirbium. Focusing on steady state, we have

$$\Sigma^B_u = \max_{(p_u,\tau_u)} \{\alpha(\tau_u)(u - p_u - V^u)\} \text{ st } \frac{\alpha(\tau_u)}{\tau_u}\left(p_u - c - V^S\right) = \Sigma^S \tag{12}$$

[15] Moen (1997) in a labor market context has heterogeneous firms and homogeneous workers. For other directed search models of one- or two-sided heterogeneity, see Mortensen and Wright (IER already in refs), Shimer (2005 JPE), Shi (2002 ReStud and 2006 EER), and Julien, Kennes and King "Efficient Bidding and Equilibrium Unemployment" (Canadian Journal of Economics, 2005). Also relevant are McAfee (1993 Econometrica), Peters and Severinov (1997 JET), Burdett Shi and Wright (2001 JPE), and Albrecht, Gautier and Vroman (2014 AER). In monetary economics, direct search models include Lagos and Rocheteau (2005), Rocheteau and Wright (2005) and Menzio et.al. (2013).

[16] As discussed in Moen (1997), Mortensen and Wright (2002) and elsewhere, rather than sellers posting, it is equivalent to have buyers posting $p$ to attract sellers, or to have third parties called market makers posting to attract both buyers and sellers. The latter interpretation may be especially relevant for real estate economics, where one could interpret market makers as realtors.

Using the constraint to eliminate $p_u$ and taking the FOC wrt $\tau_u$, we get

$$\alpha'(\tau_u)\left(u - c - V^u - V^S\right) - \Sigma^S = 0. \tag{13}$$

If $\tau_u < \infty$, then since in equilibrium $\Sigma^S = \alpha(\tau_u)/\tau_u\left(p - c - V^S\right)$, (16) implies

$$\frac{\alpha'(\tau_u)\tau_u}{\alpha(\tau_u)} = \frac{p - c - V^S}{u - c - V^u - V^S}. \tag{14}$$

The LHS of (22) is the elasticity of matching wrt participation by sellers. Thus we have the classic competitive search result, that this elasticity equals sellers' share of the surplus in the market.[17] Defining $\rho_u$ *by* the RHS of (22), this implicitly defines $\tau_u = T(\rho_u)$. Since the measure of buyers of type $u$ is fixed, as usual, one can interpret this as the "demand" for sellers in submarket $u$ as a function of their "price" $\rho_u$.

In equilibrium "market clearing" says that $\rho_u$ solves

$$\int g(u)\, T(\rho_u)\, du = \tau, \tag{15}$$

where $\tau$ on the RHS is the exogenous seller-buyer ratio in the aggregate economy. This uniquely determines $\rho_u$ and $\tau_u = T(\rho_u)$ in each submarket. Then (12) delivers $\Sigma^u$ and $rV^u = \Sigma^u$. Finally, given $\rho_u$ and $\Sigma^u$, we have $rV^S = \Sigma^S = \alpha(\tau_u)\left(p_u - c - V^S\right)$. This fully determines the equilibrium $\left(p_u, \tau_u, V^u, V^S\right)$.

As is well know, existence is standard, but there problems with uniqueness in competitive search models (e.g., see Rocheteau and Wright 2005). Still, the methods of monotone comparative statics can be employed to good effect to describe the outcomes (e.g., see Choi 2015). But as shown in the appendix, one nice feature of this model is that the equilibrium is unique.

[17] In bargaining models, efficiency obtains if the sellers' bargaining power $1 - \theta$ equals the relevant elasticity, which is the Hosios (1990) condition. The classic result is that competitive search delivers this condition, and hence efficiency, endogenously.

One can check

$$\frac{\partial V^u}{\partial u} \simeq \frac{\alpha(\tau_u)}{\tau_u + \alpha(\tau_u)} \in (0,1)\,,\ \frac{\partial p_u}{\partial u} \simeq 1 - \frac{\partial V_u^B}{\partial u} \in (0,1) \text{ and } \frac{\partial \tau_u}{\partial u} \simeq \frac{\partial V^u}{\partial u} - 1 \in (0,1)\,.$$

Therefore, across submarkets with $\tau_u \in (0, \infty)$, higher $u$ implies higher $p_u$ and lower $\tau_u$. Table 3 shows the comparative statics under constant elasticity matching function.

| | $G$ | $c$ | $\tau$ | $r$ | $\alpha$ |
|---|---|---|---|---|---|
| $\bar{p}$ | $+$ | $+$ | $-$ | $\pm$ | $\pm$ |
| $\underline{p}$ | $+$ | $+$ | $-$ | $\pm$ | $\pm$ |
| $\bar{\tau}$ | $-$ | $+$ | $+$ | $\pm$ | $\pm$ |
| $\underline{\tau}$ | $+$ | $-$ | $+$ | $\pm$ | $\pm$ |
| $\bar{p} - \underline{p}$ | $-$ | $+$ | $-$ | $+$ | $-$ |
| $V^u$ | $-$ | $\pm$ | $+$ | $\pm$ | $\pm$ |
| $V^S$ | $+$ | $-$ | $-$ | $-$ | $+$ |

Table 3: Effects of Parameters in Directed Search Model.

# 5 Sticky Prices

We now return to the substative issue with which we began – sticky house prices. Figure **??** shows the model with random search, where $f(p)$ is the equilibrium price density before, and $f(p)'$ after, some change in fundamental market conditions, e.g., an increase in $\tau$, $u$ or $c$, as shown in Table 1. The supports $[\underline{p}, \bar{p}]$ and $[\underline{p}', \bar{p}']$ overlap, as is the case whenever the change in conditions is not too big. Any seller posting $p \in [\underline{p}, \underline{p}')$ before the change must raise his price, since his $p$ is not in the new Burdett-Judd support; any seller posting $p \in [\underline{p}', \bar{p}]$ has no incentive to change – he *could* change to some other $p \in [\underline{p}', \bar{p}']$ but it would *not* be a profitable deviation, since it would be offset exactly by a response in the probability of a sale. Obviously the argument is similar for a change in conditions that causes $f(p)$ to shift in the other direction.

Figure **??** shows how similar results emerge with directed search. There are submarkets for each buyer type $u \in [\underline{u}, \bar{u}]$, with $p = p(u)$ increasing. A change in market conditions is shown that increases $p(u)$ to $p'(u)$ for all $u$. As long as the supports $[\underline{p}, \bar{p}]$ and $[\underline{p}', \bar{p}']$ overlap, exactly as in the baseline model, sticky prices can emerge. Again, any seller posting $p \in [\underline{p}, \underline{p}')$ before the change must raise his price, since his $p$ is not in the new Burdett-Judd support, but any seller posting $p \in [\underline{p}', \bar{p}]$ has no incentive to change – he *could* change to another $p \in [\underline{p}', \bar{p}']$ but it would *not* be a profitable deviation, since it would be offset exactly by an offsetting probability of a sale. And again the argument is similar for a change in the other direction. The bottom line is that there is no particular puzzle when many sellers stick to their prices after changes in market conditions – it is an equilibrium outcome that there is no incentive to change.

# 6 Conclusion

We have analyzed models of housing markets based on price posting by sellers with either random or directed search, and shown that some sellers can stick to their listed prices after various types of shocks. While we are not necessarily unsympathetic to the idea that loss aversion, regret theory, psychological prices and unrealistic expectations may be plausible features of reality, the goal was to demonstrate that we do not need them to explain th observations that others considere puzzling. Nor do we not need menu costs. Price stickiness follows from price dispersion which follows from rudimentary search theory.

While this was the narrow objective of the exercise, the models may have applications in housing economics that go beyond discussing price dynamics, and there are certainly many relevant extensions that one could entertain. The results may also have implications that go well beyond real estate economics. Genesove and Mayer (2001), e.g., suggest the following: the observation that sellers of such an important asset exhibit loss aversion gives added credence to the finding of such behavior in experimental settings. We are not sure about credence, but it would be incorrect to say that sticky house prices constitute definitive evidence of loss aversion or related phenomena. They follow easily from search frictions.

# Appendix

**Proof of Proposition 1**: We combine (1)-(5) to obtain a system of difference equations in $\left(V_t^B, V_t^S\right)$ that defines equilibrium. To begin, rewrite (1) as

$$\begin{aligned}
V_t^B &= \beta \sum_{n=1}^{\infty} b_n(u - V_{t+1}^B) + \beta V_{t+1}^B - \beta \sum_{n=1}^{\infty} b_n \int p dF_{n,t}(p) \\
&= \beta \sum_{n=1}^{\infty} b_n(u - c - V_{t+1}^S - V_{t+1}^B) + \beta V_{t+1}^B - \beta \sum_{n=1}^{\infty} b_n \int \left(p - c - V_{t+1}^S\right) dF_{n,t}(p) \\
&= \beta \left(1 - b_0\right) \left(u - c - V_{t+1}^S - V_{t+1}^B\right) + \beta V_{t+1}^B - \beta \Phi,
\end{aligned}$$

where

$$\begin{aligned}
\Phi &= \sum_{n=1}^{\infty} n b_n \int \left(p - c - V_{t+1}^S\right) \left[1 - F_t\left(p\right)\right]^{n-1} f_t\left(p\right) dp \\
&= \tau \int \left(p - c - V_{t+1}^S\right) f_t(p) \sum_{n=1}^{\infty} s_n \left[1 - F_t(p)\right]^{n-1} dp \\
&= (R_t - c - V_{t+1}^S) \tau s_1 \int f_t(p) dp = b_1(R_t - c - V_{t+1}^S)
\end{aligned}$$

Therefore, we have

$$V_t^B = \beta \left(1 - b_0\right) \left(u - c - V_{t+1}^B - V_{t+1}^S\right) + \beta V_{t+1}^B - \beta b_1(R_t - c - V_{t+1}^S)$$

Substitute $R_t = u - V_{t+1}^B$ and re-arrange to obtain

$$V_t^B = \beta \left(1 - b_0 - b_1\right) \left(u - c - V_{t+1}^B - V_{t+1}^S\right) + \beta V_{t+1}^B.$$

Also, Lemma 2 implies

$$V_t^S = \beta \frac{b_1}{\tau}(u - c - V_{t+1}^B - V_{t+1}^S) + \beta V_{t+1}^S.$$

Putting these together and letting $\mathbf{V}_t = (V_t^B, V_t^S)$, we have a linear system $\mathbf{V}_t = \Delta(\mathbf{V}_{t+1})$, given by

$$\begin{bmatrix} V_t^B \\ V_t^S \end{bmatrix} = \beta \begin{bmatrix} \left(1 - b_0\right)\left(u - c\right) \\ b_1\left(u - c\right)/\tau \end{bmatrix} + \beta \begin{bmatrix} b_0 + b_1 & -\left(1 - b_0 - b_1\right) \\ -b_1/\tau & 1 - b_1/\tau \end{bmatrix} \begin{bmatrix} V_{t+1}^B \\ V_{t+1}^S \end{bmatrix}.$$

The matrix on the RHS has eigenvalues $\beta\left(b_0 + b_1 - b_1/\tau\right)$ and $\beta$. Notice

$$\beta \geq \beta\left(b_0 + b_1 - b_1/\tau\right) \geq \beta\left(b_0 + b_1 - b_1/\mathbb{E}n\right) \geq \beta\left(b_0 + b_1 - 1\right) \geq -\beta$$

Both eigenvalues have absolute values less than 1. Therefore, the only solution to the system moving forward in real time, $\mathbf{V}_{t+1} = \Delta^{-1}(\mathbf{V}_t)$, satisfying $\lim_{T\to\infty} \beta^T \mathbf{V}_T = 0$ is the unique steady state. It is routine to solve for steady state as given in Proposition 1. ■

**Comparative Statics:** First consider the baseline model, and let $x \simeq y$ denote that $x$ and $y$ take the same sign. It is easy to derive

$$\frac{\partial F(p)}{\partial \tau} \simeq rb_1 (u-c)(u-p) > 0$$
$$\frac{\partial F(p)}{\partial u} \simeq \frac{\partial F(p)}{\partial c} \simeq -(1+r-b_0-b_1+b_1/\tau) < 0.$$

Less obvious is

$$\begin{aligned}\frac{\partial F(p)}{\partial r} \simeq\ & -[(r+b_1/\tau)(u-c) - A + b_1(u-p)/\tau + b_1(p-c)][A - b_1(u-c)/\tau] \\ & -b_1[(r+b_1/\tau)(u-c)-A][\tau(u-p)+b(p-c)],\end{aligned}$$

where $A = (1+r-b_0-b_1+b_1/\tau)(p-c)$. Notice that for any $p \in [\underline{p}, \bar{p}]$,

$$\begin{aligned}(r+b_1/\tau)(u-c) - A &= (r+b_1/\tau)(u-c) - (1+r-b_0-b_1+b_1/\tau)(p-c) \\ &\geq (1+r-b_0-b_1+b_1/\tau)(R-c) \\ &\geq (r+b_1/\tau)(u-c) - b_1/\tau\,(u-c) > 0.\end{aligned}$$

Also notice that

$$\begin{aligned}A - b_1(u-c)/\tau &\geq (1+r-b_0-b_1+b_1/\tau)(p-c) - b_1/\tau\,(u-c) \\ &= \frac{b_1 r(u-c)}{En} > 0.\end{aligned}$$

These combine to yield $\partial F(p)/\partial r < 0$. The effects on $\underline{p}$, $\bar{p}$, $\bar{p}-\underline{p}$, $V^B$ and $V^S$ are simple and left as exercises.

The above results are for the general model. For the example with $b_1 = \pi$ and $b_2 = 1-\pi$, we have

$$\begin{aligned}\frac{\partial \bar{p}}{\partial \pi} &\simeq 1/\tau + r > 0 \\ \frac{\partial \underline{p}}{\partial \pi} &\simeq r\left(2-\pi^2\right) + 4(1-\pi)/\tau + 4r(1-\pi)/\tau + 2r^2 + (2r+1)\pi^2/\tau > 0 \\ \frac{\partial(\bar{p}-\underline{p})}{\partial \pi} &\simeq (1-\pi)^2(1-1/\tau) - (1/\tau + r) > 0 \text{ iff } r < (1-1/\tau)(1-\pi)^2 - 1/\tau.\end{aligned}$$

Slighty less simple is

$$\begin{aligned}\frac{\partial F(p)}{\partial \pi} &= \frac{1}{2(1-\pi)^2}\left[1-\frac{r(u-c)}{(1+r-\pi)(p-c)-\pi(u-p)/\tau}\right] \\ &\quad -\frac{\pi}{2(1-\pi)}\frac{r(u-c)(p-c+(u-p)/\tau)}{[(1+r-\pi)(p-c)-\pi(u-p)/\tau]^2}.\end{aligned}$$

One can now check $\partial F(p)/\partial \pi < 0$. The effects on $V^B$ and $V^S$ are simple and left as exercises.

For the example with logarithmic distribution, because $\partial b_1/\partial \omega < 0$,

$$\begin{aligned}\frac{\partial \bar{p}}{\partial \omega} &\simeq -[(1-\omega)\log(1-\omega)+\omega] < 0 \\ \frac{\partial \underline{p}}{\partial \omega} &\simeq [r+1-b_1(1-1/\tau)]\left(\frac{\partial b_1}{\partial \omega}\tau - 1/r\right) + [r(1-\omega)+b_1/\tau]\frac{\partial b_1}{\partial \omega}(1-1/\tau) < 0 \\ \frac{\partial(\bar{p}-\underline{p})}{\partial \omega} &\simeq \frac{\partial b_1}{\partial \omega}\omega(1-1/\tau)-(1-r)-b_1(1-1/\tau) < 0 \\ \frac{\partial F(p)}{\partial \omega} &\simeq \frac{\left[r\log(1-\omega)^2+\omega^2\tau\right]u+\left[\log(1-\omega)^2-\omega^2\right]c}{(r+1)\log(1-\omega)^2-\omega^2(1-\tau)} - p > \bar{p}-p > 0.\end{aligned}$$

Note that the first result uses the fact that $(1-\omega)\log(1-\omega)+\omega$ is increasing in $\omega$ and is 0 at $\omega = 0$. Again the simple effects on $V^B$ and $V^S$ are omitted

In the bargaining version of the model, we omit the simple effects of $u$ and $c$ and focus on other parameters. The effects of $\theta$ are

$$\frac{\partial \bar{p}}{\partial \theta} \simeq \frac{\partial \underline{p}}{\partial \theta} \simeq \frac{\partial(\bar{p}-\underline{p})}{\partial \theta} \simeq -r-1+b_0 < 0.$$

The effects of $r$ are

$$\begin{aligned}\frac{\partial \bar{p}}{\partial r} &\simeq 1-b_0-b_1+b_1\theta(1-1/\tau) > 0 \text{ iff } 1/\tau < \frac{1-b_0-b_1+b_1\theta}{b_1\theta} \\ \frac{\partial \underline{p}}{\partial r} &\simeq -1 < 0 \text{ and } \frac{\partial(\bar{p}-\underline{p})}{\partial r} \simeq 1-b_0-b_1+b_1\theta+b_1(1-\theta)/\tau > 0.\end{aligned}$$

The effects of $\tau$ are

$$\frac{\partial \bar{p}}{\partial \tau} \simeq -[1-b_0-b_1+\theta(r+b_1)] < 0,\ \frac{\partial \underline{p}}{\partial \tau} \simeq -[r+\theta b_1+1-b_0-b_1] < 0$$
$$\text{and } \frac{\partial(\bar{p}-\underline{p})}{\partial \tau} \simeq b_1(1-\theta) > 0.$$

This covers the results stated in the text.

**Directed-Search Model:** Recall the FOC leads to

$$\alpha'(\tau_u)\left[u-c-V^S-V^u\right]=rV^S \tag{16}$$

Use

$$V^u=\frac{\alpha(\tau_u)\left(u-c-V^S\right)-r\tau_u V^S}{r+\alpha(\tau_u)} \tag{17}$$

to obtain

$$\alpha'(\tau_u)\left(u-c-V^S\right)=V^S\left[r+\alpha(\tau_u)-\tau_u\alpha'(\tau_u)\right] \tag{18}$$

The above equation uniquely pins down $\tau_u$ given $\Sigma_s$ if $\alpha$ is strictly concave. Then, $V^S$ can be pinned down by

$$\int \tau_u g(u)\,du=\tau \tag{19}$$

Hence, the equilibrium is determined by (18) and (19). Notice from (18), one can show that $\frac{\partial\tau_u}{\partial V^S}<0$. As a result, $\int \tau_u g(u)\,du$ is monotonically decreasing in $V^S$. Therefore, the equilibrium is unique.

**Comparative Statics:** From now on, assume that $G(\cdot)=G_0(\cdot-v)$ with support $[\underline{u},\bar{u}]$and $\alpha(\tau_u)=\mu\tau_u^a$ with $a\in(0,1)$. The comparative statics wrt $G$ and $\alpha$ in Table 3 is in fact comparative statics wrt $v$ and $\mu$. We also construct examples to show that the signs of some comparative statics depends on the parameters.

**Comparative statics wrt** $v$: Notice (18) defines $\tau_u$ as a function of $V^S$, $u$, $c$ and $\mu$. Notice

$$\frac{\partial\tau_u}{\partial u} = -\frac{\alpha'(\tau_u)^2}{\alpha''(\tau_u)}\frac{1}{\left[r+\alpha(\tau_u)\right]V^S}>0, \tag{20}$$

$$\frac{\partial\tau_u}{\partial V^S} = \frac{\alpha'(\tau_u)}{\alpha''(\tau_u)}\frac{r+\alpha(\tau_u)+\alpha'(\tau_u)-\tau_u\alpha'(\tau_u)}{\left[r+\alpha(\tau_u)\right]V^S}<0 \tag{21}$$

Therefore, $\tau_u$ is increasing in $u$. (19). Therefore,

$$\int \tau_u g(u-dv)\,du=\int \tau_{u+dv}g(u)\,du=\tau$$

which implies that

$$\int \frac{\partial \tau_u}{\partial u} g(u)\, du + \frac{dV^S}{dv} \int \frac{\partial \tau_u}{\partial V^S} g(u)\, du = 0.$$

Therefore,

$$\begin{aligned}
\frac{dV^S}{dv} &= \frac{\int \frac{\alpha'(\tau_u)^2}{\alpha''(\tau_u)} \frac{g(u)}{[r+\alpha(\tau_u)]} du}{\int \frac{\alpha'(\tau_u)}{\alpha''(\tau_u)} \frac{[r+\alpha(\tau_u)+\alpha'(\tau_u)-\tau_u\alpha'(\tau_u)]g(u)}{[r+\alpha(\tau_u)]} du} > 0, \\
\frac{dV^u}{dv} &= -\frac{\alpha(\tau_u) + r\tau_u}{r+\alpha(\tau_u)} \frac{dV^S}{dv} < 0, \\
\frac{d\tau_u}{dv} &= \frac{\partial \tau_u}{\partial V^S} \frac{dV^S}{dv} < 0.
\end{aligned}$$

The second equation follows by combining (17) and (18). In addition, by (16) and the constraint of the maximization problem,

$$\eta(\tau_u)\left[u - c - V^S - V^u\right] = p_u - c - V^S \tag{22}$$

where $\eta(\tau_u) = \tau_u \alpha'(\tau_u)/\alpha(\tau_u)$ is the elasticity of the matching function w.r.t the sellers. Notice this is the well-known Hosios condition. Notice

$$V^S = \frac{\frac{\alpha(\tau_u)}{\tau_u}[p_u - c]}{r + \frac{\alpha(\tau_u)}{\tau_u}},\ V^u = \frac{\alpha(\tau_u)[u - p_u]}{r+\alpha(\tau_u)}.$$

Combine them with (22) and arrange, one can obtain.

$$\frac{u - p_u}{p_u - c} = \left[\frac{1}{\eta(\tau_u)} - 1\right] \frac{r+\alpha(\tau_u)}{r + \frac{\alpha(\tau_u)}{\tau_u}} \tag{23}$$

Here $\eta(\tau_u)$ is non-increasing, $\alpha(\tau_u)$ is increasing and $\frac{\alpha(\tau_u)}{\tau_u}$ decreasing. Therefore, if $\tau_u$ decreases, the RHS of (23) decreases and hence $p_u$ increases. This suggests that $dp_u/dv > 0$. It is worth noting that the above comparative statics hold if $G$ increases in the sense of first-order stochastic dominance.

Next, move on to $\bar{\tau}$ and $\underline{\tau}$ . Notice by (18) and (19), the effect of an increase in $v$ on $\bar{\tau}$ and $\underline{\tau}$ is the same as a decrease in $c$. Later, we show that $d\bar{\tau}/dc > 0$ and $d\underline{\tau}/dc < 0$. This suggests $d\bar{\tau}/dv < 0$ and $d\bar{\tau}/dv > 0$. Again by (23) evaluated at $\bar{u}$, because $\bar{u}$ increases and also the RHS decreases, we must have $d\bar{p}/dv > 0$. In addition, because

$$\frac{\frac{\alpha(\underline{\tau})}{\underline{\tau}}\left[\underline{p} - c\right]}{r + \frac{\alpha(\underline{\tau})}{\underline{\tau}}} = V^S = \frac{\frac{\alpha(\bar{\tau})}{\bar{\tau}}[\bar{p} - c]}{r + \frac{\alpha(\bar{\tau})}{\bar{\tau}}}$$

Therefore,

$$1+\frac{r\left[\frac{\alpha(\underline{\tau})}{\underline{\tau}}/\frac{\alpha(\bar{\tau})}{\bar{\tau}}-1\right]}{r+\frac{\alpha(\underline{\tau})}{\underline{\tau}}}=\frac{\bar{p}-c}{\underline{p}-c}.$$

Since $d\bar{\tau}/dv<0$ and $d\underline{\tau}/dv>0$ and $\alpha\left(\bar{\tau}\right)/\bar{\tau}<1$, the LHS is decreasing in $v$. Since $d\bar{p}/dv>0$, it must be $d\underline{p}/dv>0$. In addition, notice

$$d\left(\bar{p}-\underline{p}\right)/dv=-d\left(\bar{p}-\underline{p}\right)/dc<0$$

Here I use the result on $d\left(\bar{p}-\underline{p}\right)/dc$ obtained in the next subsection.

**Comparative statics wrt** $c$:First notice

$$\frac{\partial\tau_u}{\partial c}=-\frac{\partial\tau_u}{\partial u}=\frac{\alpha'\left(\tau_u\right)^2}{\alpha''\left(\tau_u\right)}\frac{1}{\left[r+\alpha\left(\tau_u\right)\right]V^S}<0.$$

Combine it with (21) and (19) to obtain

$$\frac{dV^S}{dc}=-\frac{\int\frac{\alpha'(\tau_u)^2}{\alpha''(\tau_u)}\frac{g(u)}{[r+\alpha(\tau_u)]}du}{\int\frac{\alpha'(\tau_u)^2}{\alpha''(\tau_u)}\frac{(u-c)g(u)}{[r+\alpha(\tau_u)]V^S}du}<0.$$

In addition, notice

$$\frac{d\frac{d\tau_u}{dc}}{du}\simeq\frac{\int\frac{\alpha'(\tau_u)^2}{\alpha''(\tau_u)}\frac{g(u)}{[r+\alpha(\tau_u)]}du}{\int\frac{\alpha'(\tau_u)^2}{\alpha''(\tau_u)}\frac{(u-c)g(u)}{[r+\alpha(\tau_u)]V^S}du}>0$$

This fact and $\int\frac{d\tau_u}{dc}g\left(u\right)du=0$ implies that there must exist a threshold $\tilde{u}$ which is in the interior of the support of $G$ such that

$$\frac{d\tau_u}{dc}\gtreqless0\text{ if }u\gtreqless\tilde{u}$$

Therefore, $\frac{d\bar{\tau}}{dc}>0$ and $\frac{d\underline{\tau}}{dc}<0$. Next, following a similar logic as for $d\bar{p}/dv>0$ and $d\underline{p}/dv>0$, one can show that $d\bar{p}/dc>0$ and $d\underline{p}/dc>0$.

Now use (17) and 16 to obtain

$$\frac{dV^u}{dc}\simeq-\frac{\alpha\left(\tau_u\right)/\tau_u}{\left[r+\alpha\left(\tau_u\right)/\tau_u\right]}+\frac{\int\frac{\alpha'(\tau_u)}{\alpha''(\tau_u)}\frac{\alpha'(\tau_u)g(u)}{r+\alpha(\tau_u)}du}{\int\frac{\alpha'(\tau_u)}{\alpha''(\tau_u)}\frac{[r+\alpha(\tau_u)+\alpha'(\tau_u)-\tau_u\alpha'(\tau_u)]g(u)}{r+\alpha(\tau_u)}du}$$

which can be positive when $\tau_u$ is high enough.

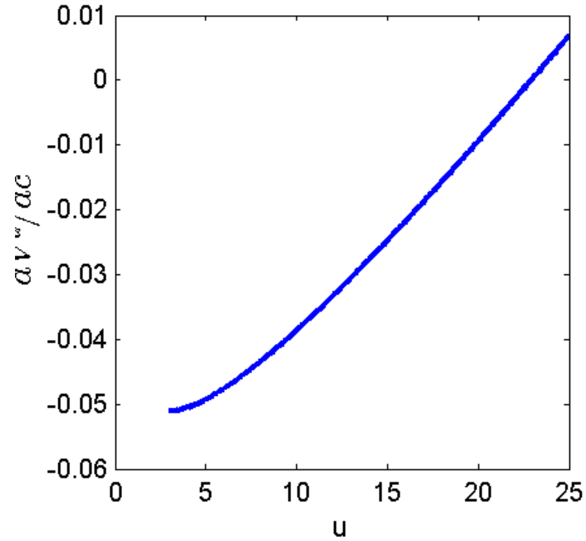



Figure 1: Example 1

**Example 1** *Now we present a numeric example in which some buyers' value increases as the cost of selling* $c$ *increases. Figure 1 plots* $\frac{dV^u}{dc}$ *under* $r = 0.2$*,* $c = 1$*,* $\alpha(\tau_u) = 0.01\tau_u^{0.1}$*,* $\tau = 6$ *and*

$$G(u) = \begin{cases} 0 & \text{if } u < 3 \\ \left[\frac{u-3}{22}\right]^{0.001} & \text{if } u \in [3, 25] \\ 1 & \text{if } u > 25 \end{cases}.$$

*One can see that when* $u$ *is small,* $\frac{dV^u}{dc} < 0$*, When* $u$ *becomes sufficiently large,* $\frac{dV^u}{dc}$ *becomes positive. In this example, most buyers have very low value and there are very few buyers have very high value. An increase in* $c$ *causes a slightly decrease in* $\tau_u$ *for low value buyers which has to be compensated by a huge increase in* $\tau_u$ *for high value buyers. This increase in* $\tau_u$ *is so large such that it dominates the effect of increasing prices.*

Under constant elasticity matching,

$$\frac{d\left(\bar{p} - \underline{p}\right)}{dc} \simeq -\frac{1}{r + \bar{\tau}^a} + \frac{1}{r + \underline{\tau}^a} - \left[\frac{\bar{\tau} - 1}{[r + \bar{\tau}^a]} - \frac{\underline{\tau} - 1}{r + \underline{\tau}^a}\right]\frac{dV^S}{dc} > 0$$

**Comparative Statics wrt $\tau$:** Next, consider comparative statics with respect to $\tau$. Following a similar logic,

$$\begin{aligned}
\frac{dV^S}{d\tau} &= 1/\int \frac{\alpha'(\tau_u)^2}{\alpha''(\tau_u)} \frac{u-c}{[r+\alpha(\tau_u)](V^S)^2} g(u)\,du < 0, \\
\frac{d\tau_u}{d\tau} &= \frac{\frac{\alpha'(\tau_u)^2}{\alpha''(\tau_u)} \frac{u-c}{[r+\alpha(\tau_u)]}}{\int \frac{\alpha'(\tau_u)^2}{\alpha''(\tau_u)} \frac{u-c}{[r+\alpha(\tau_u)]} g(u)\,du} > 0, \\
\frac{d(\bar{p}-\underline{p})}{d\tau} &\simeq \frac{-\bar{\tau}+1}{r+\alpha(\bar{\tau})} - \frac{-\underline{\tau}+1}{[r+\alpha(\underline{\tau})]} < 0
\end{aligned}$$

In addition, notice by (23) and the fact that $\tau_u$ increases, $p_u$ decreases. The buyers enjoy higher meeting probability and lower prices. Therefore, $V^u$ goes up.

**Comparative Statics wrt $r$ and $\mu$:** Next, we derive comparative statics wrt $\kappa = \mu/r$. The comparative statics wrt $\mu$ and $r$ follows naturally.

$$\begin{aligned}
\frac{\partial \tau_u}{\partial V^S} &= -\frac{\tau_u}{1-a} \frac{1+\kappa\alpha\tau_u^a - \tau_u \kappa a \tau_u^{a-1} + \kappa a \tau_u^{a-1}}{[1+\kappa a \tau_u^a] V^S} < 0, \\
\frac{\partial \tau_u}{\partial \kappa} &= \frac{\tau_u}{1-a} \frac{1}{[1+\kappa a \tau_u^a] V^S} > 0
\end{aligned}$$

One can show

$$\frac{dV^S}{d\kappa} > 0, \frac{dV^S/\kappa}{d\kappa} < 0$$

Now we investigate how $\tau_u$ changes with $\kappa$. First, notice that

$$\frac{d\tau_u}{d\kappa} \simeq -\left[1+\kappa\alpha\tau_u^a - \tau_u \kappa a \tau_u^{a-1} + \kappa a \tau_u^{a-1}\right] \frac{dV^S}{d\kappa} + 1$$

and

$$\frac{d\left[1+\kappa\alpha\tau_u^a - \tau_u \kappa a \tau_u^{a-1} + \kappa a \tau_u^{a-1}\right]}{d\tau_u} = \kappa(1-\tau_u)\, a\,(a-1)\,\tau_u^{a-2}$$

which is negative if $\tau_u < 1$ and positive if $\tau_u > 1$. Therefore, $d\tau_u/d\kappa$ is increasing in $u$ when $\tau_u$ is small and decreasing in $u$ when $\tau_u$ is large. Notice $\tau_u$ is increasing in $\tau$. Therefore, when $\tau$ is sufficiently small, $\bar{\tau} < 1$ and $\frac{d\tau_u}{d\kappa}$ is always increasing in $u$. Because $\int \frac{d\tau_u}{d\kappa} du = 0$, we must have

$$\frac{d\bar{\tau}}{d\kappa} > 0 \text{ and } \frac{d\underline{\tau}}{d\kappa} < 0.$$

As $\tau$ increases, $\bar{\tau}$ goes above 1 and we will continue to have $\frac{d\bar{\tau}}{d\kappa} > 0$ until $\tau$ reaches $\tau_1$. At $\tau_1$, $\bar{\tau}$ is sufficiently large and $\underline{\tau} < 1$. Therefore,

$$\frac{d\bar{\tau}}{d\kappa} < 0 \text{ and } \frac{d\underline{\tau}}{d\kappa} < 0$$

. As $\tau$ further increases to $\tau_2$, $\frac{d\tau_u}{d\kappa}$ is decreasing for most $u$, then to guarantee $\int \frac{d\tau_u}{d\kappa} du = 0$,

$$\frac{d\bar{\tau}}{d\kappa} < 0 \text{ and } \frac{d\underline{\tau}}{d\kappa} > 0.$$

Notice in this case, when $\tau$ is just above $\tau_2$, we continue to have $\underline{\tau} < 1$.

One can also show that

$$\frac{dV^u}{d\kappa} \simeq a - \left[1 + \kappa a \tau_u^{a-1}\right] \frac{\int \frac{\tau_u}{1-a} \frac{g(u)}{[1+\kappa a \tau_u^a]} du}{\int \frac{\tau_u}{1-a} \frac{\left(1+\kappa \alpha \tau_u^a - \tau_u \kappa a \tau_u^{a-1} + \kappa a \tau_u^{a-1}\right) g(u)}{[1+\kappa a \tau_u^a]} du}$$

which can be positive or negative depending on $\tau_u$. If $\tau_u$ is small, $\frac{dV^u}{d\kappa} < 0$. Otherwise, $\frac{dV^u}{d\kappa} > 0$.

Now let us turn to the price schedule. Notice

$$\frac{u - p_u}{p_u - c} = \left[\frac{1}{a} - 1\right] \frac{1 + \kappa \tau_u^a}{1 + \kappa \tau_u^{a-1}}$$

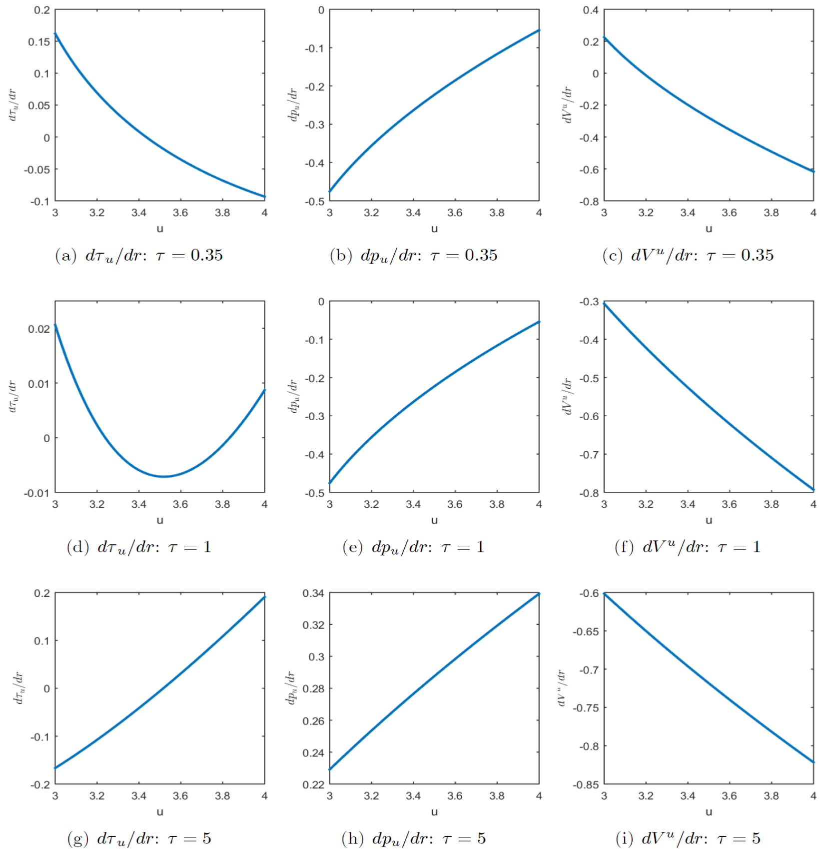
Therefore,

$$d\left(\frac{u-p}{p-c}\right) / d\kappa \simeq \left[\kappa a \tau_{_u}^{a-1} + \kappa (1-a) \tau_u^{a-2} + \kappa^2 \tau_{_u}^{2a-2}\right] \frac{d\tau_u}{d\kappa} + \tau_u^{a-1} (\tau_u - 1).$$

Therefore, if $\tau_u < 1$ and $\frac{d\tau_u}{d\kappa} < 0$, $\frac{dp_u}{d\kappa} > 0$ and if $\tau_u > 1$ and $\frac{d\tau_u}{d\kappa} > 0$, $\frac{dp_u}{d\kappa} < 0$. This immediately implies that when $\tau < \tau_1$, $\frac{d\underline{p}}{d\kappa} > 0$. And if $\tau \in (\tau_1, \tau_2)$, $\frac{d\underline{p}}{d\kappa} > 0$. And if $\tau > \tau_2$, $\frac{d\bar{p}}{d\kappa} < 0$. The following proposition summarizes the above analysis. Since $\kappa = \mu/r$, the comparative statics with respect to $\mu$ and $r$ can be derived easily.

Lastly, we move on to $d\left(\bar{p} - \underline{p}\right)/d\kappa$. Following a similar method as before, we obtain

$$\frac{d\left(\bar{p} - \underline{p}\right)}{d\kappa} = a \left[\frac{\underline{\tau} - 1}{1 + \kappa \underline{\tau}^a} - \frac{\bar{\tau} - 1}{1 + \kappa \bar{\tau}^a}\right] \frac{dV^S}{\kappa d\kappa} - \left[\frac{\bar{\tau}}{[1 + \kappa \bar{\tau}^a]} - \frac{\underline{\tau}}{[1 + \kappa \underline{\tau}^a]}\right] \frac{V^S}{\kappa^2} < 0$$



(a) $d\tau_u/dr$: $\tau = 0.35$ (b) $dp_u/dr$: $\tau = 0.35$ (c) $dV^u/dr$: $\tau = 0.35$

(d) $d\tau_u/dr$: $\tau = 1$ (e) $dp_u/dr$: $\tau = 1$ (f) $dV^u/dr$: $\tau = 1$

(g) $d\tau_u/dr$: $\tau = 5$ (h) $dp_u/dr$: $\tau = 5$ (i) $dV^u/dr$: $\tau = 5$

**Example 2 (Numeric Example)** *Figure 6 plots the comparative statics of the whole schedules with respect to* $r$ *as a function of* $u$. *It is constructed under* $r = 0.05$, $c = 1.1$, $\alpha(\tau_u) = 2\sqrt{\tau_u}$ *and* $u$ *follows a uniform distribution on* $[3, 4]$. *Three values of* $\tau$ *are considered:* $0.35$, $1$ *and* $5$. *Notice these comparative statics should have the opposite sign of those with respect to* $\kappa$. *By the previous proposition, when* $\tau$ *is small,* $\frac{d\bar{\tau}}{d\kappa} > 0$, $\frac{d\underline{\tau}}{d\kappa} < 0$ *which suggests that* $\frac{d\bar{\tau}}{dr} < 0$, $\frac{d\underline{\tau}}{dr} > 0$. *This is shown in Figure 6(a). As* $\tau$ *increases, according to the previous proposition,* $\frac{d\bar{\tau}}{dr} > 0$, $\frac{d\underline{\tau}}{dr} > 0$. *This is shown in Figure 6(d). If* $\tau$ *further increases,* $\frac{d\bar{\tau}}{dr} > 0$, $\frac{d\underline{\tau}}{dr} < 0$ *as shown in Figure 6(g). In addition,* $dp_u/dr$ *may be negative or positive depending on* $\tau_u$. *Lastly, the sign of* $dV^u/dr$ *is also not determined. As predicted above, when* $\tau_u$ *is sufficiently low,* $dV^u/dr$ *may be positive. This is shown in Figure 6(c)*

■

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