Information Disclosure in Housing Auctions*

Alina Arefeva
University of Wisconsin-Madison
Wisconsin School of Business

Delong Meng
Shanghai Jiao Tong University

December 15, 2020

Abstract

We study the optimal selling mechanism and information disclosure policy for a house seller. The seller can select any selling mechanism, including an auction, and release additional information about the house to buyers. Release of information adjusts the buyers' values and bids. We find that the optimal mechanism is a combination of the optimal auction and full information disclosure. But if the seller uses a second-price auction instead, concealing additional information about the house may be optimal for her. Moreover, the seller can extract buyers' private value adjustments by selling them contracts similar to European call options.

Keywords: house selling, bidding wars, auctions, optimal mechanism, information disclosure, microstructure, institutions

JEL Codes: R31, D82, D44

*First version: January 17, 2016. Arefeva: arefeva@wisc.edu, Meng: nealthcounts@outlook.com. We thank (in random order) Paul Milgrom, Gabriel Carroll, Andy Skrzypacz, Michael Ostrovsky, Jeremy Bulow, Brad Larsen, Jonathan Levin, Takuo Sugaya, Shota Ichihashi, Xing Li, Yiqing Xing, Phillip Thai Pham, Weixin Chen, Simon Board, our discussants Erling R. Larsen, Jos van Bommel, Yuka Nishikawa, John M. Clapp, Roberto Pinheiro and seminar participants at Stanford University, Johns Hopkins Carey Business School, University of Wisconsin-Madison, Wisconsin School of Business, Missouri State University, Stockholm Business School, Shanghai University, 2017 American Economic Association Annual Meeting, 2017 EEA-ESEM Congress, 2017 Urban Economic Association, 2017 European Meeting of Econometric Society, 2018 American Real Estate Society, 2018 Eastern Finance Association, 2018 AREUEA National Conference, 2019 Southwestern Finance Association Conference, 2019 European Association for Research in Industrial Economics (EARIE), 2020 Econometric Society and Bocconi University Virtual World Congress, 2020 European Economic Association Conference for helpful discussions.

Introduction

Selling a home is a major financial decision. However, most home sellers participate in the housing market infrequently[1] and, hence, have limited experience and knowledge in the home selling process. Real estate agents help home sellers to market and get the best price for the house, but they may be inexperienced (Gilbukh and Goldsmith-Pinkham (2020)) or have biased incentives (Rutherford, Springer, and Yavas (2005), Levitt and Syverson (2008)). The key question for home sellers is what is the best way to sell the house to maximize the expected revenue.

This paper sets up the optimal mechanism problem of the home seller who deals with one or multiple interested buyers. The main focus of the paper is whether or not the seller should share additional information that the seller possesses about the house. However, we allow the seller to also select any feasible selling mechanism at the same time.

We find that the optimal mechanism is a combination of full information disclosure and an optimal auction. In our setting, the release of information increases the dispersion of the buyers' estimates of house value. An optimal auction selects the buyer with the maximum marginal revenue. Because maximum is a convex function, higher dispersion of values increases expected revenue, so full information disclosure is optimal. Additionally, if the seller runs the optimal auction without being able to choose the mechanism, the full information disclosure is still optimal. In the baseline model, we assume that the seller can observe new information, released to buyers. But this is without loss of generality because the seller can use the handicap auction, proposed by Eso and Szentes (2007), to elicit the buyer's values and earn the same expected revenue. We show how to implement the handicap auction in our setting, which includes offering buyers to purchase contacts similar to European call options, and then running a modified second-price auction.

Even though the seller's optimal mechanism is a combination of full information disclosure and an optimal auction, it is challenging to implement the optimal auction. In practice, housing auctions, or bidding wars, are conducted using ascending auctions. For example, in the US, auctions are informal. Typically, real estate agents facilitate bidding by submitting sealed-bid offers when multiple interested buyers are involved. In this case, buyers often compete by submitting their best and final offers or offers that include a separate agreement, called an escalation clause[2]. The escalation clause is usually an addendum to a purchase offer for a home. In this clause, the buyer specifies that if the

[1]Most homeowners stay in their home for nine years on average, see Ngai and Tenreyro (2014).

[2]The name of the clause may vary across states. For example, in Wisconsin, it is called the acceleration clause instead of the escalation clause.

seller can serve the buyer another offer with a higher purchase price, the buyer is willing to increase his offer by a certain amount until a ceiling cap[3]. The escalation clause allows to implement an English ascending bid auction[4]. An ascending auction is weakly strategically equivalent to a sealed-bid second-price auction because it means that only one buyer is willing to continue at the current price, which represents the second-highest bid.

In addition to our analysis of the optimal mechanism, we study the second-price auction because it similar to the auction process often employed in reality, does not require the seller to know the distribution of house values to conduct the auction, and is easy to model. If the seller runs the second-price auction and there are two bidders, the expected revenue is a minimum of two bids. Since minimum is a concave function in new information, we know from Board (2009) that the seller should not reveal information. When there are more than two bidders, the expected revenue can be either concave or convex depending on whether new information changes the winning buyer. If the allocation changes the winning buyer, the expected revenue is locally concave, so the seller should release new information, and vice versa if not.

We get that the seller should use a full information disclosure policy in the optimal mechanism and the optimal auction, and could conceal information in the second-price auctions. What explains these differences in the results? First, new information could asymmetrically shift the buyer's value distributions, so the revenue equivalence theorem does not necessarily hold and predictions from different auction formats can vary. Second, new information can change which bidder buys the houses, that is, change the allocation. When the allocation changes, the revenue is convex in new information in the optimal auction and is locally concave in new information in the second-price auction. When the revenue is convex, the seller should release the information, and vice versa when it is concave, explaining differences in predictions. This last point is also the key difference

[3]An example of the escalation/acceleration clause attached to the buyer's purchase offer is "If seller received any bona fide offer on the property before May 10th, 2020, with a net purchase price equal to or higher than \$350,000 buyer agrees to pay \$1,000 more than said offer, up to a maximum purchase price of \$370,000, provided seller delivers a copy of the offer within 2 days of actual receipt of said offer."

[4]The home sale process is similar in Australia, Norway, New Zealand, UK and Singapore, where homes are also auctioned off to potential buyers, with some variation in the institutional details. See Lusht (1994), Lusht (1996), Genesove and Hansen (2019) for Australia, Anundsen and Larsen (2018) for Norway, Dotzour, Moorhead, and Winkler (1998) for New Zealand, Merlo and Ortalo-Magné (2004) and Haurin, McGreal, Adair, Brown, and Webb (2013) for UK, Chow, Hafalir, and Yavas (2015) for Singapore, Han and Strange (2015) for Canada, Hungria-Gunnelin (2018) for Sweden, Stevenson and Young (2015) for Ireland. Usually, the bidding process stops when one of the buyers places the highest bid and none of the other buyers are interested in continuing, which is an English ascending auction.

from Milgrom and Weber (1982)'s linkage principle. In their setting new information does not change the allocation.

The paper contributes to several strands of literature. First, we add to the discussion of the optimal home selling strategies. Most of the prior literature[5] discussed the seller's choice of the asking price that allows to maximize the revenue except for Arnold and Lippman (1995), Quan (2002), Gan (2013) who consider the seller's choice between two mechanisms: sequential search and an auction. We add to this literature by allowing the seller to optimize over any individually rational and incentive-compatible selling mechanisms and information disclosure policy. We find that the optimal mechanism is the combination of the optimal auction and full information disclosure. This is consistent with the note in Adams, Kluger, and Wyatt (1992) that sellers should auction the property when facing several multiple buyers at once, although they do not consider the joint problem of selecting the mechanism and the information disclosure policy. If the distribution of buyers' values is symmetric, the optimal mechanism can be implemented by first releasing all available information about the house, for example, by allowing pre-bidding home inspections, and then running the second-price auction with an optimally set reserve price. We also allow asymmetric distributions of house values, in this sense being closest to Emmerling, Yavas, and Yildirim (2020).

Second, we contribute to the literature on information disclosure in real estate markets. Myers, Puller, and West (2020) study the mandate to disclose the home's energy efficiency, introduced in the City of Austin, Texas, in 2009, and provide empirical evidence that information disclosure policies helps to capitalize the home energy efficiency into house prices. They also find puzzling evidence that not all sellers comply with the disclosure policy. They use the bargaining model, which explains this puzzle through the existence of the information disclosure costs and the seller's ignorance about the energy efficiency costs.

We contribute to this discussion by allowing the seller to jointly choose the mechanism and information disclosure policy. The information disclosure could include any information that affects buyers' house valuations additively, for example, energy efficiency costs, potential future repair costs, past home improvements, and hidden home features. Within a general framework, we find that full information disclosure policy is part of the optimal mechanism. However, if the seller conducts a commonly used second-price auction, then

[5] Arnold (1999), Haurin, Haurin, Nadauld, and Sanders (2010), Merlo, Ortalo-Magné, and Rust (2015), Han and Strange (2016), Albrecht, Gautier, and Vroman (2016), Guren (2018) and further references in Han and Strange (2015).

the seller may find it optimal to conceal additional information. This could be an alternative explanation of the puzzling partial information disclosure in Myers, Puller, and West (2020).

Third, the paper contributes to the literature on bidding wars and auctions in housing markets[6] by allowing the seller to optimize over the selling mechanism and information disclosure. This provides theoretical grounds for analyzing the joint determination of prices, sales, probability of sale (inverse of the time on the market) using the bidding data across different countries and institutions settings.

1 The Model

A risk-neutral seller decides how to sell to one of $N \geq 1$ risk-neutral bidders. The seller's valuation of the house is normalized to zero. Denote the buyer i's true house value as V_i. When bidder i tours the house, he independently draws his signal of the value $v_i \sim F_i[\underline{v}_i, \overline{v}_i]$. The signal distributions F_i could be asymmetric. We assume that F_i has full support, and that $v_i - \frac{1-F_i(v_i)}{f_i(v_i)}$ is non-decreasing as in the standard auction models[7].

The seller has additional private information ϵ_i about the value of the house that she could reveal to the bidders. Revealing information reduces bidder i's house value to $V_i = v_i - \epsilon_i$, where $\mathbb{E}[\epsilon_i | v_1, \ldots, v_N] = 0$ for all v. One of the interpretations of this additive adjustment ϵ_i is the estimate of the future repair costs of bidder i. The ϵ_i's could be correlated with each other, but they are independent of v.

We analyze the optimal selling mechanism and information disclosure policy for the seller who commits to this mechanism and policy, as in standard auction models[8].

2 The Optimal Mechanism

We start by setting up the optimal mechanism problem of the seller. Generally, we could consider all possible mechanisms, including the indirect mechanisms in which a buyer

[6] Quan (1994), Mayer (1998), Haurin, McGreal, Adair, Brown, and Webb (2013), Han and Strange (2014), Stacey (2016), Smith (2019), Arefeva (2019).

[7] The requirement $v_i - \frac{1-F_i(v_i)}{f_i(v_i)}$ makes the marginal revenue function of the seller weakly decreasing in the probability of sale ("quantity").

[8] The assumption about the seller's commitment to the mechanism allows us to rely on the revelation principle, see the next section. It is a standard assumption is in the auction models because, if the seller cannot commit to the mechanism, we cannot use the revelation principle, significantly complicating the analysis, see Skreta (2015).

is asked to report some function of his signal such as a bid or a message. However, we concentrate on the truthful equilibria of direct mechanisms in which buyers directly report their signals. It is because of the revelation principle. The revelation principle guarantees that the outcome of any equilibrium of any mechanism can be implemented by a truthful equilibrium of some direct mechanism. Hence, we analyze a direct mechanism in which a buyer is asked to report his signal and the mechanism determines which buyer gets the house and how much each bidder pays.

Bidder i privately observes the signal v_i. Then bidder i submits report $\tilde{v}_i$ about his signal v_i. The seller can then release additional information ϵ. If the bidder did not make a report before the release of information, he must make a report after the release of information. In equilibrium, all bidders will report their signals right away, before the release of information, so this requirement is not binding. We require the bidder to make a report when the seller releases information. If the seller reveals additional private information ϵ, then it becomes common knowledge. We will relax this assumption in Section 5.

The seller can allocate the house and make transfers both before and after release of information. Suppose that bidders $i_1, ..., i_k$ report their signals before the information revelation. A mechanism consists of four functions $(X_{1i}, T_{1i}, X_{2i}, T_{2i})$ for each bidder i, where $X_{1i}(\tilde{v}_{i_1}, ..., \tilde{v}_{i_k}), T_{1i}(\tilde{v}_{1_i}, ..., \tilde{v}_{i_k})$ are the allocation and the transfer before releasing of information based on reported values $\tilde{v}$ and $X_{2i}(\tilde{v}_1, ..., \tilde{v}_N; \epsilon_1, ..., \epsilon_N), T_{2i}(\tilde{v}_1, ..., \tilde{v}_N; \epsilon_1, ..., \epsilon_N)$ are the allocation and transfer after the release of information based on the bidders' reports and repair costs.

The individual rationality (IR) constraints must be satisfied before and after the seller reveals additional information. Specifically, the mechanism must guarantee bidder i expected utility is non-negative if he makes a report before release of information, and at least ϵ_i after the release of information. The interpretation is that the buyer must be interested in following through with the house purchase both before and after the results of the inspection report are released.

The mechanism must also satisfy the incentive compatibility (IC) constraint. In particular, if the bidder makes a report before the release of information, then his IC constraint must take into account his payoffs before and after the release of information.

Theorem 2.1. *The optimal mechanism is to release the information and then run the optimal auction.*

Proof. We require that the optimal mechanism satisfies the individual rationality constraints, that is the expected utility of a bidder from participating in the mechanism is non-negative. Hence, each bidder i is willing to report his signal v_i in equilibrium. This allows us to simplify the notation below.

Let $v = (v_1, ..., v_N)$ and $\epsilon = (\epsilon_1, ..., \epsilon_N)$. A mechanism consists of four functions for each bidder i: $(X_{1i}(v), T_{1i}(v), X_{2i}(v; \epsilon), T_{2i}(v; \epsilon))$, where $X_{1i}(v), T_{1i}(v)$ are the allocation and the transfer for bidder i before the release of information based on reported values v and $X_{2i}(v; \epsilon), T_{2i}(v; \epsilon)$ are the allocation and transfer after the release of information based on the bidders' reports v and repair costs ϵ.

Since there is only one house, the allocation rule must satisfy

$$\sum_{i=1}^{N} X_{1i}(v) + \sum_{i=1}^{N} X_{2i}(v; \epsilon) \leq 1, \quad \forall \epsilon, v. \tag{2.1}$$

Let $T_{1i}(v_i) = \int_{v_{-i}} T_{1i}(v_i, v_{-i}) dv_{-i}$ and $P_{1i}(v_i) = \int_{v_{-i}} X_{1i}(v_i, v_{-i}) dv_{-i}$ denote bidder's i expected transfer and chance of receiving the house if the seller does not release the information. Similarly, $T_{2i}(v_i, \epsilon) = \int_{v_{-i}} T_{2i}(v_i, v_{-i}; \epsilon) dv_{-i}$ and $P_{2i}(v_i, \epsilon) = \int_{v_{-i}} X_{2i}(v_i, v_{-i}; \epsilon) dv_{-i}$ denote bidder's i expected transfer and chance of receiving the house if the seller releases the information.

The mechanism must satisfy the individual rationality (IR) constraints for each bidder if the seller does not release the information

$$P_{1i}(v_i) v_i - T_{1i}(v_i) \geq 0,$$

and if the seller releases the information

$$P_{2i}(v_i, \epsilon)(v_i - \epsilon_i) - T_{2i}(v_i, \epsilon_i) \geq 0.$$

The bidder decides whether to report the signal v_i', and then the seller decides whether to disclosure the information. Because the individual rationality constraints are satisfied, all bidders report the signal independently of the information disclosure policy of the seller. The mechanism must satisfy the incentive compatibility (IC) constraint which ensures that bidder i is motivated to report the true signal $v_i' = v_i$:

$$\begin{aligned} S_i(v_i) = \max_{v_i'} \{ & P_{1i}(v_i') v_i - T_{1i}(v_i') + \mathbb{E}_\epsilon [P_{2i}(v_i', \epsilon)(v_i - \epsilon_i) - T_{2i}(v_i', \epsilon) + \\ & + (1 - P_{1i}(v_i') - P_{2i}(v_i', \epsilon)) \times 0] \}, \end{aligned}$$

where $S_i(v_i)$ is bidder's i expected utility from participating in the mechanism.

The envelope theorem implies that

$$S_i(v_i) = S_i(\underline{v}_i) + \int_{\underline{v}_i}^{v_i} P_{1i}(x)dx + \mathbb{E}_\epsilon \int_{\underline{v}_i}^{v_i} P_{2i}(x,\epsilon)dx, \tag{2.2}$$

where $S_i(\underline{v}_i) = 0$.

Given that we require the mechanism to be incentive-compatible, the bidders report the signals truthfully, $v_i' = v_i$, and the expected utility from the IC constraint is

$$S_i(v_i) = P_{1i}(v_i)v_i - T_{1i}(v_i) + \mathbb{E}_\epsilon[P_{2i}(v_i,\epsilon)(v_i - \epsilon_i) - T_{2i}(v_i,\epsilon_i)]. \tag{2.3}$$

The seller's profit from type v_i is

$$\pi_i(v_i) = T_i(v_i) + \mathbb{E}_\epsilon T_{2i}(v_i,\epsilon_i).$$

Rearranging (2.3) and using (2.2) gives

$$\begin{aligned}&\pi_i(v_i) = T_i(v_i) + \mathbb{E}_\epsilon T_{2i}(v_i,\epsilon_i) = \\ &= P_{1i}(v_i)v_i + \mathbb{E}_\epsilon P_{2i}(v_i,\epsilon)(v_i-\epsilon_i) - \int_{\underline{v}_i}^{v_i} P_{1i}(x)dx - \mathbb{E}_\epsilon \int_{\underline{v}_i}^{v_i} P_{2i}(x,\epsilon)dx.\end{aligned}$$

Then the expected profit from bidder i is

$$\begin{aligned}\int_{\underline{v}_i}^{\bar{v}_i} \pi_i(v_i)f_i(v_i)dv_i = \int_{\underline{v}_i}^{\bar{v}_i} [P_{1i}(v_i)v_i - \int_{\underline{v}_i}^{v_i} P_{1i}(x)dx + \\ + \mathbb{E}_\epsilon P_{2i}(v_i,\epsilon)(v_i-\epsilon_i) - \mathbb{E}_\epsilon \int_{\underline{v}_i}^{v_i} P_{2i}(x,\epsilon)dx]f_i(v_i)dv_i.\end{aligned}$$

Denote $u(v_i) = \int_{\underline{v}_i}^{v_i} P_{1i}(x)dx$ and apply integration by parts to terms of type $\int_{\underline{v}_i}^{\bar{v}_i}\int_{\underline{v}_i}^{v_i} P_{1i}(x)dxf_i(v_i)dv_i = \int_{\underline{v}_i}^{\bar{v}_i} u(v_i)f_i(v_i)dv_i$:

$$\begin{aligned}&\int_{\underline{v}_i}^{\bar{v}_i} u(v_i)f_i(v_i)dv_i = -\int_{\underline{v}_i}^{\bar{v}_i} u(v_i)d(1-F_i(v_i)) = \\ &= -[u(v_i)(1-F_i(v_i))|_{\underline{v}_i}^{\bar{v}_i} - \int_{\underline{v}_i}^{\bar{v}_i}(1-F_i(v_i))du(v_i)] = \int_{\underline{v}_i}^{\bar{v}_i}(1-F_i(v_i))P_{1i}(v_i)dv_i\end{aligned}$$

The seller's expected profit from bidder i can be rewritten as

$$\int_{\underline{v}_i}^{\bar{v}_i} \pi_i(v_i) f_i(v_i) dv_i = \int_{\underline{v}_i}^{\bar{v}_i} [P_{1i}(v_i)(v_i - \frac{(1-F_i(v_i))}{f_i(v_i)}) + \mathbb{E}_\epsilon P_{2i}(v_i,\epsilon)(v_i - \epsilon_i) - \frac{(1-F_i(v_i))}{f_i(v_i)}] f_i(v_i) dv_i.$$

Now we use Bulow and Roberts (1989)'s analogy between the problem of the monopolist and the problem of the seller in the auction. Let $G(V)$, $g(V)$ denote the pdf and cdf of house value V. Then we can think about the probability of sale, $q = 1 - G(V)$, as the quantity, the bid $V = G^{-1}(1-q)$ as the price, the profit, or revenue, as their product $q \times V$. Then the marginal revenue is

$$\begin{aligned} MR = \frac{dqG^{-1}(1-q)}{dq} &= G^{-1}(1-q) + q\frac{dG^{-1}(1-q)}{dq} = \\ = G^{-1}(1-q) - \frac{q}{f(G^{-1}(1-q))} &= V - \frac{1-G(V)}{g(V)} \end{aligned}$$

This expression for the marginal is often called the virtual value, where the term $(1 - G(V))/g(V)$ is referred to as the information rent. The information rent represents the surplus that a buyer gets because he has private information on how suitable is the seller's house for his needs.

If the seller conceals the information, then the best estimate of buyer i's house value is $V_i = v_i$, and, if the seller releases information, $V_i = v_i - \epsilon_i$. Our simplifying assumption is that the additive adjustments ϵ become common knowledge when the seller releases information. Because of this assumption, the distributions of the true value and signal coincide, e.g. $G(V) = F(v)$, and the information rent can be rewritten using the distribution of signals as $(1 - F(v))/f(v)$. We show in Section 5 that the seller can achieve the same expected revenue if additive adjustments ϵ are private information of buyers so deviating from this simplifying assumption is without loss of generality.

If the seller does not reveal information, the marginal revenue from bidder i is

$$MR_{1i}(v_i) = v_i - \frac{1-F_i(v_i)}{f_i(v_i)}.$$

If the seller reveals information, the marginal revenue from bidder i is

$$MR_{2i}(v_i,\epsilon_i) = v_i - \epsilon_i - \frac{1-F_i(v_i)}{f_i(v_i)} = MR_{1i}(v_i) - \epsilon_i$$

We can use the marginal revenue functions to rewrite the expected seller's profit from bidder i as

$$\int_{\underline{v}_i}^{\bar{v}_i} \pi_i(v_i) f_i(v_i) dv_i = \int_{\underline{v}_i}^{\bar{v}_i} [P_{1i}(v_i) MR_{1i}(v_i) + \mathbb{E}_\epsilon P_{2i}(v_i, \epsilon) MR_{2i}(v_i, \epsilon)] f_i(v_i) dv_i.$$

For each vector of types v, the seller chooses the allocation probabilities $P_{1i}(v_i)$ and $P_{2i}(v_i, \epsilon)$ to maximize the expected profit from all bidders:

$$\sum_{i=1}^{N} P_{1i}(v_i) MR_{1i}(v_i) + \mathbb{E}_\epsilon \sum_{i=1}^{N} P_{2i}(v_i, \epsilon) MR_{2i}(v_i, \epsilon).$$

From the feasibility constraint (2.1), we know that

$$\sum_{i=1}^{N} (P_{1i}(v_i) + P_{2i}(v_i, \epsilon)) \leq 1.$$

Notice that if $\max_i MR_{1i}(v_i) \leq 0$ for all bidders, then the seller should release the information. So if $\max_i MR_{1i}(v_i) > 0$ for some bidder i, then without loss of generality assume that bidder 1 has the highest marginal revenue MR, and let P_1 denote the probability of distributing the house to this bidder under no-disclosure policy, e.g. $P_{11}(v_1)$. Then under the policy of full information disclosure, the seller should allocate the object to the bidder with the highest marginal revenue with probability $1 - P_1$. Then the seller's expected profit is equal to

$$\begin{aligned} &\mathbb{E}_v[P_1 \cdot \max\{MR_{11}(v_1), \ldots, MR_{1N}(v_N), 0\} + \\ &+ (1 - P_1) \cdot \mathbb{E}_\epsilon \max\{MR_{21}(v_1, \epsilon_1), \ldots, MR_{2N}(v_N, \epsilon_N), 0\}]. \end{aligned}$$

Since $\mathbb{E}[\epsilon|v] = 0$ and max is convex, then by the Jensen's inequality

$$\max\{MR_{11}(v_1), \ldots, MR_{1N}(v_N), 0\} \leq \mathbb{E}_\epsilon \max\{MR_{21}(v_1, \epsilon_1), \ldots, MR_{2N}(v_N, \epsilon_N), 0\}.$$

Hence, the seller should set $P_1 = 0$. We also use this argument to prove theorem 3.1. So in the optimal mechanism the seller discloses the information and allocates the house to the bidder with the highest MR if the highest MR is positive. This describes Myerson (1981)'s optimal auction after seller's release of information. Hence, the optimal mechanism is then a combination of the full information disclosure policy and the optimal auction.

According to the mechanism, the bidders have to report their values after the information is disclosed, but not before. But the same argument can be made only if a subset of bidders report their values before information disclosure because

$$\max\{MR_{11}(v_1), \ldots, MR_{1k}(v_k), 0\} \leq \max \mathbb{E}_\epsilon\{MR_{11}(v_1), \ldots, MR_{1N}(v_N), 0\}.$$

Therefore, the optimal mechanism includes two rounds: first, the seller discloses information and then runs an optimal auction. □

3 Information Disclosure in the Optimal Auction

We have shown that the optimal mechanism for the seller is releasing information and running an optimal auction. However, this requires optimizing over both the mechanism and the information disclosure policy. What if the seller selected a mechanism beforehand, and then decides on the optimal information disclosure policy? In this and next sections we consider the problem of choosing the optimal information disclosure policy, conditional on the format of the auction. We start with the optimal auction as it is part of the optimal mechanism. Then in the next section, we consider the second-price auction because it is often used in real estate auctions.

In analyzing the optimal auction, we write it down as the direct mechanism as in the previous section, so that buyers report their signals v and the seller decides which buyer gets the house and how much the buyer pays. When house values are symmetrically distributed, this mechanism can be implemented as the second-price auction with an optimally selected reserve price[9]. Because we allow asymmetric distributions, the implementation of the optimal auction in our setting can be the second-price auction with the optimally selected buyer-specific reserve prices. But asymmetric, non-anonymous treatment of different buyers is often prohibited or undesirable, see Deb and Pai (2017) for discussion.

In the optimal auction, the buyer submits their reports v_i, then the seller calculates the marginal revenue from each bidder MR_i. If the marginal revenue of every bidder is negative, then the seller retains the house. Otherwise, she allocates the house to the bidder with the highest marginal revenue.

[9] Bidding starts at the reserve price, and the buyer who bids the most gets the house and pays the second-highest price.

The seller's expected revenue under no disclosure policy is

$$R_1 = \mathbb{E}_v \max\{MR_{11}(v_1), \ldots, MR_{1N}(v_N), 0\}, \tag{3.1}$$

where zero represents the marginal revenue that the seller gets if she keeps the house.

If the seller discloses information, then her revenue is

$$\begin{aligned} R_2 &= \mathbb{E}_\epsilon \mathbb{E}_v \max\{MR_{21}(v_1, \epsilon_1), \ldots, MR_{2N}(v_N, \epsilon_N), 0\} \\ &= \mathbb{E}_\epsilon \mathbb{E}_v \max\{MR_{11}(v_1) - \epsilon_1, \ldots, MR_{1N}(v_N) - \epsilon_N, 0\}. \end{aligned} \tag{3.2}$$

Since $\mathbb{E}[\epsilon|v] = 0$ and max is convex, the Jensen's inequality implies that $R_2 \geq R_1$. Hence, the seller should reveal information. Bulow and Klemperer (1996) used the convexity argument to show that a second-price auction with $N+1$ bidders generates more revenue than an optimal auction with N bidders. We summarize our result as Theorem 3.1:

Theorem 3.1. *If the seller runs an optimal auction, it is optimal for the seller to disclose all available information.*

We have thus far demonstrated that the expected revenue increases if the seller reveals information in an optimal auction. Could we obtain similar results for the expected efficiency gains and information rent? Unfortunately, we cannot derive an analog of Theorem 3.1 because the efficiency and information rent are neither convex nor concave, see Appendix A.

The conclusion of Theorem 3.1 is similar to the Milgrom and Weber (1982)'s linkage principle that states that revealing information increases the seller's revenue. To understand this, decompose the efficiency gains from allocation of the house to the bidder as the sum of the seller's revenue and the winning bidder's information rent. In Milgrom and Weber (1982), new information is correlated with bidders' value estimates. So the release of new information increases the bidders' estimates without changing the winning bidder, i.e. without changing the allocation. However, making the information public reduces the information rent that the winning bidder earns. Because the revenue is the efficiency net of the information rent, the revenue increases.

How is our result different from the linkage principle? In our setting revealing information could change the allocation of the house and the information rent might go up, in which case the efficiency increases even more.

Our result on the optimality of the full information disclosure in the optimal auction is consistent with the result on the optimal mechanism. Within the optimal mechanism problem, the seller can optimize over the mechanism and information disclosure policy at the same time, the seller chooses to fully disclose the information and run the optimal auction. So if the seller first selects the optimal auction as the selling mechanism, and then optimizes over the information disclosure policy, the seller should release additional information.

4 The Second-price Auction

We turn to the second-price auction with no reserve price. In this auction, the buyer with the highest bid wins and pays the second-highest bid. The dominant strategy for a buyer is to bid[10] his estimate of the house value V_i.

We start our discussion of the information disclosure in the second-price with a special case of two bidders, then move on to three bidders and then summarize results for any number of bidders.

4.1 Two Bidders

Board (2009) discovered that in the case of two bidders the seller should not reveal information.

Proposition 4.1. *(From Board (2009)) In a second-price auction with two bidders the seller should not reveal any information.*

Proof. The buyer's dominant strategy in the second-price auction is to bid his estimate of the house value. If the seller does not reveal information the value of ϵ, bidder i's estimate of the house value is given by i's signal $V_i = v_i - \mathbb{E}_i \epsilon_i = v_i$. The winning buyer pays the second highest price, which is $\min\{v_1, v_2\}$ in the case of two bidders. Hence, if the seller does not reveal information, her expected revenue is

$$R_1 = \mathbb{E}_v \min\{v_1, v_2\}.$$

[10]We allow the bidders to place negative bids. Since we normalized the house value of the seller to zero, we interpret negative bids as values below the seller's assessment of the house value.

If the seller reveals additional information ϵ, her revenue equals

$$R_2 = \mathbb{E}_\epsilon \mathbb{E}_v \min\{v_1 - \epsilon_1, v_2 - \epsilon_2\}.$$

Since minimum is a concave function, Jensen's inequality implies that $R_1 \geq R_2$, so the seller should never reveal information. $\square$

At first glance, Proposition 4.1 seems to contradict Proposition 3.1. Indeed, if the value distributions are symmetric, and the seller is committed to sell, then the optimal auction is equivalent to the second-price auction. To highlight this apparent contradiction consider the symmetric case, i.e. $F_1 = F_2$. We have

$$\mathbb{E}_v \min\{v_1, v_2\} = \mathbb{E}_v \max\{MR_{11}(v_1), MR_{12}(v_2)\}.$$

Hence, the seller's revenue from not revealing information is the same in Proposition 3.1 and Proposition 4.1. Why then should the seller reveal information in the optimal auction and not reveal information in the second-price auction? The difference occurs after the seller reveals information.

Revealing information makes the bidders' value distributions asymmetric because ϵ_1 and ϵ_2 could be different. Because the bidders' value distributions become asymmetric, the revenue equivalence theorem may not hold, as argued by Maskin and Riley (2000). Specifically, when the bidders' values are asymmetrically distributed, the seller may not allocate the good to the bidder with the highest marginal revenue in the second-price auction. As a result, the second-price auction yields less expected revenue than the optimal auction after the seller reveals information, which explains why the optimal information disclosure strategies differ for these two auctions.

4.2 More than Two Bidders

We next analyze the seller's expected revenue when there are more than two bidders. The key to determining the optimal information disclosure strategy is the functional form of the expected revenue with respect to new information ϵ. As discussed in the previous two sections, the seller's expected revenue is convex in ϵ in the optimal auction and concave in ϵ in the second-price auction with two bidders. When the seller's revenue is convex, the full information disclosure is optimal, and vice versa for the second-price auction with two bidders. In this section, we show that, when there are more than two bidders in the second-price auction, the expected revenue is neither convex nor concave in general.

Hence, the seller the optimal information disclosure may depend on the parameters of the environment.

We use an example to argue that if the seller releases information, the expected revenue is neither convex or concave. Consider a example with three bidders in which $v_1 > v_2 > v_3 > ... > v_N$ and $\epsilon_i = 0$ for all $i \neq 3$. Now we show that, as we vary ϵ_3, the expected revenue is neither convex nor concave.

The buyers' dominant strategies is to place bids $b_1 = v_1, b_2 = v_2$ and $b_3 = v_3 - \epsilon_3$. When $\epsilon_3 > v_3 - v_2$, the ranking of the bids is $v_1 > v_2 > v_3 - \epsilon_3$, so the first bidder wins and pays the second-highest bid v_2. When $v_3 - v_2 > \epsilon_3 > v_3 - v_1$, the ranking of the bids is $v_1 > v_3 - \epsilon_3 > v_2$, so the first bidder wins and pays the second highest-bid $v_3 - \epsilon_3$. Finally, when $\epsilon_3 < v_3 - v_2$, we know that $v_3 - \epsilon_3 > v_1 > v_2$, so the third bidder gets the house and pays v_1. Figure 1 plots the seller's expected revenue as the function of the additive innovation for the third bidder ϵ_3. As can be seen from the graph, the seller's revenue is neither convex nor concave in ϵ_3. Hence, the seller's optimal information disclosure policy depends on realization of ϵ_3 and ambiguous in general.

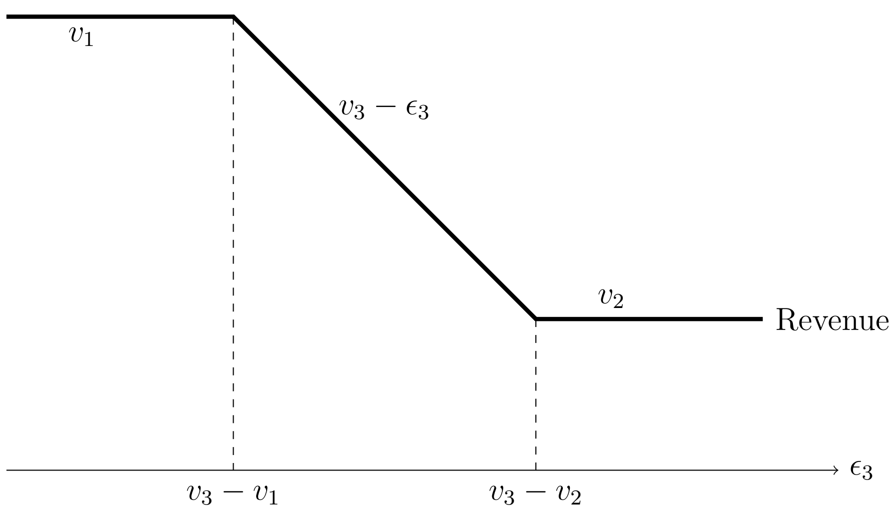

Figure 1: The revenue is concave when the allocation changes.

We can generalize this observation to the case of N bidders. Notice that in Figure 1 the revenue is concave at $v_3 - v_1$ and convex at $v_3 - v_2$. When ϵ_3 is close to $v_3 - v_1$, the allocation of the house changes between buyer 1 and buyer 3, so the second-price is the minimum of the bids of buyers 1 and 3, which is concave. When ϵ_3 is close to $v_3 - v_2$, bidder 1 always gets the house, so the second-price is the maximum of the bids of buyers 2 and 3, which is convex.

The next proposition formalizes the above observation that the non-convexity of the revenue is due to the change in allocation. To generalize this, we return to considering any ranking of $v_1, v_2, \ldots, v_N$ and any $\epsilon \in \mathbb{R}^N$. Let $SP(\epsilon)$ denote the second largest element of $\{v_i - \epsilon_i\}_{i=1}^N$. We say that $SP(\epsilon)$ is locally convex (or concave) if there exists a $\delta > 0$ such that the $SP(\epsilon)$ function is convex (or concave) when we restrict its domain to points within a Euclidean distance of δ from ϵ.

Proposition 4.2. *Let $M = \max\{v_1 - \epsilon_1, \ldots, v_N - \epsilon_N\}$.*

- *If there is exactly one i such that $v_i - \epsilon_i = M$, then $SP(\epsilon)$ is locally convex.*
- *If there are exactly two i's such that $v_i - \epsilon_i = M$, then $SP(\epsilon)$ is locally concave.*
- *If there are at least three i's such that $v_i - \epsilon_i = M$, then $SP(\epsilon)$ is neither locally convex nor locally concave.*

Proof. Renumber buyers so that the buyer with the highest bid $v_i - \epsilon_i$ is the first, the second-highest bid as the second, and so forth. Then $M = v_1 - \epsilon_1 \geq v_2 - \epsilon_2 \geq \cdots \geq v_N - \epsilon_N$.

If $v_1 - \epsilon_1 > v_2 - \epsilon_2$, then, for small enough perturbations of ϵ, bidder 1 is still the highest bidder, so the second-price is the maximum of the bids from bidders $2, 3, \ldots, N$, which is convex.

If $v_1 - \epsilon_1 = v_2 - \epsilon_2 > v_3 - \epsilon_3$, then, for small enough perturbations of ϵ, either bidder 1 or bidder 2 is the highest bidder, and the second price is the minimum of the bids from bidder 1 and bidder 2, which is concave.

If $v_1 - \epsilon_1 = v_2 - \epsilon_2 = \cdots = v_k - \epsilon_k$ for some $k \geq 3$, then, for small enough perturbations of ϵ, the second-price is the second order statistics of the k bidders' bids, which is neither convex nor concave. $\square$

The logic of Proposition 4.2 is that if the highest bidder remains the same, then the second-price is the maximum of the remaining bidders' bids, which is convex. But if the highest bidder changes due to ϵ, the revenue is non-convex. Hence, the non-convexity of the revenue for the second-price auction comes from the change in allocation of the house from the highest bidder before the release of information to the new highest bidder after the release of information.

In the optimal auction, the change in allocation makes the revenue function convex. Specifically, when the allocation changes from bidder i to bidder j, the revenue is the convex function $\max\{MR_i, MR_j\}$. In the second-price auction, however, the change in allocation breaks the convexity of the revenue function. The non-convexity occurs precisely at the points when the allocation changes as Proposition 4.2 shows.

5 The Seller Cannot Observe Information ϵ

Thus far we have assumed that the seller could observe additional information ϵ, e.g. repair costs of buyers. Buyers may reveal this additional information during the house selling process, for example, by asking the seller to reduce the price by the estimated repair costs after the home inspection. However, it is also possible that buyers do not reveal this additional information. Hence, an immediate concern is that, if the seller cannot observe ϵ, then the bidders could extract more information rent, so the seller may not want to reveal information in the optimal auction. We show that this concern can be resolved by using a handicap auction, suggested by Eso and Szentes (2007), which gives her the same expected revenue as in the case when ϵ is observable. To illustrate how the handicap auction works, we start with an example.

Example 5.1. There is one bidder. Suppose $\epsilon \sim U[-\frac{1}{2}, \frac{1}{2}]$ and the distribution of v is degenerate with $v = 0$ with probability one. The seller can use any selling mechanism and choose between disclosing or not additional value adjustments ϵ. We want to compare the expected revenue from the optimal behavior of the seller when we observe ϵ and when he does not.

First, consider the case when the seller observes ϵ. If she does not reveal information, the expected revenue is zero, the buyer values the house at zero, so $R_1 = 0$. If the seller reveals information, she could use the optimal auction. In this setting with one buyer, the optimal auction is equivalent to charging a posted price of $-\epsilon$ whenever it is negative. So the seller's expected revenue is then $R_2 = \mathbb{E}\max\{-\epsilon, 0\} = \int_{-\frac{1}{2}}^{0}(-\epsilon)d\epsilon = 1/8$.

Now consider the case when the seller does not observe ϵ. The seller still decides whether or not to release the information about ϵ. For example, the seller can allow buyers to conduct a home inspection to determine the repair costs. The buyers' estimate of the repair costs may not be observable to the seller, but she can still decide whether or not to allow the buyer to conduct the inspection.

In this case, the seller could use the following mechanism: the buyer must pay 1/8 for information on ϵ, and then the buyer could purchase the house for a zero price. Zero is only a normalization of the buyer's value in this example, we do not mean that the seller is giving out the house for free. The buyer is willing to pay for this information because the buyer's expected payoff after information disclosure is exactly $\int_{-1/2}^{0}(-\epsilon)\cdot d\epsilon = 1/8$. Hence, when ϵ is unobservable, the seller extracts the same revenue as in the case when ϵ is observable.

The key insight from Example 5.1 is that the seller could take advantage of the bidders' uncertainty about additional information ϵ and ask them to pay for this information before it is revealed. In general, the handicap auction is conducted in two rounds:

1. Bidder i reports v_i' and pays $c_i(v_i')$ to receive the information about ϵ_i and an option to purchase the house in the second round. Then the seller reveals the information ϵ to buyers.

2. The seller runs a modified second-price auction with zero reserve price: the highest bidder has the option to purchase the house at the price, equal to the sum of the second-highest price and an additional premium of $(1 - F_i(v_i'))/f_i(v_i')$. The winning buyer decides whether to buy the house or not.

The contracts offered in the first round are similar to European call options because the buyer buys the right to purchase the house in the second round at a specific premium.

This mechanism produces the same expected revenue as the optimal mechanism when ϵ is unobservable if the price for information $c_i(v_i')$ is selected to incentivize truth-telling $v_i' = v_i$. To see this, first, notice that the handicap auction allocates the house to the bidder with the highest marginal revenue. Indeed, bidder i's house value is $v_i - \epsilon_i$, but he has to pay an additional premium $(1 - F_i(v_i))/f_i(v_i)$ if he wins the auction. So the bidder's strategy is to bid $v_i - \epsilon_i - (1 - F_i(v_i))/f_i(v_i)$, which is precisely his marginal revenue $MR_i(v_i, \epsilon_i)$. Hence, the bidder with the highest marginal revenue gets the house.

Second, consider the behavior of the bidder in the second round given his report v_i'. The buyer submits his bid and decides if he wants to exercise his option to purchase the house at the second-highest price. Since the option price $c(v_i')$ is sunk, he ignores it when deciding whether to move forward with the house purchase at the end of the auction. His second-round utility is

$$U_i(v_i, v_i') = \mathbb{E}_{v_{-i}}\mathbb{E}_\epsilon \max\{v_i - \epsilon_i - \frac{1 - F_i(v_i')}{f_i(v_i')} - b^{(2)}, 0\} = \tag{5.1}$$

$$= \mathbb{E}_{v_{-i}}\mathbb{E}_\epsilon (v_i - \epsilon_i - \frac{1 - F_i(v_i')}{f_i(v_i')} - b^{(2)}) \mathbf{1}\left(v_i - \epsilon_i - \frac{1 - F_i(v_i')}{f_i(v_i')} - b^{(2)} \geq 0\right), \tag{5.2}$$

where $b^{(2)} = \max_{j \neq i}\{v_j - \epsilon_j - (1 - F_j(v_j))/f_j(v_j), 0\}$ is the second-price that accounts for zero reserve price and $\partial U_i(v_i, v_i')/\partial v_i = \mathbb{E}_{v_{-i}}\mathbb{E}_\epsilon \mathbf{1}\left(v_i - \epsilon_i - \frac{1-F_i(v_i')}{f_i(v_i')} - b^{(2)} \geq 0\right)$.

Finally, the bidder reports truthfully $v_i' = v_i$ in the first round if the incentive compatibility constraint holds:

$$S_i(v_i) = \max_{v_i'}(U_i(v_i, v_i') - c_i(v_i')) \tag{5.3}$$

We can set the price for the option to buy the house, $c_i(v_i')$, in (5.3) as

$$c_i(v_i') = U_i(v_i, v_i') - S_i(v_i') \tag{5.4}$$

to incentivize the bidder to report truthfully. That is, in the right-hand side of (5.3), $v_i = v_i'$ solves

$$\max_{v_i'}(U_i(v_i, v_i') - U_i(v_i, v_i') + S_i(v_i')) = \max_{v_i'} S_i(v_i') = S_i(v_i)$$

Since the second-highest price does not depend on v_i or v_i', we can apply the Envelope Theorem to (5.3) so that $dS(v_i)/dv_i = dU(v_i, v_i')/dv_i = \partial U_i(v_i, v_i')/\partial v_i$ at $v_i' = v_i$. Integrating $dS(v_i)/dv_i = \partial U_i(v_i, v_i)/\partial v_i$ and using the Fubini's theorem to exchange the expectation and integration gives us the bidder's expected payoff from the mechanism:

$$S_i(v_i) = \mathbb{E}_{v_{-i}}\mathbb{E}_{\epsilon} \int_{\underline{v}_i}^{v_i} \mathbf{1}\left(x - \epsilon_i - \frac{1 - F_i(x)}{f_i(x)} - b^{(2)} \geq 0\right) dx \tag{5.5}$$

Hence, the combination of correctly set price for information $c_i(v_i)$ allows the seller to maximize revenue by eliciting the true signals of buyers v_i without observing them directly.

6 Conclusion

In this paper, we analyze the optimal mechanism and information disclosure policy for a homeowner who maximizes the expected revenue from the sale when one or more buyers are interested in the house. We find that the optimal mechanism is a combination of the optimal auction and full information disclosure. We then show that if the seller first selects the optimal auction as the selling mechanism and then optimizes over the information disclosure policy, full information disclosure is still optimal.

We also investigate the optimal information disclosure for the home seller who uses the second-price auction for three reasons. First, the implementation of the optimal auction is challenging, while the second-price auction is easier to conduct and detail-free. Second, we allow for asymmetric distributions of home values, so the revenue equivalence theorem does not necessarily hold, and different auction types may not produce the same revenue. Third, the second-price auction is often used in practice in real estate auctions. For the second-price auctions, we show that the result of the full information disclosure breaks down, so the seller may find it optimal to conceal information to maximize expected revenue.

We explain that the key to understanding the optimal mechanism and information disclosure policy is how the information disclosure affects the allocation of the house. In the optimal mechanism and optimal auction, the revenue is a convex function in new information. Then revealing information maximizes expected revenue. In the second-price auction, the revenue can be either convex or concave in new information. In this case, the seller's optimal information disclosure depends on the specific circumstances, potentially explaining partial information disclosure policies in practice.

This study shows that there is potential for improving the selling mechanism for real estate assets, including implementation of the full information disclosure policies by the sellers and use of optimal auctions when one or multiple buyers are involved.

The model is highly stylized, focuses on the selling mechanisms while abstracting from other institutional details of real estate markets. For example, we do not consider the common house values or market dynamics among other realistic features of real estate markets. We hope to spur future research in these directions. The model can be applied to other markets, in which the seller is dealing directly with the buyers and there is a significant component of the idiosyncratic buyer's taste in the value of the good and the seller can release additional information that adjusts this value.

References

Adams, P. D., B. D. Kluger, and S. B. Wyatt (1992): "Integrating auction and search markets: the slow Dutch auction," The Journal of Real Estate Finance and Economics, 5, 239–253.

Albrecht, J., P. A. Gautier, and S. Vroman (2016): "Directed search in the housing market," Review of Economic Dynamics, 19, 218 – 231, special Issue in Honor of Dale Mortensen.

Anundsen, A. K. and E. R. Larsen (2018): "Testing for Micro-efficiency in the Housing Market," International Economic Review, 59, 2133–2162.

Arefeva, A. (2019): "How Auctions Amplify House-Price Fluctuations," Working Paper.

Arnold, M. A. (1999): "Search, Bargaining and Optimal Asking Prices," Real Estate Economics, 27, 453–481.

Arnold, M. A. and S. A. Lippman (1995): "Selecting a selling institution: Auctions versus Sequential Search," Economic Inquiry, 33, 1–23.

Board, S. (2009): "Revealing Information in Auctions: the Allocation Effect," Economic Theory, 38, 125–135.

Bulow, J. and P. Klemperer (1996): "Auctions Versus Negotiations," American Economic Review, 86, 180–194.

Bulow, J. and J. Roberts (1989): "The Simple Economics of Optimal Auctions," Journal of Political Economy, 97, 1060–90.

Chow, Y. L., I. E. Hafalir, and A. Yavas (2015): "Auction versus Negotiated Sale: Evidence from Real Estate Sales," Real Estate Economics, 43, 432–470.

Deb, R. and M. M. Pai (2017): "Discrimination via Symmetric Auctions," American Economic Journal: Microeconomics, 9, 275–314.

Dotzour, M., E. Moorhead, and D. Winkler (1998): "The Impact of Auctions on Residential Sales Prices in New Zealand," Journal of Real Estate Research, 16, 57–72.

Emmerling, T. J., A. Yavas, and Y. Yildirim (2020): "To accept or not to accept: Optimal strategy for sellers in real estate," Real Estate Economics.

Eso, P. and B. Szentes (2007): "Optimal Information Disclosure in Auctions and the Handicap Auction," Review of Economic Studies, 74, 705–731.

Gan, Q. (2013): "Optimal Selling Mechanism, Auction Discounts and Time on Market," Real Estate Economics, 41, 347–383.

Genesove, D. and J. Hansen (2019): "The Role of Auctions and Negotiation in Housing Prices," Reserve Bank of Australia Research Discussion Paper.

Gilbukh, S. and P. Goldsmith-Pinkham (2020): "Heterogeneous Real Estate Agents and the Housing Cycle," Working Paper.

Guren, A. M. (2018): "House Price Momentum and Strategic Complementarity," Journal of Political Economy, 126, 1172–1218.

Han, L. and W. C. Strange (2014): “Bidding Wars for Houses,” Real Estate Economics, 42, 1–32.

——— (2015): “The Microstructure of Housing Markets: Search, Bargaining, and Brokerage,” Handbook of Regional and Urban Economics, 5, 813–886.

——— (2016): “What is the role of the asking price for a house?” Journal of Urban Economics, 93, 115–130.

Haurin, D., S. McGreal, A. Adair, L. Brown, and J. R. Webb (2013): “List price and sales prices of residential properties during booms and busts,” Journal of Housing Economics, 22, 1 – 10.

Haurin, D. R., J. L. Haurin, T. Nadauld, and A. Sanders (2010): “List Prices, Sale Prices and Marketing Time: An Application to U.S. Housing Markets,” Real Estate Economics, 38, 659–685.

Hungria-Gunnelin, R. (2018): “An analysis of auction strategies in apartment sales,” Journal of European Real Estate Research, 11, 202–223.

Levitt, S. D. and C. Syverson (2008): “Market Distortions When Agents Are Better Informed: The Value of Information in Real Estate Transactions,” Review of Economics and Statistics, 90, 599–611.

Lusht, K. M. (1994): “Order and price in a sequential auction,” The Journal of Real Estate Finance and Economics, 8, 259–266.

——— (1996): “A Comparison of Prices Brought by English Auctions and Private Negotiations,” Real Estate Economics, 24, 517–530.

Maskin, E. and J. Riley (2000): “Asymmetric Auctions,” The Review of Economic Studies, 67, 413–438.

Mayer, C. J. (1998): “Assessing the Performance of Real Estate Auctions,” Real Estate Economics, 26, 41–66.

Merlo, A. and F. Ortalo-Magné (2004): “Bargaining over residential real estate: evidence from England,” Journal of Urban Economics, 56, 192 – 216.

Merlo, A., F. Ortalo-Magné, and J. Rust (2015): "THE HOME SELLING PROBLEM: THEORY AND EVIDENCE," International Economic Review, 56, 457–484.

Milgrom, P. and R. Weber (1982): "A Theory of Auctions and Competitive Bidding," Econometrica, 50, 1089–1122.

Myers, E., S. L. Puller, and J. West (2020): "Mandatory Energy Efficiency Disclosure in Housing Markets," Working Paper, n/a.

Myerson, R. B. (1981): "Optimal Auction Design," Mathematics of Operations Research, 6, 58–73.

Ngai, L. R. and S. Tenreyro (2014): "Hot and Cold Seasons in the Housing Market," American Economic Review, 104, 3991–4026.

Quan, D. C. (1994): "Real Estate Auctions: A Survey of Theory and Practice," Journal of Real Estate Finance and Economics, 23–49.

——— (2002): "Market Mechanism Choice and Real Estate Disposition: Search Versus Auction," Real Estate Economics, 30, 365–384.

Rutherford, R., T. Springer, and A. Yavas (2005): "Conflicts between principals and agents: evidence from residential brokerage," Journal of Financial Economics, 76, 627 – 665.

Skreta, V. (2015): "Optimal auction design under non-commitment," Journal of Economic Theory, 159, 854 – 890, symposium Issue on Dynamic Contracts and Mechanism Design.

Smith, E. (2019): "High and low activity spells in housing markets," Review of Economic Dynamics.

Stacey, D. (2016): "COMMITMENT AND COSTLY SIGNALING IN DECENTRALIZED MARKETS," International Economic Review, 57, 1507–1533.

Stevenson, S. and J. Young (2015): "The Role of Undisclosed Reserves in English Open Outcry Auctions," Real Estate Economics, 43, 375–402.

A Disclosure and Efficiency and Information Rent

The Optimal Auction In Theorem 3.1 we used a convexity argument to prove that revenue increases after the seller discloses information. Can we apply the same argument to study the effect of information disclosure on the efficiency and information rent? Unfortunately, the efficiency and information rent are neither convex nor concave, so we cannot conclude whether they increase or decrease after the seller reveals information.

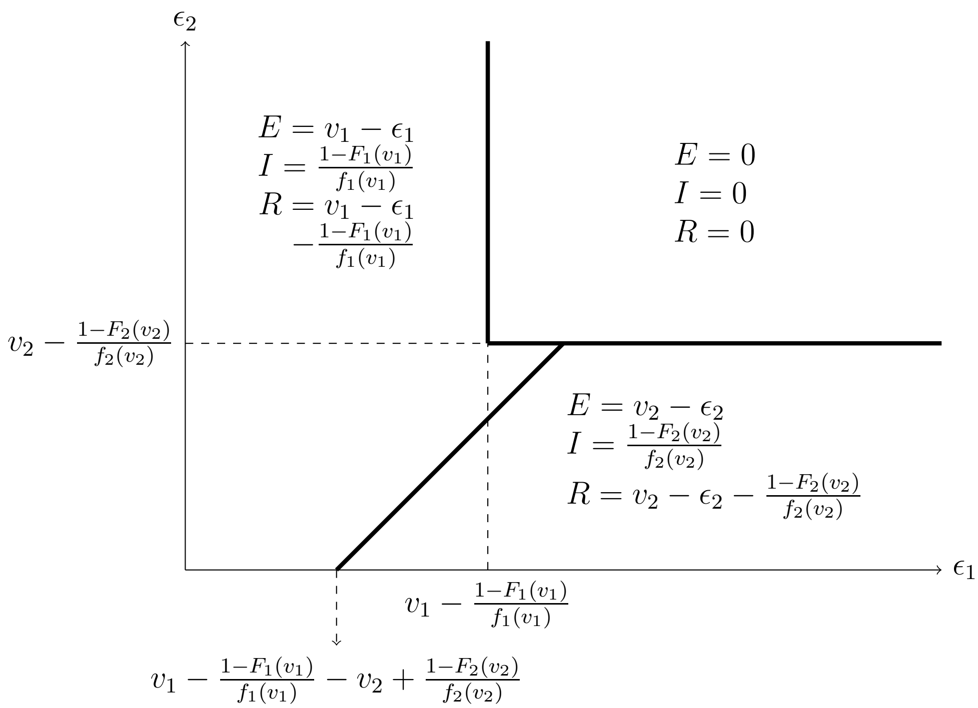

Figure 2: The efficiency and information rent are neither convex nor concave.

Figure 2 illustrates the efficiency, E, information rent, I, and revenue, R, in an optimal auction with two bidders for all possible realizations of ϵ_1 and ϵ_2 given the signals of the buyers v_1 and v_2. The solid lines divide the space (ϵ_1, ϵ_2) into three regions based on three possible allocations of the house. The top right corner represents the case when the seller keeps the house, which means the efficiency, information rent, and revenue all equal to 0. The bottom right region represents bidder 2 getting the house, and the region to the left represents bidder 1 getting the house. When bidder i gets the good, the efficiency is $v_i - \epsilon_i$, the information rent is $\frac{1-F_i(v_i)}{f_i(v_i)}$, and the revenue is $v_i - \epsilon_i - \frac{1-F_i(v_i)}{f_i(v_i)}$.

The efficiency and the information rent are neither convex nor concave in terms of (ϵ_1, ϵ_2). For example, consider the case when $\epsilon_2 > v_2 - \frac{1-F_2(v_2)}{f_2(v_2)}$. Figure 2 shows that bidder 1 gets the good if $\epsilon_1 < v_1 - \frac{1-F_1(v_1)}{f_1(v_1)}$, and the seller keeps the good otherwise. As we vary ϵ_1, neither the efficiency nor the information rent is continuous in ϵ_1. Indeed, neither $v_1 - \epsilon_1$ nor $\frac{1-F_1(v_1)}{f_1(v_1)}$ approaches 0 as ϵ_1 approaches the boundary point where the allocation changes. Hence, the efficiency and information rent, as functions of ϵ_1, contain jumps, and they are neither convex nor concave.

The Second-price Auction In the second-price auction the highest bidder gets the house, so the efficiency after revealing information is

$$\max\{v_1 - \epsilon_1, v_2 - \epsilon_2, \ldots, v_N - \epsilon_N\},$$

which is convex in ϵ. Hence, information disclosure increases the efficiency.

In the case with two bidders, the information rent also increases after the seller discloses information. For two bidders the information rent is $\max\{(v_1-\epsilon_1)-(v_2-\epsilon_2), (v_2-\epsilon_2)-(v_1-\epsilon_1)\}$, which is convex in ϵ. Moreover, Proposition 4.1 shows that information disclosure decreases the revenue. Since efficiency increases, the information rent must increase by an amount exceeding the increase in efficiency.

With more than two bidders, the information rent is neither concave nor convex. For example, consider $v_1 > v_2 > v_3 > \cdots > v_N$ and $\epsilon_i = 0$ for all $i \neq 3$. As we vary ϵ_3, the information rent is neither concave nor convex. Indeed, if $\epsilon_3 < v_3 - v_1$, then bidder 3 gets the house, and the second-price is v_1, so the information rent is $(v_3 - \epsilon_3) - v_1$. If $v_3 - v_1 < \epsilon_3 < v_3 - v_2$, then agent 1 gets the house, and the second-price is $v_3 - \epsilon_3$, so the information rent is $v_1 - (v_3 - \epsilon_3)$. If $\epsilon_3 > v_3 - v_2$, then bidder 1 gets the house, and the second-price is v_2, so the information rent is $v_1 - v_2$. As Figure 3 shows, the information rent is neither convex nor concave.

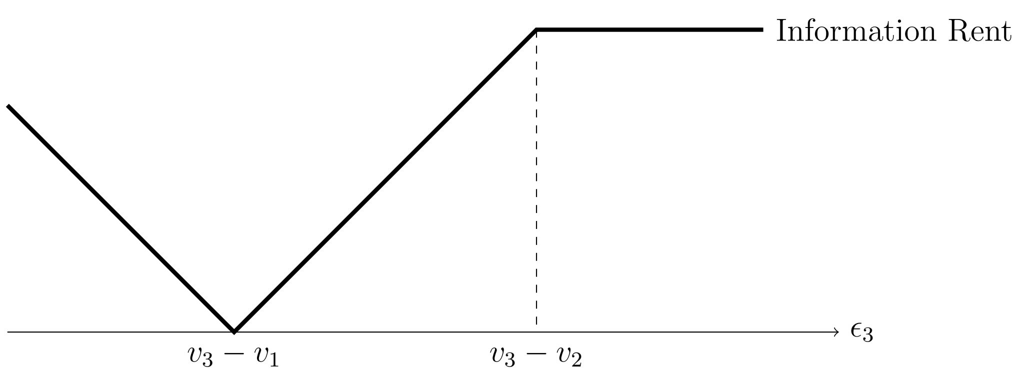

Figure 3: The information rent is neither convex nor concave.

We summarize the effect of information disclosure on the efficiency, the information rent, and the revenue as follows. In Milgrom and Weber (1982) the efficiency remains constant, but the information rent decreases, so the revenue increases. In our setting information disclosure could change the allocation of the good, so the efficiency also changes. In particular, for the second-price auction the efficiency increases; for two bidders the information rent increases even more, and the revenue decreases, but for more than two bidders the information rent and the revenue could either increase or decrease. For the optimal auction both the efficiency and the information rent could either increase or decrease, but the revenue always increases.