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Auctions with external incentives: Experimental evidence

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Abstract

We consider auctions where bidders have external incentives and focus on the case where their valuations in the auction are positively correlated with their productivity which matters in a second stage job market. We study how this affects bidding behavior and wages in the job market and proceed to test the model's implication in an experiment where treatments differ according to which bids are disclosed. Our results broadly confirm the theoretical prediction that bidders tend to overbid, and their bidding behavior and wages are influenced by the disclosure rule. The data also suggests that the dispersion in worker wages is affected by the disclosure rule, suggesting the importance of reputational bidding.

Keywords: Auctions, signaling, disclosure, experiments.

JEL Classification: C92, D44, D82.

1 Introduction

Often, bidders care about the reputational effects of their bidding. For instance, this is the case when managers bid for a takeover or licence (as in spectrum auctions) on behalf of shareholders. The reason is that bidding may provide information about managers' valuations of the target/licence, which, in turn, may reveal something about managers' own ability because the latter affects the valuations: the higher a given manager's ability, the more profitable the acquisition or licence will be and therefore the higher the valuation of the target/licence. Insofar managers' career prospects and future rewards depend on the post-auction inferences of markets about managerial ability/skill to evaluate/manage assets, and managers are aware of this, the type of information that is disclosed at the end of the auction will influence their bidding. Similar effects apply to sports agents bidding for a free player, collectors who offer consultancy services when they bid for a work of art to add in their collection.

In such environments, therefore, auction disclosure rules that pre-specify the type of information released at the end of the auction, become important as they may have an impact on auction revenues, the bidders' careers prospects and/or the level and distribution of post-auction wages and managerial compensations. These effects will in turn influence government revenues, the interaction of market discipline and efficiency/performance of managers of potential targeted firms, the regulation of art auctions, the scope of salary caps and existence of undisclosed fees in sports transfer markets, to mention few. The significance of these makes it imperative to understand the effects of various disclosure rules on auction and post-auction outcomes.

This paper is an experimental investigation of the implications of realistic disclosure rules on bidding behaviour, auction outcomes and post-auction remuneration of bidders services in a perfectly competitive market. Specifically, we run sealed-bid first-price auctions followed by

Bertrand competition between employers for the services of all bidders. The benefits to employers from hiring bidders are proportional to the bidders' valuations of the auctioned object. Valuations are private information of bidders. The winning bidder's identity is publicly disclosed. Treatments differ in terms of the information released at the end of the auction about submitted bids to employers (before the latter start competing).

Our theoretical setup is based on Giovannoni and Makris (2014), and as in that paper, we focus on four different disclosure rules. For each of these rules, the identity of the winner and of the bidders whose bids are revealed are always disclosed, as it would be natural in most conceivable applications. We have disclosure rule $\mathcal{A}$ (for "all"), where all the bids are revealed; disclosure rule $\mathcal{N}$ (for "none") where none of the bids are disclosed; disclosure rule $\mathcal{W}$ (for "winner") where only the winning bid is disclosed - as in Dutch auctions - and disclosure rule $\mathcal{S}$ (for "second") where only the highest losing bid is disclosed, as in a second-price sealed-bid auction where the price is disclosed. We also consider, as a benchmark, the situation (disclosure rule $\mathcal{T}$) where valuations are revealed at the end of the first-stage auction so that signalling through bids does not apply. A departure from Giovannoni and Makris (2014) is that we explicitly model the market where workers are offered jobs by firms as Bertrand competition. As a result, we can characterize here the equilibrium wages for each bidder.[1]

Using the experimentally generated data, the estimated bidding functions are, as predicted, linear in worker values and exhibit overbidding. However they generally differ from their theoretical counterparts. This discrepancy is primarily driven by the fact that overbidding is much smaller than that predicted by the model. Nevertheless, , the predicted differences in bidding across disclosure rules are in large part confirmed. In particular, the data supports the quali-

[1]In their paper, the analysis holds for any number of bidders and any underlying distribution, whereas here we focus on two bidders (”workers”) and uniform distributions.

tative predictions made by the model in terms of the effects of the disclosure rules on both the bidding functions' intercepts and slopes. In terms of behavior in the second market, we have, as predicted by theory, that firms break even on average, although the dispersion in worker wages is affected by informational constraints: it is lowest when firms have no information about bidding behavior of workers, and it is highest in the treatment where valuations are revealed and the treatment where the losing bid is revealed. The model also suggests that equilibrium wages will be affected by disclosure rules and our results broadly confirm the qualitative predictions of the model.

There is a theoretical literature that deals with cases where reputational effects distort bidding behavior. Goeree (2003), Haile (2003), Das Varma (2003), Salmon and Wilson (2008) focus on the comparison of various price mechanisms *for a given disclosure rule* whereas Giovannoni and Makris (2014) which focus on the comparison between various disclosure rules. Katzman and Rhodes-Kropf (2008) considers different disclosure rules but not the full range of possibilities with two bidders as we do. Also, and this applies to Molnar and Virag (2008), in their setting reputational incentives matter only for the winners. Importantly, for our purposes, none of the existing papers have looked at the issues of reputational effects in auctions from an experimental perspective and to the best of our knowledge, this is the first paper to do so. There is a significant literature on standard auctions (se e the survey in Kagel and Levin 2014) but very little on auctions where there is an aftermarket which potentially feeds back to the auctions itself. An exception to this is a small literature which focuses on the case of auctions with resale (e.g. Georganas 2011, Georganas and Kagel 2011, Lange, List and Field 2011) but in all of these cases the signaling motive in bidding is absent.

The organization of the paper is as follows. In the next section, we present and analyze the theoretical model that underpins our experiments. In section 3 we describe the experiments and in section 45 we present and discuss our empirical results. Section 5 concludes. An appendix contains some additional analysis and proofs.

2 The Model and Analysis

The theoretical model underpinning our experimental design consists of two auctions stages with two bidders in each stage. Specifically, the first stage is a first-price auction where two "workers" bid for a single unit of an indivisible good in a standard IPV setting. Each worker $i \in \{1, 2\}$ has a valuation x_i for the good and the valuations are independently and uniformly distributed on $[0, 100]$. Thus, expected utility for worker i in this auction if she bids b_i and the other worker j bids b_j is equal to

$$\left[\Pr(b_i > b_j) + \frac{1}{2}\Pr(b_i = b_j)\right](x_i - b_i)$$

We denote $\mathbf{x} = (x_1, x_2)$ and $\mathbf{b} = (b_1, b_2)$ while capital letters denote random variables and small letters their realizations.. The second stage consists of two parallel first-price auctions. In second-stage auction 1, two "firms" A and B bid for worker 1's employment while in second-stage auction 2, the same two "firms" A and B bid for worker 2's employment. Workers have no choice to make at this stage; worker i simply receives the winning wage in second-stage auction i. Each firm's valuation for i's employment is αx_i while she obtains zero if she does not employ i. Let w_l^i be the salary offer from firm $l \in \{A, B\}$ to worker i and let $\mathbf{w}_l = \left(w_l^1, w_l^2\right)$ be the wage profile offered by firm l. Then, expected utility for firm l in this stage if she offers $\mathbf{w}_l$ and the other firm m offers $\mathbf{w}_m$ is equal to

$$u_l(\mathbf{w}_l, \mathbf{w}_m, \mathbf{x}) =$$

$$\left[\Pr\left(w_l^1 > w_m^1\right) + \frac{1}{2}\Pr\left(w_l^1 = w_m^1\right)\right]\left(\alpha x_1 - w_l^1\right) + \left[\Pr\left(w_l^2 > w_m^2\right) + \frac{1}{2}\Pr\left(w_l^2 = w_m^2\right)\right]\left(\alpha x_2 - w_l^2\right)$$

Given the above, the total expected utility for worker i over the two stages, given x_i, $\mathbf{b} = (b_i, b_j)$ and $\mathbf{w}^i = \left(w_A^i, w_B^i\right)$ is equal to

$$U_i\left(\mathbf{w}^i, \mathbf{b}, x_i\right) = \left[\Pr\left(b_i > b_j\right) + \frac{1}{2}\Pr\left(b_i = b_j\right)\right]\left(x_i - b_i\right) + \max\left\{w_A^i, w_B^i\right\}$$

whereas the total payoff for firm l corresponds to the firm's payoff for the second stage. Thus, in this setting, we assume that workers' willingness to pay for the object in the first stage auction is a (positively correlated) signal of her productivity for firms in the second period. In particular, note that winning or losing the first period auction has no consequence for the second stage wages in itself, but as we shall discuss shortly, it may affect what firms know about the workers' valuations.

We will consider several versions of this setting, corresponding to different treatments in our experiments, which differ from each other according to how much information is publicly disclosed about workers' valuations and bids in the first stage auction. We will denote with $\mathcal{I}^{\phi}$ the information available to the firms under the ϕ disclosure rule. Since this is publicly available information, it will be common knowledge amongst the firms and the workers. Let $\omega \in \{1, 2\}$ denote the winner of the first stage auction and $-\omega$ denote the loser. The disclosure rules are:

1. *Transparent*: $\phi = \mathcal{T}$. Here x_1 and x_2 are publicly revealed and so $\mathcal{I}^{\mathcal{T}}$=$\mathbf{x}$.

2. *All bids:* $\phi = \mathcal{A}$. Here b_1 and b_2 are publicly revealed and so $\mathcal{I}^{\mathcal{A}}$=$\mathbf{b}$.

3. *Winner's bid:* $\phi = \mathcal{W}$. Here only the identity of the winner and her bid are publicly revealed and so $\mathcal{I}^{\mathcal{W}}$= (ω, b_ω)

4. *Second bid:* $\phi = \mathcal{S}$. Here only the identity of the loser and her bid are publicly revealed and so $\mathcal{I}^{\mathcal{S}}$= $(\omega, b_{-\omega})$

5. *No bids:* $\phi = \mathcal{N}$. Here only the identity of the winner is publicly revealed and so $\mathcal{I}^{\mathcal{N}} = \omega$

These are the possible disclosure rules with two bidders. Some auctions can be even more secretive, so that the identity of the winner or even that of some/all bidders is unknown. Obviously, in such cases there is no scope for using the auction as a signaling device.

We begin our analysis by considering the firms' problem. In general, firm l faces the expected utility

$$E\left[u_l\left(\mathbf{w}_l, \mathbf{w}_m, \mathbf{X}\right)|\mathcal{I}^{\phi}\right] = u_l\left(\mathbf{w}_l, \mathbf{w}_m, E\left(\mathbf{X}|\mathcal{I}^{\phi}\right)\right) = u_l\left(\mathbf{w}_l, \mathbf{w}_m, E\left(X_1|\mathcal{I}^{\phi}\right), E\left(X_2|\mathcal{I}^{\phi}\right)\right)$$

where the notation emphasizes that the firm must form expectations regarding the workers' valuations given the information $\mathcal{I}^{\phi}$ available at the end of the auction. The first equality follows from risk-neutrality, whereas the second follows from the independence of the valuations. Since the information is publicly available, both firms form the same expectation, $E\left(X_i|\mathcal{I}^{\phi}\right)$, for each worker i and the following proposition follows immediately

Proposition 1: There is a unique Nash equilibrium $(\widehat{\mathbf{w}}_A, \widehat{\mathbf{w}}_B)$ where for each worker i

$$\widehat{w}_A^i = \widehat{w}_B^i = \alpha E\left(X_i|\mathcal{I}^{\phi}\right)$$

Proof. For each firm, the value of employing a worker is a fraction α of the worker's valuation of the good in the first stage. Given that, for each worker, both firms have the same beliefs about her valuation, firms take part in a pure common value auction with symmetric information, and the result follows immediately. ■

Proposition 1 allows us to rewrite the expected utility for worker i as

$$U_i\left(\mathbf{b}, x_i, \phi\right) = \left[\Pr\left(b_i > b_j\right) + \frac{1}{2}\Pr\left(b_i = b_j\right)\right]\left(x_i - b_i\right) + \alpha E\left(X_i|\mathcal{I}^{\phi}\right)$$

We will now consider symmetric and strictly increasing Bayesian Nash Equilibria in pure strategies of the first stage auction under the above payoff for each bidder i, which we denote with β^{ϕ}. Obviously, these equilibria together with the Nash equilibrium of the second stage constitute Perfect Bayesian equilibria of the whole game. Following Giovannoni and Makris (2014), we also make a further restriction on off-the-equilibrium-path beliefs:

Assumption A We assume that in any such equilibrium, any bid b_i lower than $\beta^{\phi}(0)$ is believed to come from valuation $x_i = 0$ and any bid b_i higher than $\beta^{\phi}(100)$ is believed to come from valuation $x_i = 100$. Further, if there is a bid b_i and a valuation $\widehat{x}$ such that $b_i \in \left(\lim_{x_i \to \widehat{x}^-} \beta^{\phi}(x_i), \lim_{x_i \to \widehat{x}^+} \beta^{\phi}(x_i)\right)$ then b_i is believed to come from valuation $x_i = \widehat{x}$.[2]

Assumption A allows us to associate to each vector of bids $\mathbf{b}$ a corresponding vector $\mathbf{z}$ of valuations, which we refer to as *announcements*.[7] For convenience, we will define the functions

$$E\left(X_i | \mathcal{I}^{\phi}, \omega\right) = v_{\omega}^{\phi}(x_j, z_i)$$
$$E\left(X_i | \mathcal{I}^{\phi}, -\omega\right) = v_{-\omega}^{\phi}(x_j, z_i)$$

as the publicly held beliefs at the end of the first-stage auction about i's productivity, given the disclosure rule and the fact that i won or lost the auction. This notation emphasizes that these beliefs may be, in equilibrium, a function of the other bidder's valuation and i's own announcement. Then, following an announcement z_i, the expected utility for bidder i as a function of z_i and valuation x_i is

$$EU_i(z_i, x_i, \phi) = \frac{1}{100}\left[\int_0^{z_i}\left(x_i + \alpha v_{\omega}^{\phi}(X_j, z_i) - \beta^{\phi}(z_i)\right) dX_j + \int_{z_i}^{100} \alpha v_{-\omega}^{\phi}(X_j, z_i) dX_j\right]$$

[2]See Giovannoni and Makris (2014) for a discussion of assumption A and our focus on these equilibria.

[7]That is, with z_i such that $\beta_{\phi}^{-1}(b_i) = z_i$ if $b_i \in \beta_{\phi}(X_i)$, $z_i = 100$ if $b_i > \beta_{\phi}(100)$ and $z_i = \widehat{x}$ if $b_i \in (\lim_{x \to \widehat{x}^-} \beta_{\phi}(x), \lim_{x \to \widehat{x}^+} \beta_{\phi}(x))$.

where we emphasize that this is an expectation with respect to j's valuation, conditional on equilibrium play from her. We define an *effective valuation* as

$$\psi^{\phi}(x_i) = x_i +$$

$$\alpha v_{\omega}^{\phi}(x_i, x_i) - \alpha v_{-\omega}^{\phi}(x_i, x_i) + \alpha \left[\int_0^{x_i} \left(\left. \frac{\partial v_{\omega}^{\phi}(X_j, z_i)}{\partial z_i} \right|_{z_i = x_i} \right) dX_j + \int_{x_i}^{100} \left(\left. \frac{\partial v_{-\omega}^{\phi}(X_j, z_i)}{\partial z_i} \right|_{z_i = x_i} \right) dX_j \right]$$

We call these effective valuations because they capture all that is at stake for individual i in the first stage auction (assuming equilibrium play). We have the direct utility from winning the auction x_i, but also the reputational returns that i can expect in the second stage auction as a function of her valuation. The component $\alpha v_{\omega}^{\phi} - \alpha v_{-\omega}^{\phi}$ captures the net reputational gain to the bidder from winning the auction, while the remaining term in the square brackets captures the additional reputational net gain from marginally increasing the announcement. This definition allows us to state, following on from Giovannoni and Makris (2014), the following proposition:

Proposition 2: The equilibrium in first-price sealed-bid auctions with a disclosure rule ϕ, β^{ϕ}, is given by[3]

$$\beta^{\phi}(x_i) = \frac{1}{x_i} \int_0^{x_i} \psi^{\phi}(s) ds, \;\; x_i \in [0, 100]$$

Proof: The proof follows standard steps, but for details see the appendix. ■

We leave the calculations for the appendix, but the result is that for our specific disclosure

[3]Given that $N = 2$ and that we have a uniform distribution, the bidding function is well-defined at $x_i = 0$.

rules the bidding functions become

$$
\begin{aligned}
\beta^{\mathcal{T}}(x_i) &= \frac{1}{2}x_i \\
\beta^{\mathcal{A}}(x_i) &= \frac{1}{2}x_i + 100\alpha \\
\beta^{\mathcal{W}}(x_i) &= \left(\frac{3}{4}\alpha + \frac{1}{2}\right)x_i \\
\beta^{\mathcal{S}}(x_i) &= \left(\frac{1}{2} - \frac{3}{4}\alpha\right)x_i + 150\alpha \\
\beta^{\mathcal{N}}(x_i) &= \frac{1}{2}x_i + 50\alpha
\end{aligned}
$$

The intuition for the bidding function $\beta_{\mathcal{T}}$ is straightforward: since valuations are publicly revealed at the end of the first stage auction, bidders have no incentive to use bids as a signalling device and as a consequence the standard behavior of the IPV setting obtains. All other disclosure rules imply overbidding relative to $\beta_{\mathcal{T}}$ because now signalling through bids is important for second stage outcomes and, in particular, being perceived to have high valuation is beneficial.[4] However, the way overbidding obtains depends on the disclosure rule. It will be instructive to start with a comparison between $\beta_{\mathcal{A}}$ and $\beta_{\mathcal{W}}$. For $\beta_{\mathcal{A}}$, note first that in a monotonic equilibrium such as this, bids reveal exactly a bidder's valuation and so other bidders' bids have no impact on reputational returns. Thus, $\alpha v_{\omega}^{\mathcal{A}}(x_i, x_i) - \alpha v_{-\omega}^{\mathcal{A}}(x_i, x_i) = 0$. On the other hand, in auctions where the disclosure rule is $\mathcal{W}$, winning or losing does matter for inferences about x_i because if i wins then x_i becomes known, while if i loses then firms believe x_i to be below the highest competing announcement (which is x_i at the margin between winning or losing) so that

$$
v_{\omega}^{\mathcal{W}}(x_i, x_i) - v_{-\omega}^{\mathcal{W}}(x_i, x_i) = \alpha x_i - \alpha E\left[X_i | X_i < x_j\right] > 0
$$

In addition, we have the reputational gain/loss (relative to the increase in the likelihood of winning the auction) from increasing marginally the perception of the after-market about bidder

[4] Giovannoni and Makris (2014) show that if being perceived to have a *low* valuation is beneficial then *under-bidding* will occur in equilibrium.

i's valuation by means of increasing bidder i's announcement marginally. For disclosure rules $\mathcal{A}$ and $\mathcal{W}$ this relative gain/loss conditional on disclosure is the same, but with the former own bid is always disclosed, while with the latter, such gain/loss only applies when i wins. The result is that in auctions where the disclosure rule is $\mathcal{A}$, bidders with different valuations have similar incentives for overbidding whereas with disclosure rule $\mathcal{W}$ the incentive is much higher for bidders with high valuations (who are likely to win and have their precise valuation publicly revealed) than with low ones (who are likely to lose and for whom all that will be known is that their valuation is below the winner's).[5] The intuition for $\mathcal{S}$ auctions is the same as in $\mathcal{W}$ auctions but in reverse: now it is low valuations who are likely to be disclosed and bidders with such valuations have a greater incentive to overbid.[6] Finally, with disclosure rule $\mathcal{N}$, only the identity of the winner is disclosed so that the only signalling comes from winning or losing the auction. But because none of the bids is disclosed the net reputational gain from winning the auction must be

$$\alpha v_{\omega}^{\mathcal{N}}(x_i, x_i) - \alpha v_{-\omega}^{\mathcal{N}}(x_i, x_i) = \alpha E_{X_j}\left[E_{X_i}\left[X_i | X_i > X_j\right]\right] - \alpha E_{X_j}\left[E_{X_i}\left[X_i | X_i < X_j\right]\right] = const.$$

and so bidders of all valuations have the same incentive to overbid.

We conclude by pointing out that the first stage equilibrium strategies described above also allow us to determine the equilibrium wages paid to the two workers in the second stage auction. Let $\widehat{w}^{i\phi}(x_i, x_j)$ denote the equilibrium wage for individual i under disclosure rule ϕ and assuming

[5] The fact that in $\mathcal{A}$ auctions the overbidding incentives are the *exactly* the same across valuations is a consequence of the fact that we have two bidders and a uniform distribution (which is also responsible for the linearity in the bidding functions).

[6] Thus, for disclosure rule $\mathcal{S}$ the incentive to overbid for low types "flattens" the bidding function. It is easy to see that these incentives cannot be too great otherwise the bidding function is no longer increasing and the equilibrium we focus on does not exist. With our parametrization this means that we need $\alpha < \frac{2}{3}$.

that valuations are x_i and x_j. If we note that in equilibrium

$$\alpha E\left(X_i|\mathcal{I}^{\phi},\omega\right)=\alpha v_{\omega}^{\phi}(x_j,x_i)\text{ and }E\left(X_i|\mathcal{I}^{\phi},-\omega\right)=\alpha v_{-\omega}^{\phi}(x_j,x_i)$$

and define as $I\left(x_i,x_j\right)$ the indicator function that is equal to one if $x_i>x_j$ and zero otherwise, we immediately have[7]

$$\widehat{w}^{i\mathcal{T}}\left(x_i,x_j\right)=\alpha x_i$$

$$\widehat{w}^{i\mathcal{A}}\left(x_i,x_j\right)=\alpha x_i$$

$$\widehat{w}^{i\mathcal{W}}\left(x_i,x_j\right)=\alpha x_i I\left(x_i,x_j\right)+\frac{\alpha}{2}x_j\left(1-I\left(x_i,x_j\right)\right)$$

$$\widehat{w}^{i\mathcal{S}}\left(x_i,x_j\right)=\frac{\alpha}{2}\left(x_j+100\right)I\left(x_i,x_j\right)+\alpha x_i\left(1-I\left(x_i,x_j\right)\right)$$

$$\widehat{w}^{i\mathcal{N}}\left(x_i,x_j\right)=75\alpha I\left(x_i,x_j\right)+25\alpha\left(1-I\left(x_i,x_j\right)\right)$$

and, in terms of the first-stage bids this gives us[8]

$$\widehat{w}^{i\mathcal{T}}\left(b_i,b_j\right)=\alpha x_i$$

$$\widehat{w}^{i\mathcal{A}}\left(b_i,b_j\right)=2\alpha b_i-200\alpha^2$$

$$\widehat{w}^{i\mathcal{W}}\left(b_i,b_j\right)=\frac{4\alpha b_i}{2+3\alpha}I\left(b_i,b_j\right)+\frac{2\alpha b_j}{2+3\alpha}\left(1-I\left(b_i,b_j\right)\right)$$

$$\widehat{w}^{i\mathcal{S}}\left(b_i,b_j\right)=2\alpha\frac{b_j+50-225\alpha}{2-3\alpha}I\left(b_i,b_j\right)+4\alpha\frac{b_i-150\alpha}{2-3\alpha}\left(1-I\left(b_i,b_j\right)\right)$$

$$\widehat{w}^{i\mathcal{N}}\left(b_i,b_j\right)=75\alpha I\left(b_i,b_j\right)+25\alpha\left(1-I\left(b_i,b_j\right)\right)$$

[7] In the experimental setting we cannot in principle exclude that two workers bid the same amount in the first stage auction and this creates the issue of how to define a winner. This matters particularly with disclosure rules $\mathcal{W},\mathcal{S}$ and $\mathcal{N}$. We resolve the problem by determining the winner via a lottery and providing the information according to the disclosure rule. For example, with disclosure rule $\mathcal{W}$, if $b_i=b_j$ but i wins the lottery, only her bid is disclosed.

[8] See the appendix for details. Obviously, in the $\mathcal{T}$ treatment, the valuations are known to the firms.

3 Experimental Design and Procedures

Our experiment implements the model laid out in Section 2, and the treatment variables correspond to the information from the first stage auction conditions firms have before taking part in the second auction. Following on from the theoretical analysis, we consider five different treatments: Winner, corresponding to disclosure rule $\mathcal{W}$ in the model, in which firms only observe the bid made by the winning worker; Second (disclosure rule $\mathcal{S}$), in which firms only observe the bid made by the losing worker; All (disclosure rule $\mathcal{A}$), in which firms observe both winning and losing bids; Transparent (disclosure rule $\mathcal{T}$), in which firms observe the private values of both workers; and finally None (disclosure rule $\mathcal{N}$), in which firms only observe the identity of the winning and losing workers.

Upon arrival to the laboratory, subjects sat in individual computer booths. Subjects were given written copies of the instruction sets (see the Appendix for copies of the instruction sets), and they were told everybody in a given role was reading the same set of instructions. Subjects had a minimum of 10 minutes in which to read the instructions; after that time elapsed, subjects had the opportunity to ask clarification questions in private. Once all queries were answered, the experiment started.

Subjects were assigned to the role of firm or worker at the beginning of the experiment, and they kept their roles until the end of the experiment. Subjects had five practice periods in which to familiarize themselves with the software interface and the auction environment. Once the five practice periods were concluded, the experimenters made a public announcement that all further rounds would be incentivized. In every period of the experiment (including the practice periods), subjects were randomly matched with three other participants in the session. There were a total of 35 incentivized rounds in the experiment. The payment consisted of the payoff from three randomly picked rounds, plus a show-up fee. Since our theory predicted firms would make zero profits, we set the show-up fee for workers to be equal to £5, and the show-up fee for firms to be £10.

Decisions were made through the Z-Tree interface (Fischbacher, 2007). Subjects were recruited from a pool of volunteers, all of whom were undergraduate students from a wide range of disciplines using the lab's ORSEE system (Greiner, 2004). We conducted three sessions with 12 participants in each session for each of the treatments, for a total of 180 participants, none of whom had ever taken part in an auction or market experiment before. Sessions lasted on average 90 minutes, and the average payment was equal to £18.50.

4 Results

We start the analysis of the results by presenting some summary statistics. We then proceed by presenting the econometric analysis of the bidding behavior, first by workers in the first stage auction, and then by firms in the second stage auction.

4.1 Summary Statistics

A first test of the effect of the second market on worker bidding behavior is to compare bidding in the Transparent treatment, where there is no possibility of signalling, to all other conditions. Indeed we find overbidding in all four treatments relative to Transparent (Second = Transparent: $F(1,14) = 4.59, p = 0.050$; Winner = Transparent: $F(1,14) = 22.69, p < 0.001$; All = Transparent: $F(1,14) = 17.73, p < 0.001$; None = Transparent: $F(1,14) = 4.78, p = 0.046$. F-tests based on OLS regression using session-level clustered standard errors.)

Turning to the behavior of firms in the second stage auction, we see that the average winning bid for the worker who won the first stage (Winning Worker Wage) is very close to $0.4 \times$ Winning

	SECOND	WINNER	ALL	TRANSPARENT	NONE
First stage auction					
Worker Private Value	48.19	48.95	47.92	49.32	48.85
	(29.37)	(29.01)	(28.86)	(29.28)	(29.25)
Worker Bid	40.06	41.88	43.15	36.36	41.98
	(21.66)	(24.38)	(22.28)	(21.93)	(22.77)
Second stage auction					
Winning Worker Wage	21.93	23.79	22.52	24.86	20.64
	(9.29)	(9.36)	(8.11)	(8.89)	(3.84)
Losing Worker Wage	12.94	10.49	12.85	12.48	11.11
	(9.06)	(4.29)	(9.11)	(10.35)	(2.62)
Firm Profit	1.84	2.44	1.48	1.06	3.67
	(10.29)	(8.49)	(7.35)	(3.89)	(11.89)
N	630	630	630	630	630

Standard deviations in parentheses. Wage is the winning bid in the 2nd auction.

Table 1: Summary statistics

Worker Bid. The same is true in the case of the relationship between the Losing worker's wage and his bid. We would therefore expect firms to make close to zero profits. This is indeed the case: average per period firm profits are close to zero (Firm payoff= 0: WINNER, $t = 13.20, p < 0.001$; SECOND, $t = 1.46, p = 0.171$; ALL, $t = 1.85, p = 0.092$; TRANSPARENT, $t = 7.87, p < 0.001$, t-tests on OLS regression using session-level clustered standard errors.)

Observation 1: *There is significant overbidding in the first-stage auction in treatments where there are aftermarket concerns while the bids in the second-stage auction are very close to private values.*

In the experimental literature on auctions, overbidding in first-price auctions is a common phenomenon (see Kagel and Levin 2014 for a survey) but this should not be confused with our setting where overbidding is an equilibrium response to the signaling incentives in the model. The emphasis here is on the comparison between the $\mathcal{T}$ treatment, where the incentive to use first stage bids as signals is absent, and all the other treatments.

DV: $b_{i,t}$	(Transparent)	(Winner)	(Second)	(All)	(None)
$x_{i,t}$	0.69***	0.79***	0.66***	0.71***	0.72***
	(0.05)	(0.02)	(0.01)	(0.05)	(0.01)
Cons	2.53	3.32*	8.11**	9.15**	6.61*
	(1.42)	(0.87)	(1.57)	(1.92)	(2.01)
N	630	630	630	630	630
R^2	0.84	0.88	0.81	0.84	0.87

***, **, *: significant at 1%, 5% and 10% level.

Session-level clustered standard errors in parentheses.

Table 2: OLS estimates of bidding function

4.2 Worker Bidding Behavior

We now proceed to the main section of the data analysis where we econometrically estimate the bidding behavior of workers in the first stage auction as a function of information conditions. Before we report our findings a few methodological notes are warranted. Firstly, we note that the private value of a worker in a given period was a number uniformly distributed between 0 and 100, in increments of 0.01. Likewise the action set for workers was any number between 0 and their private value in increments of 0.01. This provides a sufficiently rich set for us to ignore the truncation of the bidding set at 0 and 100. We also note that our random matching protocol precludes the use of panel data methods. An observation in our data set is a variable $b_{i,j,t}$ corresponding to a bid by player i in group j in period t. The random matching protocol means it is virtually impossible for any given four subjects to be in the same group j for 35 consecutive periods. As such, we do our estimation of the workers' bidding function through OLS, clustering standard errors at the session level to account for the fact that observations may be correlated within sessions. We estimate the following econometric model:

$$b_{i,t} = \beta_0 + \beta_1 x_{i,t} + u_{i,t} \tag{1}$$

where $b_{i,t}$ is the bid placed by worker i in period t, $x_{i,t}$ is the private value of worker i in period t, and $u_{i,t}$ is an error term.[9] Table 2 summarizes the estimation results.

We begin by testing the hypothesis that our estimated bidding functions match their theoretical counterparts, using the results from our econometric model. In the TRANSPARENT treatment, we reject the hypothesis that $\beta_0 = 0$ and $\beta_1 = 0.5$ ($F(2,2) = 129.30, p = 0.008$). In the WINNER treatment, we reject the hypothesis that $\beta_0 = 0$ and $\beta_1 = 0.8$ ($F(2,2) = 2520.91, p < 0.001$). In the SECOND treatment, we reject the hypothesis that $\beta_0 = 60$ and $\beta_1 = 0.2$ ($F(2,2) = 639.83, p = 0.002$). In the ALL treatment, we reject the hypothesis that $\beta_0 = 40$ and $\beta_1 = 0.5$ ($F(2,2) = 669.17, p = 0.001$). Finally, in the NONE treatment, we reject the hypothesis that $\beta_0 = 20$ and $\beta_1 = 0.5$ ($F(2,2) = 2274.34, p < 0.001$). The left panel of Figure 1 displays the predicted bidding functions, and the right panel displays the estimated bid functions using our linear econometric specification. This leads to our second observation.

Observation 2: *The estimated bidding functions are significantly different to the predicted bidding functions.*

Despite the fact that our results do not match the point predictions of the model, we are more interested in understanding whether our model predicts results qualitatively. That is, we would like to know whether the comparative statics predictions of the model hold in the data. To do this, we estimated a joint model of the form $b_{i,t} = \beta_0 X + \beta_1 x_{i,t} \times X + u_{i,t}$, where X is a vector of treatment dummies, with bootstrapped standard errors based on three independent

[9] We also ran additional regressions with an additional quadratic term on $x_{i,t}$, or with a time trend to account for learning effects. Neither coefficient was significant, so we do not present the results from these estimations for the sake of brevity.

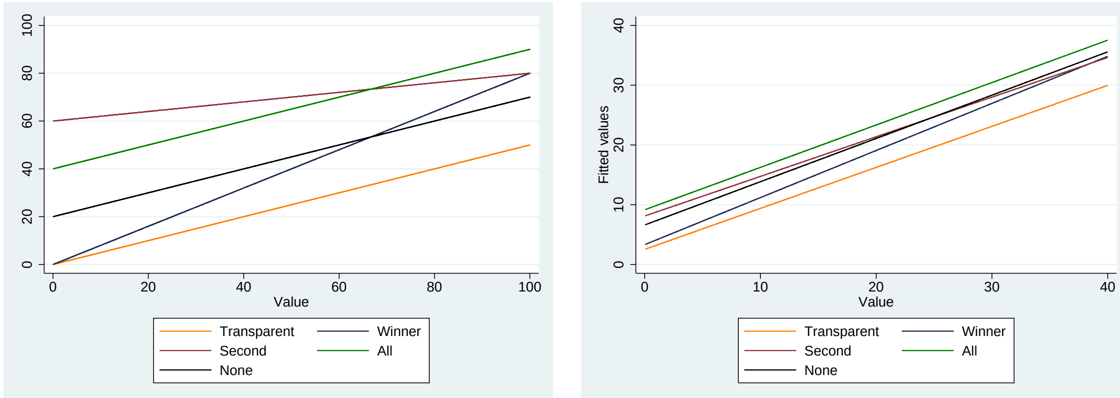

Figure 1: Predicted and estimated bidding functions.

sessions. We then performed a series of χ^2-tests testing for the joint equality of the intercept and slope coefficients of pairs of treatments. Table 3 reports the p-values of these tests.

In addition to the joint test of differences of the bidding function (i.e. slope plus intercept), we are interested in testing differences in intercept coefficients separately, as they provide evidence of overbidding behavior for when the realization of private values is low; and differences in slope coefficients, which reflect responsiveness of (over-)bidding to increases in realized private value. Table 4 reports the p-values of these tests.

As predicted, we find no difference in intercept coefficient between Winner and Transparent, while all other estimated bidding functions have larger coefficients than Transparent. We find that despite All having an higher estimated intercept coefficient than Second the difference is not significant.

Likewise, the slope coefficient of Winner is higher than Transparent ($F(1,14) = 5.17, p = 0.039$), and None ($F(1,14) = 17.69, p < 0.001$), though not significantly different to the slope coefficient in All ($F(1,14) = 2.88, p = 0.112$). Finally, theory predicts the bidding functions in Transparent, All, and None to have the same slope, and that prediction is verified by our data (Transparent = All: $F(1,14) = 0.15, p = 0.706$; Transparent = None: $F(1,14) =$

	TRANSPARENT	WINNER	SECOND	ALL
WINNER	< 0.001	-		
SECOND	0.002	< 0.000	-	
ALL	< 0.001	< 0.000	0.066	-
NONE	0.023	0.001	< 0.000	0.501

Note: p-values refer to $\chi^2(2)$ tests.

Table 3: Significance tests on joint equality of intercept and slope coefficient on estimated bidding functions

$0.79, p = 0.389$; ALL = NONE: $F(1, 14) = 0.11, p = 0.748$.

Observation 3: *The estimated bid functions are significantly different than predicted; however, the data is consistent with most comparative static predictions based on disclosure rules.*

This observation can be best understood if the focus on the intercept and the slope of the bidding functions separately. As far as the intercept is concerned, in the WINNER treatment, workers whose valuations are very low understand that overbidding would not be particularly beneficial to them as their valuation can be inferred only if they win and that is unlikely to happen. On the other hand, in the ALL and SECOND treatments, a worker with the same valuations understands that their valuation is very likely to be inferred and so they significantly overbid. As far as the slopes are concerned, the theory predicts that in the WINNER treatment the slope be the greatest and that is because only the winner's valuation can be inferred precisely, which reinforces the incentive to win the object, while the opposite should be the case in the SECOND treatment where the incentive to win the object is counterbalanced by the fact that the winner's valuation won't be inferred precisely, with the ALL treatment being the intermediate case where all the valuations can be inferred.

The only qualitative prediction that fails is that we expected the intercept in the SECOND

	TRANSPARENT	WINNER	SECOND	ALL
WINNER	0.575	-		
SECOND	0.008	0.006	-	
ALL	0.006	0.005	0.627	-
NONE	0.070	0.093	0.498	0.297

Note: p-values refer to $F(1, 14)$ tests.

Table 4: Significance tests on equality of intercept on estimated bidding functions

treatment to be higher than that in the ALL treatment whereas we find the reverse. This is probably due to the fact that the SECOND treatment is the most difficult to comprehend.

4.3 Firm Bidding Behavior

We now turn to the bidding behavior by firms in the second stage auction. Table 1 suggests bidding behavior was quite competitive, as average profits were close to zero in all treatments. In this section we will model the bidding behavior by firms for the winning and losing worker separately, as a function of key parameters of the game. We start by estimating the following econometric specification:

$$b^g_{j,t} = \beta_0 + \beta_1 b^w_{i,t} + \beta_2 x^w_{i,t} + \beta_3 b^l_{i,t} + \beta_4 x^l_{i,t} + u_{j,t} \tag{2}$$

where $b^g_{j,t}$ is the bid made by firm j in period t to worker $g \in \{\text{winner, loser}\}$; $b^w_{i,t}$ and $b^l_{i,t}$ are the bids by the auction winner and loser, respectively; $x^w_{i,t}$ and $x^l_{i,t}$ are the private values of the auction winner and loser, respectively; and $u_{j,t}$ is an error term.[10] We also take advantage of the fact that each firm had to place a bid for each worker to calculate of the difference in the bids for winner and loser. This in turn aids us in testing how the relevant information was treated differently when bidding for each of the workers.

[10]We considered alternative specifications but quadratic terms on bids were not significant.

	Winner		Second		All		Transparent		None	
DV:	b^w_{jt}	b^l_{jt}	b^w_{jt}	b^l_{jt}	b^w_{jt}	b^l_{jt}	b^w_{jt}	b^l_{jt}	b^w_{jt}	b^l_{jt}
$b^w_{i,t}$	0.35***	0.13***			0.34***	0.01	0.01	0.03*	0.05	0.01
	(0.03)	(0.004)			(0.02)	(0.01)	(0.01)	(0.02)	(0.04)	(0.02)
$x^w_{i,t}$							0.36***	-0.03**	-0.036	0.001
							(0.001)	(0.01)	(0.025)	(0.01)
$b^l_{i,t}$			0.34***	0.41***	0.02	0.36***	0.01	-0.01	0.05	0.04*
			(0.08)	(0.03)	(0.02)	(0.02)	(0.01)	(0.01)	(0.04)	(0.02)
$x^l_{i,t}$							-0.01	0.37***	-0.04	-0.03*
							(0.01)	(0.01)	(0.03)	(0.02)
Cons	1.25	1.45***	9.42***	-0.24	1.11**	-0.15	-0.11	0.18	18.66***	9.13***
	(1.12)	(0.47)	(1.80)	(0.49)	(0.47)	(0.47)	(0.13)	(0.32)	(1.54)	(0.70)
R^2	0.57	0.35	0.46	0.76	0.70	0.66	0.88	0.86	0.02	0.02
N	630	630	630	630	630	630	630	630	630	630

***, **, *: significant at 1%, 5% and 10% level.

Bootstrapped standard errors based on session-level clusters in parentheses.

Table 5: OLS estimates of firm bidding function

Before we analyze the estimation results, recall that the value of hiring of worker i in period t to a firm was equal to $0.4x_{i,t}$. When firms only have access to the bid of one of the workers, their estimated bidding strategies differ on the basis of the target worker. In WINNER, the estimated bidding function for the winning worker has a positive though not significant intercept and a gradient very close to 0.4 (though marginally significantly different $\chi^2(1) = 3.41, p = 0.06$). In contrast the estimated bidding function for the losing worker is significantly flatter although again the gradient is significantly smaller than the 0.2 predicted by the theory ($\chi^2(1) = 404.51, p < 0.001$); while the intercept is positive and significant, it is not significantly different than that of the bidding function for the winning worker. Thus, from a qualitative point of view the results seem to support the theory.

We observe a markedly different patter in SECOND. The estimated bidding function for the losing worker has a zero intercept and a slope coefficient of 0.4 ($\chi^2(1) = 0.14, p = 0.71$), while the bidding function for the winning worker (whose bid is unobserved) is nominally flatter, though not significantly different to $0.4 : \chi^2(1) = 0.58, p = 0.45$) but with a large positive and significant intercept. The theory predicts a significant intercept (20) and a slope of

A very similar pattern emerges when we analyze firms' bidding behavior in ALL: the slope on the bid coefficient of the target worker is slightly (winning worker: $\chi^2(1) = 15.99, p < 0.001$; losing worker: $\chi^2(1) = 2.99, p = 0.084$) lower than 0.4, and they disregard the bidding behavior of the other worker in the first stage auction. Importantly, the intercept coefficient on the estimated bidding function for the winning worker is now much smaller, though still significantly different to zero.

In TRANSPARENT, as expected, the only significant coefficients are those on the private values of the workers, rather than the coefficients on their bids. Interestingly, in the estimated bidding function for the losing worker, we find a very small negative but significant coefficient on the

DV: $w_{i,t}$	(Transparent)	(All)	(Winner)	(Second)	(None)
$x_{i,t}$	0.37***				
	(0.01)				
$b_{i,t}$		0.38***			
		(0.03)			
$b_{i,t} \times I(b_{i,t}, b_{j,t})$			0.03***		
			(0.002)		
$b_{j,t} \times [1 - I(b_{i,t}, b_{j,t})]$			-0.004		
			(0.002)		
$b_{i,t} \times [1 - I(b_{i,t}, b_{j,t})]$				0.03**	
				(0.003)	
$b_{j,t} \times I(b_{i,t}, b_{j,t})$				0.01	
				(0.01)	
$I(b_{i,t}, b_{j,t})$					-0.01
					(0.07)
Cons	0.35	0.99**	7.40**	2.35	15.94**
	(0.25)	(0.17)	(0.93)	(2.13)	(1.85)
N	630	630	630	630	630
R^2	0.90	0.76	0.55	0.45	0.00

***, **, *: significant at 1%, 5% and 10% level. Session-level clustered standard errors in parentheses.

Table 6: OLS estimates of wage functions using worker bids from first stage auction – except for Transparent. $I(b_{i,t}, b_{j,t})$ indicates the winner of the first auction.

winning worker's private value, indicating perhaps some mark-down by firms. Lastly, we analyze bidding behavior in NONE. As expected, only the intercepts are significant, and the intercept on the bidding function for the winning worker is significantly higher than that for the losing worker.

We conclude the analysis of firm behavior by estimating a structural model of firms' bidding functions $\widehat{w}^{i\phi}(b_i, b_j)$. We order the presentation of results in ascending cognitive difficulty for firms. The first treatment is TRANSPARENT, where firms observe workers' private values directly. The coefficient on $x_{i,t}$ is very close, albeit marginally significantly different to the prediction of 0.4 ($F(1,2) = 13.30, p = 0.068$). In the ALL treatment, we observe a positive and significant coefficient on the worker bid, although lower than the predicted 0.8 by the theory ($F(1,2) = 227.28, p = 0.004$). In the WINNER condition, while coefficients are markedly different than their theoretical counterparts, we do observe the qualitative prediction that the coefficient on $b_{i,t} \times I(b_{i,t}, b_{j,t})$ is larger than that on $b_{j,t} \times [1 - I(b_{i,t}, b_{j,t})]$ ($F(1,2) = 192.11, p = 0.005$). The same is also true of firm bidding behavior in the SECOND treatment ($F(1,2) = 37.91, p = 0.025$). However, the structural model on firm bidding behavior in NONE shows no significant difference in wages for the winner and loser of the first auction, unlike the theoretical prediction.

Observation 4: *Firms respond to the relevant information provided by the disclosure rule in each treatment.*

5 Conclusions

This paper is the first to present an experimental analysis of signaling through auctions and does so in a context where bidders' valuations in a first-stage auction are positively correlated with the expected returns in an aftermarket, much like in Giovannoni and Makris (2014). We interpret the aftermarket as a labor market where the first-stage bidders (workers) have a productivity that is a (linear) function of their first-stage valuations. The labor market is designed so that in equilibrium workers take all the surplus and equilibrium wages are therefore equal to what the firms believe to be their expected productivity. In this setting, we put forward a theory that predicts overbidding in the first-stage auction. More interestingly, the theory also predicts that different disclosure rules about what is known about bidding at the end of the auction influences bidding in the first-stage auction and wages in the second-stage auction. Our experiments show that both the predictions concerning bids and those concerning wages are, by and large, confirmed by participant's behavior in the experiment. This suggests that reputational concerns in auctions may be sufficiently a significant factor that should be considered in auction design, with particular emphasis on disclosure rules.

Future research should explore whether these effects are still significant for other assumptions about the labor market, for example, one where firms have greater barganining power.

6 Appendix

To reduce clutter we omit the superscript ϕ from β^{ϕ}. Define

$$\Psi^{\phi}\left(x_i, x_j, z_i\right) = x_i + \alpha v_{\omega}^{\phi}(x_j, z_i) - \alpha v_{-\omega}^{\phi}(x_j, z_i)$$

and note that

$$EU_i(x_i, z_i, \phi) \equiv \frac{1}{100}\left[\int_0^{z_i}\left[\Psi^{\phi}\left(x_i, X_j, z_i\right) - \beta(z_i)\right] dX_j + \int_0^{100} \alpha v_{-\omega}^{\phi}(X_j, z_i) dX_j\right]$$

is the expected utility of valuation x_i from bidding $\beta(z_i)$. Suppose now that a symmetric and strictly increasing equilibrium β exists. Note then that in a such an equilibrium

$$\frac{1}{100}\left[\int_0^{\beta^{-1}(b_i)}\left[\Psi^{\phi}\left(x_i, X_j, \beta^{-1}\left(b_i\right)\right) - b_i\right] dX_j + \int_0^{100} \alpha v_{-\omega}^{\phi}(X_j, \beta^{-1}\left(b_i\right)) dX_j\right]$$

is the expected profit of valuation x_i from bidding $b_i \geq 0$, with, by assumption A, $\beta^{-1}(b_i) \equiv 0$ if $b_i < \beta^{-1}(0)$, $\beta^{-1}(b_i) \equiv 100$ if $b_i \geq \beta^{-1}(100)$, and $\beta^{-1}(b_i) \equiv \widehat{x}$ if $b_i \in \left(\lim_{x_i \to \widehat{x}^-} \beta^{-1}(x_i), \lim_{x_i \to \widehat{x}^+} \beta^{-1}(x_i)\right)$. Moreover, β, being strictly increasing, is almost everywhere differentiable. The first-order condition (FOC) for a maximum of the expected profit of valuation x_i is (except in points of non-differentiability of $\beta(.)$)

$$\Psi^{\phi}\left(x_i, \beta^{-1}(b_i), \beta^{-1}(b_i)\right) - b_i + \alpha \int_0^{\beta^{-1}(b_i)} \frac{\partial}{\partial z_i} v_{\omega}^{\phi}(X_j, \beta^{-1}(b_i)) dX_j + \alpha \int_{\beta^{-1}(b_i)}^{100} \frac{\partial}{\partial z_i} v_{-\omega}^{\phi}(X_j, \beta^{-1}(b_i)) dX_j$$

$$= \beta^{-1}(b_i)\beta'(\beta^{-1}(b_i))$$

So, if β is a symmetric and strictly increasing equilibrium, then it must be that $b_i = \beta^{-1}(x_i)$, with $\beta(x_i) > 0$ for any $x_i > 0$, and hence

$$\Psi^{\phi}(x_i, x_i, x_i) - \beta(x_i) + \alpha \int_0^{x_i} \frac{\partial}{\partial z_i} v_{\omega}^{\phi}(X_j, x_i) dX_j + \alpha \int_{x_i}^{100} \frac{\partial}{\partial z} v_{-\omega}^{\phi}(X_j, x_i) dX_j = \beta'(x_i) x_i$$

almost everywhere in $x \in (0, 100]$.

One can easily see that if β is a symmetric and strictly increasing equilibrium, then it must be continuous: if $\hat{x}$ was a jump point then bidding $lim_{x \to \hat{x}^-} \beta(x)$ is preferred to bidding $lim_{x \to \hat{x}^+} \beta(x)$ by bidder of valuation $\hat{x}$ (resp. $\hat{x} + \varepsilon$, where ε is arbitrarily small) when $lim_{x \to \hat{x}^+} \beta(x) = \beta(\hat{x})$ (resp. when $lim_{x \to \hat{x}^-} \beta(x) = \beta(\hat{x})$); such deviation does not have an effect on the auction's outcome and the reputational return, but leads to lower price upon winning. Note also that in any symmetric and strictly increasing equilibrium, $\beta(0)0 = 0$. Continuity of β, and hence $\beta(x_i)x_i$, implies, therefore, that the differential equation

$$\Psi^{\phi}(x_i, x_i, x_i) + \alpha \int_0^{x_i} \frac{\partial}{\partial z_i} v_{\omega}^{\phi}(X_j, x_i) dX_j + \alpha \int_{x_i}^{100} \frac{\partial}{\partial z} v_{-\omega}^{\phi}(X_j, x_i) dX_j = \frac{d[\beta(x_i)x_i]}{dx_i}, \ x_i \in (0, 100]$$

with the boundary condition $\beta(0)0 = 0$ has unique, for any $x \in [0, 100]$, solution the proposed equilibrium,

$$\beta(x_i) = \frac{1}{x_i}\int_0^{x_i}\left[\Psi^{\phi}(s,s,s) + \alpha\int_0^{s}\frac{\partial}{\partial z_i}v_{\omega}^{\phi}(X_j,x_i)dX_j + \alpha\int_s^{100}\frac{\partial}{\partial z}v_{-\omega}^{\phi}(X_j,x_i)dX_j\right]ds$$

$$= \frac{1}{x_i}\int_0^{x_i}\left[s + \alpha v_{\omega}^{\phi}(s,s) - \alpha v_{-\omega}^{\phi}(s,s) + \alpha\int_0^{s}\frac{\partial}{\partial z_i}v_{\omega}^{\phi}(X_j,x_i)dX_j + \alpha\int_s^{100}\frac{\partial}{\partial z}v_{-\omega}^{\phi}(X_j,x_i)dX_j\right]ds$$

$$= \frac{1}{x_i}\int_0^{x_i}\psi^{\phi}(s)\,ds$$

It remains thus to show that $\beta(x_i)$ is indeed an equilibrium. To this end, note first that, given that competitors deploy $\beta(x_i)$, any bidder is indifferent over any bid weakly lower than $\beta(0)$. Also, any bidder strictly prefers $\beta(100)$ to any higher bid. We have that

$$\frac{\partial EU_i(x_i,z_i,\phi)}{\partial z_i}$$

$$= \frac{1}{100}\left[\Psi^{\phi}(x_i,z_i,z_i) - \beta(z_i) - \frac{d\beta_{\phi}(z_i)}{dz_i}z_i + \alpha\int_0^{z_i}\frac{\partial}{\partial z_i}v_{\omega}^{\phi}(X_j,z_i)dX_j + \alpha\int_{z_i}^{100}\frac{\partial}{\partial z_i}v_{\omega}^{\phi}(X_j,z_i)dX_j\right]$$

So,

$$\frac{\partial EU_i(x_i,z_i,\phi)}{\partial z_i} - \frac{\partial EU_i(z_i,z_i,\phi)}{\partial z_i} = \frac{1}{100}[\Psi^{\phi}(x_i,z_i,z_i) - \Psi^{\phi}(z_i,z_i,z_i)].$$

Given that $\Psi^{\phi}(x_i,z_i,z_i)$ is strictly increasing in x_i, we have that if $z_i < x_i$ then $\frac{\partial EU_i(x_i,z_i,\phi)}{\partial z_i} > \frac{\partial EU_i(z_i,z_i,\phi)}{\partial z_i}$, and vice versa. That is, $\frac{\partial EU_i(x_i,z_i,\phi)}{\partial z_i}$ is strictly increasing in x_i. Note also that $\beta(z_i)$ satisfies $\frac{\partial EU_i(z_i,z_i,\phi)}{\partial z_i} = 0$ for any $z_i \in (0,100]$. These, in turn, imply that for any z_i and x_i such that $0 < z_i < x_i \leq 100$ we have $\frac{\partial EU_i(x_i,z_i,\phi)}{\partial z_i} > 0$, while for any z_i and x_i such that $0 \leq x_i < z_i \leq 100$ we have $\frac{\partial EU_i(x_i,z_i,\phi)}{\partial z_i} < 0$. Note also that for any $x_i > 0$ bidding $\beta(0)$ is not optimal. To see this, note first that from the above we have that $\frac{\partial EU_i(x_i,z_i,\phi)}{\partial z_i} \geq 0$ for any $z_i = \varepsilon$ where ε is arbitrarily small. So, it will be enough to show that $EU_i(x_i,0,\phi) \leq \lim_{z_i\to 0^+} EU_i(x_i,z_i,\phi)$. This holds as an equality by continuity of $v_{-\omega}^{\phi}(x_j,z_i)$. Thus, $z_i = x_i$ is indeed indeed a global maximum of $EU_i(x_i,z_i,\phi)$, for any $x \in [0,100]$, given that competitors deploy β. Thus, β is an equilibrium.■

Bidding Functions

Define

$$M(x) = E[X_i|X_i > x] = \frac{1}{1-\frac{x}{100}} \int_x^{100} X_i \frac{1}{100} dX_i = \frac{1}{2}(x+100)$$
$$\Lambda(x) = E[X_i|X_i < x] = \frac{1}{\frac{x}{100}} \int_0^{x} X_i \frac{1}{100} dX_i = \frac{1}{2}x$$

then it is easy to see that

$$v_\omega^{\mathcal{T}}(x_j, z_i) = x_i; v_{-\omega}^{\mathcal{T}}(x_j, z_i) = x_i$$

$$v_\omega^{\mathcal{A}}(x_j, z_i) = z_i; v_{-\omega}^{\mathcal{A}}(x_j, z_i) = z_i$$

$$v_\omega^{\mathcal{W}}(x_j, z_i) = z_i; v_{-\omega}^{\mathcal{W}}(x_j, z_i) = \frac{1}{2}x_j$$

$$v_\omega^{\mathcal{S}}(x_j, z_i) = \frac{1}{2}(x_j+100); v_{-\omega}^{\mathcal{S}}(x_j, z_i) = z_i$$

$$v_\omega^{\mathcal{N}}(x_j, z_i) = \frac{1}{100}\int_0^{100}\left(\frac{1}{2}(y+100)\right)dy = 75; v_{-\omega}^{\mathcal{N}}(x_j, z_i) = \frac{1}{100}\int_0^{100}\left(\frac{1}{2}y\right)dy = 25$$

which gives

$$\psi^{\mathcal{T}}(x_i) = x_i$$

$$\psi^{\mathcal{A}}(x_i) = x_i + 100\alpha$$

$$\psi^{\mathcal{W}}(x_i) = x_i\left(\frac{3}{2}\alpha + 1\right)$$

$$\psi^{\mathcal{S}}(x_i) = x_i\left(1 - \frac{3}{2}\alpha\right) + 150\alpha$$

$$\psi^{\mathcal{N}}(x_i) = x_i + 50\alpha$$

and

$$\beta^{\mathcal{T}}(x_i) = \frac{1}{2}x_i$$

$$\beta^{\mathcal{A}}(x_i) = \frac{1}{2}x_i + 100\alpha$$

$$\beta^{\mathcal{W}}(x_i) = x_i\left(\frac{3}{4}\alpha + \frac{1}{2}\right)$$

$$\beta^{\mathcal{S}}(x_i) = x_i\left(\frac{1}{2} - \frac{3}{4}\alpha\right) + 150\alpha$$

$$\beta^{\mathcal{N}}(x_i) = \frac{1}{2}x_i + 50\alpha$$

These and propositions 1 imply that

$$\widehat{w}^{i\mathcal{T}}(x_i, x_j) = \alpha x_i$$

$$\widehat{w}^{i\mathcal{A}}(x_i, x_j) = \alpha x_i$$

$$\widehat{w}^{i\mathcal{W}}(x_i, x_j) = \alpha x_i I(x_i, x_j) + \frac{\alpha}{2}x_j(1 - I(x_i, x_j))$$

$$\widehat{w}^{i\mathcal{S}}(x_i, x_j) = \frac{\alpha}{2}(x_j + 100) I(x_i, x_j) + \alpha x_i(1 - I(x_i, x_j))$$

$$\widehat{w}^{i\mathcal{N}}(x_i, x_j) = 75\alpha I(x_i, x_j) + 25\alpha(1 - I(x_i, x_j))$$

or, noting that for all disclosure rules $\phi \neq \mathcal{T}$, $x = \left(\beta^{\phi}\right)^{-1}(b)$, we have

$$\widehat{w}^{i\mathcal{T}}(b_i, b_j) = \alpha x_i$$

$$\widehat{w}^{i\mathcal{A}}(b_i, b_j) = 2\alpha b_i - 200\alpha^2$$

$$\widehat{w}^{i\mathcal{W}}(b_i, b_j) = 4\frac{\alpha}{3\alpha + 2}b_i I(b_i, b_j) + 2\frac{\alpha}{3\alpha + 2}b_j(1 - I(b_i, b_j))$$

$$\widehat{w}^{i\mathcal{S}}(b_i, b_j) = 2\alpha\frac{225\alpha - b_j - 50}{3\alpha - 2}I(b_i, b_j) + 4\alpha\frac{150\alpha - b_i}{3\alpha - 2}(1 - I(b_i, b_j))$$

$$\widehat{w}^{i\mathcal{N}}(b_i, b_j) = 75\alpha I(b_i, b_j) + 25\alpha(1 - I(b_i, b_j))$$

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