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On the "Exclusion Principle" in All-Pay Auctions with Incomplete Information

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Abstract

The number, and types, of participants in an auction can meaningfully affect the outcome of the competition. In a complete-information, all-pay context, previous studies proved that in first-price auctions, if the auctioneer maximizes the total bid received, then under appropriate conditions on the bidders' values, it may be optimal for them to exclude some participants, in particular the best ones. In this paper, we investigate whether the same principle can still hold with incomplete information. In the simplest context of independent and identically distributed values, by considering the symmetric Bayes–Nash Bidding Equilibrium, we show that this principle does not hold in all-pay auctions, whether in first- or second-price auctions, as the auctioneer would want to admit as many bidders as possible when maximizing the total bid. Exclusion of some bidders instead may be optimal if, in a first-price all-pay auction, the auctioneer maximizes the highest bid. Such findings exhibit an interesting duality with the complete-information case, since the opposite conclusions follow. Moreover, in a first-price, winner-only pays auction, including as many bidders as possible would be convenient for the auctioneer in terms of both maximizing the total bid and the first bid. Finally, a comparison of first-price all-pay auctions with winner-only pays auctions with incomplete information shows the following interesting relation: The total bid in all-pay auctions is equal to the highest bid in winner-only pays auctions and, by Revenue Equivalence, is also equal to the second-highest bid. Therefore, whether or not exclusion is profitable for the auctioneer depends upon the type of the auction, the goal of the auctioneer, and the information distribution among bidders and the auctioneer.

Keywords: exclusion principle; auctions; incomplete information

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1. Introduction

A key issue in auction and contest design is how to attract the appropriate pool of potential bidders to enter and compete aggressively. However, if it is clear that the pool of bidders could crucially affect the final outcome of a competitive auction, the question of how many bidders should be included, and what characteristics they should possess, becomes less clear. Indeed, on the one hand, numerous participants may be a key element in auctions to spur competition and challenge incumbents [1]. On the other hand, two versions of the "exclusion principle" have been proposed, advocating for, and positioning as optimal, a reduced pool of participants in two different contexts. Broadly speaking, the first version states that, in sales auctions with incomplete information, where only the winner pays and the auctioneer aims to maximize revenue, the optimal reserve price (minimal acceptable price) should be set to exclude some participants [2]. Therefore, those who can afford to

bid above the reserve price know that their opponents will all be highly competitive and, in turn, will submit more aggressive offers. The second version of the exclusion principle concerns all-pay auctions with complete information [3,4] where all bidders pay what they offer, and the auctioneer maximizes the sum of the submitted prices. In this context, the auctioneer may find it optimal to exclude the candidates with the highest willingness to pay, as this would encourage stronger competition among the remaining bidders, which would maximize the total sum of the prices bid. Instead, still under complete information, if the auctioneer maximizes the highest submitted price he would not want to exclude any potential participants, especially so the ones with the highest willingness to pay. Past experimental works, however, have challenged these theoretical findings [5].

Based on the second version of the exclusion principle, in this paper, we focus on the simplest formulation of an all-pay auction to discuss whether Baye et al.'s findings still hold in a standard private value auction framework with incomplete information. Though all-pay auctions, contests, and their applications to economics and politics have attracted a lot of attention [6–8] and have been widely studied up until recently [2,9–19] the issue addressed in the paper does not seem to have been investigated previously.

Interestingly, by considering a standard symmetric Bayes–Nash Equilibrium bidding function, what we find with incomplete information is a reversal of the above 'established' results with complete information. More explicitly, while when the highest price wins and the auctioneer maximizes the sum of the expected bids it is best for them to include as many bidders as possible, when the auctioneer pursues first-price maximization, they may find it optimal to restrict the pool of participants. To gain a better understanding of the results, we also considered first-price winner-only pays auctions with incomplete information, obtaining that full inclusion of bidders is best for both total bid and first-price maximization. Based on such findings, our interpretation is that the nature of all-pay auctions, as compared to winner-only pays auctions, seems to favor the exclusion of some potential bidders; however, with an important difference between complete and incomplete information.

This paper is structured as follows: In Section 2 we introduce the all-pay incomplete-information model and related main results. Section 3 compares the findings of Section 2 to winner-only pays auctions with incomplete information, while Section 4 concludes the work.

2. All-Pay First-Price Auctions with Incomplete Information

Consider an indivisible object on sale and n players competing for it in a sealed-bid first-price auction. Their values v_i are distributed as i.i.d absolutely random variables defined over the closed interval $[0,\ a]$, with $a > 0$, according to the distribution function $F(x)$ and density $F'(x) = f(x)$. Moreover, suppose $b_i(v_i)$ is player $i's$ bid as a function of his own value, with $i = 1, \ldots, n$, and $\Pi_i(b_i(v_i))$ being player $i's$ profit, defined as follows:

$$\Pi_i(b_i(v_i)) = \begin{cases} v_i - b_i(v_i) & \textit{if player i wins the auction with no tie} \\ \dfrac{v_i - b_i(v_i)}{k} & \textit{if there are k best offers, including player i's} \\ -b_i(v_i) & \textit{if player i does not win the auction} \end{cases}$$

Therefore, player $i's$ expected profit is given by

$$E\Pi_i(b_i(v_i)) = v_i \prod_{j \neq i} P\big(b_j(v_j) \leq b_i(v_i)\big) - b_i(v_i)$$

We are interested in deriving the symmetric Bayes–Nash Equilibrium bidding function $b_i(v_i) = b(v)$. We do so by a standard envelope theorem application [20] to obtain

$$\frac{dE\Pi_i}{d\mathrm{v}_i} = F\left(b_j^{-1}(b_i(v_i)\right)^{n-1} \tag{1}$$

In a symmetric equilibrium it is $b_j(v) = b_i(v)$ hence $b_j^{-1}(b_i(v_i) = v_i$. Therefore

$$F\left(b_j^{-1}(b_i(v_i)\right)^{n-1} = F(\mathrm{v}_i)^{n-1}$$

Solving the differential Equation (1), we obtain

$$E\Pi_i(v_i) = \int_0^{v_i} F(x)^{n-1}dx$$

and so

$$E\Pi_i(v_i) = \int_0^{v_i} F(x)^{n-1}dv_i = v_iF(\mathrm{v}_i)^{n-1} - b_i(v_i)$$

from which the well-known symmetric Bayes–Nash Equilibrium bidding function [1,2] is given by

$$b_i(v_i) = v_iF(\mathrm{v_i})^{n-1} - \int_0^{v_i} F(x)^{n-1}dx = \int_0^{v_i} [F(\mathrm{v}_i)^{n-1} - F(x)^{n-1}]dx \tag{2}$$

Therefore, $\sum_{i=1}^n Eb_i(v_i)$, where $Eb_i(v_i) = \int_0^a b_i(v_i)f(v_i)dv_i$ is the expected bid made by player i, representing the total expected offer received by the auctioneer. If, in a symmetric equilibrium, $Eb_i(v_i)$ is the same for all players, then $\sum_{i=1}^n Eb_i(v_i) = nEb_i(v_i)$, defining, from now on, $b_i(v_i) = b_i(v_i; n)$, and the following holds:

Proposition 1. ***Inclusion Principle with Expected Total Bid Maximization in a First-Price All-Pay Auction****: In the symmetric equilibrium of an all-pay auction with incomplete information, if the auctioneer maximizes the expected total effort* $\sum_{i=1}^n Eb_i(v_i, n) = nEb_i(v_i, n)$*, then it is optimal for her to admit as many bidders as possible.*

Proof. By definition,

$$Eb_i(v_i; n) = \int_0^a \int_0^{v_i} [F(\mathrm{v}_i)^{n-1} - F(x)^{n-1}]\, dx\, f(v_i)dv_i \geq 0$$

This can be re-written as

$$Eb_i(v_i; n) = \int_0^a F(\mathrm{v}_i)^{n-1}f(v_i)v_idv_i - \int_0^a \int_x^a F(x)^{n-1}f(v_i)\, dx\, dv_i$$

and as

$$Eb_i(v_i; n) = \frac{a}{n} + \frac{(n-1)}{n}\int_0^a F(x)^n dx - \int_0^a F(x)^{n-1}dx \tag{3}$$

which reaches a maximum at some $n = n^* > 0$, since it is equal to zero at $n = 1$ and tends to zero as n increases.

It follows that

$$nEb_i(v_i; n) = a - \int_0^a \left[F(x)^n + nF(x)^{n-1}(1 - F(x))\right]dx \tag{4}$$

Therefore, to prove this result, it suffices to show that

$$g(n) = F(x)^n + nF(x)^{n-1}(1 - F(x))$$

decreases with n. But simple algebraic manipulations imply that

$$g(n) > g(n+1) > 0$$

if and only if

$$n(1 - F(x))^2 > 0$$

which is true for $n = 1, 2, \ldots$, and the conclusion follows. □

Intuitively, this result suggests that, when compared with complete information, the auctioneer would never want to exclude potential participants because the increase in total expected bid obtained by allowing an extra participant to enter would more than counterweigh the possible decrease in the price offered by each single bidder. That is, with incomplete information, when $n > n^*$, the decrease in individuals' bids, due to an extra bidder, is sufficiently small because the bids are already quite small.

However, rather than focusing on total bid maximization, the auctioneer may pursue expected first price maximization. The following proposition discusses how this may lead to excluding some of the potential participants:

Proposition 2. ***Exclusion Principle in an All-Pay Auction With Expected First Price Maximization****: In the symmetric equilibrium of a first-price all-pay auction with incomplete information, if the auctioneer maximizes the expected highest bid* $Eb_{(1)}\left(v_{(1)}, n\right)$*, then it may be optimal for her to exclude some of the bidders.*

Proof. In a first-price all pay-auction, the highest expected bid for the auctioneer is

$$Eb_{(1)}\left(v_{(1)}, n\right) = n\int_0^a \int_0^{v_{(1)}} [F\left(v_{(1)}\right)^{n-1} - F(x)^{n-1}][F\left(v_{(1)}\right)^{n-1} f\left(v_{(1)}\right)]dv_{(1)}dx$$

Namely,

$$Eb_{(1)}\left(v_{(1)}, n\right) = \frac{na}{2n-1} + \frac{n-1}{2n-1}\int_0^a F(x)^{2n-1}dx - \int_0^a F(x)^{n-1}dx \tag{5}$$

Clearly, $Eb_{(1)}\left(v_{(1)}, n = 1\right) = 0$, and $\lim_{n\to\infty} Eb_{(1)}\left(v_{(1)}, n\right) = \frac{a}{2}$, but the shape of Equation (5) can be meaningfully affected by the form of $F(x)$ and, under specific conditions on $F(x)$, allow for exclusion. □

Indeed, as the following example illustrates, if the probability distribution is appropriately concentrated towards the upper bound, limiting the number of participants may be preferable for the auctioneer. Consider $a = 1$, $F(x) = x^k$, and $f(x) = kx^{k-1}$ with $k > 0$—that is, a *power law* family of distributions defined over the unit interval $[0, 1]$, parametrized by k. Then,

$$Eb_{(1)}\left(v_{(1)}, n, k\right) = \frac{n}{2n-1} + \frac{n-1}{2n-1}\int_0^1 x^{k(2n-1)}dx - \int_0^1 x^{k(n-1)}dx$$

which, when solved, leads to

$$Eb_{(1)}\left(v_{(1)}, n, k\right) = \frac{n}{2n-1} + \frac{n-1}{(2n-1)[k(2n-1)+1]} - \frac{1}{k(n-1)+1} \tag{6}$$

Differentiating (6) with respect to k, we obtain

$$\frac{dEb_{(1)}\left(v_{(1)},n,k\right)}{dk} = -\frac{(n-1)(2n-1)^2}{[(2n-1)(k(2n-1)+1)]^2} + \frac{(n-1)}{(k(n-1)+1)^2} > 0 \tag{7}$$

which implies that $Eb_{(1)}\left(v_{(1)},n,k\right)$ is increasing with k. Moreover, $Eb_{(1)}\left(v_{(1)},n,k\right)$ tends to $\frac{n}{2n-1}$ as k increases. But since $\frac{n}{2n-1}$ is decreasing with $n \geq 1$, and such that $\frac{n}{2n-1} > \frac{1}{2} = \frac{a}{2}$, it follows that for small n and large k, the value of $Eb_{(1)}\left(v_{(1)},n,k\right)$ may be larger than $\frac{1}{2}$.

Indeed, the Table 1 below presents some simple numerical simulations showing how both inclusion and exclusion may take place.

Table 1. $Eb_{(1)}\left(v_{(1)},n,k\right)$ *for different values of* n *and* k.

$n\downarrow k\rightarrow$	**1**	**2**	**3**	**4**	**5**	**20**	**100**	**200**	**1000**
2	0.25	0.38	0.45	0.4	0.52	0.62	0.65	0.66	0.66
3	0.33	0.43	0.48	0.51	0.52	0.58	0.59	0.59	0.59
4	0.37	0.45	0.49	0.51	0.52	0.56	0.59	0.57	0.57
10	0.45	0.48	0.49	0.5	0.51	0.52	0.52	0.52	0.52
15	0.47	0.49	0.5	0.5	0.51	0.51	0.51	0.51	0.51
20	0.47	0.49	0.5	0.5	0.5	0.51	0.51	0.51	0.51
100	0.49	0.50	0.5	0.5	0.5	0.5	0.5	0.5	0.5
200	0.49	0.50	0.5	0.5	0.5	0.5	0.5	0.5	0.5
1000	0.5	0.50	0.5	0.5	0.5	0.5	0.5	0.5	0.5

The horizontal arrow indicates the values of K while the vertical arrow of n.

The above Table 1 exhibits a few interesting points. First, there exists a threshold value for k, between 4 and 5, which separates inclusion from exclusion. In fact, for $k \leq 4$, inclusion is preferred, while for $k \geq 5$, exclusion is more convenient. In particular, $n = 2$ is the optimal number of bidders for the auctioneer. Then, based on this, the highest level of $Eb_{(1)}\left(v_{(1)},n,k\right)$ that can be obtained is equal to $0.66 = \frac{2}{3}$ when k is sufficiently large and $n = 2$. That is, the largest possible expected payoff level can be obtained with a minimum number of competitors and a probability distribution which is skewed towards the upper bound of the domain.

The next proposition shows that when the auctioneer aims to maximize the total bid, inclusion is robust with respect to a remarkable award criterion.

Proposition 3. *Inclusion Principle With Expected Total Bid Maximization in a Second Price All-Pay Auction: In the symmetric equilibrium of a second price all-pay auction with incomplete information, if the auctioneer maximizes the total effort* $nEb_i(v_i)$*, then it is optimal for her to include as many bidders as possible.*

Proof. We define $g(x)$ and $G(x)$ as the density and distribution functions of the second-order statistics, respectively. Then, based on [10], the expected symmetric equilibrium bidding function in the war of attrition is given by

$$Eb_i^{(2)}(v_i;n) = \int_0^a g(v_i)\int_0^{v_i} x\frac{g(x)}{1-G(x)}dxdv_i$$

Hence,

$$Eb_i^{(2)}(v_i;n) = \int_0^a \frac{xg(x)}{1-G(x)}dx \int_x^a g(v_i)\,dx\,dv_i = \int_0^a \frac{xg(x)(1-G(x))}{1-G(x)}dx = \int_0^a xg(x)dx$$

which coincides with the symmetric equilibrium in dominant strategies of the standard Vickrey, winner-pays auction and is equal to

$$Eb_i^{(2)}(v_i;n) = a - \int_0^a \Big[F(x)^n + nF(x)^{n-1}(1-F(x))\Big]dx$$

which is increasing in n, also implying that $nEb_i^{(2)}(v_i;n) = n^2 Eb_i(v_i,n)$ is increasing in n. □

Hence, Propositions 1 and 3 suggest that with total bid maximization, the auctioneer would be better off adopting the second, rather than the first, price mechanism.

3. Comparison with Winner-Pays Bidding Auctions

For the sake of completion, as well as to gain further insights into the above findings, in this section, we compare the previous results to a winner-only-pays auction. Indeed, it is well-known that bidders' behavior in all-pay auctions is typically different from winner-pays auctions [2]. As a function of the number of bidders n, it is well-known that the symmetric equilibrium bidding function of a winner-pays auction $b_i^w(v_i,n)$ is given by [20]:

$$b_i^w(v_i,n) = v_i - \frac{\int_0^{v_i} F(x)^{n-1}dx}{F(\mathrm{v}_i)^{n-1}} = \int_0^{v_i}[1 - \frac{F(x)^{n-1}}{F(\mathrm{v}_i)^{n-1}}]dx = \frac{b_i(v_i,n)}{F(\mathrm{v}_i)^{n-1}} \geq b_i(v_i,n)$$

Namely, the winner-only pays symmetric equilibrium bidding function is the all-pay bidding function multiplied by a scale factor $F(\mathrm{v}_i)^{1-n}$. A comparison with Equation (2) immediately suggests that the scaling factor is precisely due to the winner-only pays feature of the auction since, now, losers will not pay the total they bid. Next, we will discuss how such a scalar factor affects the previous conclusions in a winner-pays auction where the auctioneer aims to maximize the total expected bid. Our interest in such a mechanism is not simply for comparison with all-pay auctions per se; rather, we also wish to explore this mechanism for when the auctioneer is interested in "transparency" and in inducing as high a level of competition as possible (like in public procurement), goals which are well-represented by a concern for total bid.

Proposition 4. ***Inclusion Principle with Expected Total Bid Maximization****: In the symmetric equilibrium of a first-price winner-pays auction with incomplete information, if the auctioneer maximizes total expected bid* $\sum_{i=1}^n b_i^w(v_i,n) = nEb_i^w(v_i,n)$*, then it is optimal for her to admit as many bidders as possible.*

Proof. By definition,

$$b_i^w(v_i,n) = \frac{\int_0^{v_i}[F(\mathrm{v}_i)^{n-1} - F(x)^{n-1}]dx}{F(\mathrm{v}_i)^{n-1}} \tag{8}$$

and so

$$Eb_i^w(v_i,n) = \int_0^a \int_0^{v_i}[1 - \frac{F(x)^{n-1}}{F(\mathrm{v}_i)^{n-1}}]\,dx\,f(v_i)dv_i$$

which can be rewritten as

$$Eb_i^w(v_i, n) = a - \left(\frac{n-1}{n-2} \int_0^a F(x)dx - \frac{1}{n-2} \int_0^a F(x)^{n-1} dx \right)$$

which is equal to zero for $n = 1$, not defined at $n = 2$, and decreasing for $n > 2$, such that

$$\lim_{n \to \infty} Eb_i^w(v_i, n) = Ev = \int_0^a [1 - F(v)]dv$$

Indeed, if we define $h(n-1) = \left(\frac{n-1}{n-2} \int_0^a F(x)dx - \frac{1}{n-2} \int_0^a F(x)^{n-1} dx \right) \geq 0$, it is clear to see that $h(n) > h(n-1)$, since

$$h(n) - h(n-1) = \frac{(n-2)}{(n-1)} \int_0^a [F(x) + F(x)^{n-1}(1 - F(x))]dx \geq 0$$

Therefore, the total bid is given by

$$nEb_i^w(v_i, n) = na + \frac{n}{n-2} \int_0^a F(x)^{n-1} dx - \frac{n(n-1)}{n-2} \int_0^a F(x)dx$$

which tends to infinity as n increases; hence, the conclusion follows. □

Therefore, even though the individual equilibrium bid is decreasing with n, their sum increases with n.

We now discuss maximization of expected first price.

Proposition 5. ***Inclusion Principle With Expected First Price Maximization****: In the symmetric equilibrium of a first-price winner-pays auction with incomplete information, if the auctioneer maximizes the highest expected bid* $Eb_{(1)}^w \left(v_{(1)}, n \right)$*, then it is optimal for her to admit as many bidders as possible.*

Proof. In a first-price winner-pays auction, the highest expected bid for the auctioneer is

$$Eb_{(1)}^w \left(v_{(1)}, n \right) = n \int_0^a \int_0^{v_{(1)}} [1 - \frac{F(x)^{n-1}}{F\left(\mathrm{v}_{(1)} \right)^{n-1}}] F\left(\mathrm{v}_{(1)} \right)^{n-1} f\left(v_{(1)} \right) dv_{(1)} dx$$

Namely,

$$Eb_{(1)}^w \left(v_{(1)}, n \right) = n \int_0^a \int_0^{v_{(1)}} [F\left(v_{(1)} \right)^{n-1} - F(x)^{n-1}] f\left(v_{(1)} \right) dv_{(1)} dx = nEb_i(v_i; n)$$

which proves the result. □

We conclude by observing that Equation (3) is the expected value of the second-highest-order statistics, namely the expected revenue in the symmetric weakly dominant equilibrium strategy of a standard Vickrey auction, where only the winner pays. Hence, this gives rise to the following Revenue Equivalence result between all-pay and winner-pays auctions.

Corollary 1. ***Revenue Equivalence****: In the context of the symmetric equilibrium bidding function of a first-price all-pay auction with incomplete information, the expected total bid received is equal to the expected revenue of the auctioneer in first- and second-price winner-only pays auctions with incomplete information.*

4. Conclusions

In this paper, considering a scenario where the auctioneer maximizes the total bid in the context of political lobbying, we investigated whether the "exclusion principle", characterized by Baye et al. (1993) in [3], for all-pay auctions with complete information would hold for contests with incomplete information. By considering symmetric bidding equilibrium functions, we discussed how incomplete information may reverse the findings with complete information. In particular, while it is best for the auctioneer to admit as many bidders as possible when their goal is to maximize the total bid, excluding some of the participants may be preferable if the auctioneer wishes to obtain the highest price. Though further research work is needed in this direction, comparison with winner-only pays auctions with incomplete information seems to suggest that exclusion of bidders may be more likely in contests with an all-pay structure. In particular, more research on the robustness of the results to the bidders' risk attitudes, asymmetries of value distributions, and possible value correlations is needed.

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