Information Sharing in Private Value Lottery Contest *

Zenan Wu† Jie Zheng‡

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Abstract

We investigate players' incentives to disclose information on their private valuations of the prize ahead of a rent-seeking contest: Information sharing arises in equilibrium if types are concentrated enough, whereas sharing information is strictly dominated if types are sufficiently dispersed.

Keywords: Tullock Contests; Private Values; Information Sharing

JEL Classification Codes: D44, D82, C72.

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†Corresponding author. School of Economics, Peking University, Beijing 100871, China. Email: zenan@pku.edu.cn

‡Corresponding author. School of Economics and Management, Tsinghua University, Beijing 100084, China. Email: zhengjie@sem.tsinghua.edu.cn

1 Introduction

As a prevalent stochastic mechanism to allocate resources, Tullock contests with different information environments have been studied intensively.[1] Most studies take as given the information structure players face before the contest starts.[2] In this paper, we endogenize information in a natural way: A communication stage is added before the contest. This allows us to examine players' incentives on information sharing explicitly. Specifically, we focus on a symmetric Tullock contest with two-sided private information except that players can commit to an information disclosure rule before knowing their values of winning.

Our main finding (Proposition 1) is that, if player's types are sufficiently concentrated, information exchange occurs in all equilibria. However, if player's types are sufficiently dispersed, sharing information is strictly dominated. On the one hand, our result, which depends on the type distribution, provides a stark contrast to Proposition 2 in Kovenock et al. (2015), where information sharing is always strictly dominated under all-pay auction with private values, regardless of the type distribution. On the other hand, our type-dependent result differs from the information-sharing result in a Cournot game (e.g., Li, 1985; Shapiro, 1986), where each firm prefers committing to disclose its private marginal cost before choosing quantity.

We also consider the designer's optimal information disclosure problem by adopting the criteria of total revenue and social welfare, respectively. We show that the asymmetric information environment can soften competition and generate less revenue relative to symmetric information environments (Proposition 2), whereas the comparison of social welfare depends on the distribution of player's types (Proposition 3).[3]

2 The Model

Two risk neutral players $i = A, B$ compete for a single prize by simultaneously bidding non-negative values x_A and x_B. The success function of player i under the portfolio (x_A, x_B) is given by

$$p_i(x_A, x_B) = \begin{cases} x_i/(x_A + x_B) & \text{if } x_A + x_B > 0 \\ 1/2 & \text{otherwise} \end{cases}.$$

Each player privately knows his value of winning $v_i \in \{v_L, v_H\}$, where $v_H > v_L > 0$. Player i's value of winning is independently distributed from $\Pr(v_i = v_H) = \Pr(v_i = v_L) = \frac{1}{2}$. Before being

[1] For a list that is indicative, but by no means exhaustive, see Malueg and Yates (2004), Fey (2008), for two-sided incomplete information; see Hurley and Shogren (1998), Einy et al. (2013), Wärneryd (2003, 2013) for one-sided incomplete information.

[2] Recently, Denter et al. (2014), Wasser (2013), and Zhang and Zhou (2016) consider the optimal information design problem of the contest designer in Tullock contest models.

[3] There is growing literature on information disclosure policy in contests. Among many others, Fu et al. (2014) study the optimal symmetric disclosure policy in a multi-prize all-pay auction with private information and show that concealing the information leads to higher expected total effort to the contest designer; Jiao et al. (2017) consider information disclosure policy in a single-prize all-pay auction with asymmetric information and find that the optimal policy depends on the trade off between the information (dis)advantage and the cost (dis)advantage between the two players.

informed about v_i, each player chooses and commits to an information disclosure rule $r_i \in \{S, N\}$, where S stands for sharing and N stands for concealing private information. The information is verifiable, i.e., each player can conceal but cannot misreport his information. The expected payoff of player i conditional on the bids (x_A, x_B) and the value of winning v_i, denoted by $u_i(\cdot)$, is

$$u_i(x_A, x_B, v_i) := p_i(x_A, x_B) \cdot v_i - x_i.$$

2.1 Sub-game after (r_A, r_B)

We solve the game by backward induction, and characterize the equilibrium payoffs for each sub-game. First consider the case where both players agree to share information, that is, $(r_A, r_B) = (S, S)$. Information becomes public before players make their bids. Leininger (1993) analyzed such a contest for any positive values of v_A and v_B, and the unique equilibrium bids $x_A^*(v_A, v_B)$ and $x_B^*(v_A, v_B)$ are given by

$$x_A^*(v_A, v_B) = \frac{v_A v_B}{(v_A + v_B)^2} v_A \text{ and } x_B^*(v_A, v_B) = \frac{v_A v_B}{(v_A + v_B)^2} v_B.$$

Next, we consider the case where both players keep their information secret, that is, $(r_A, r_B) = (N, N)$. No information is exchanged between the two players and the game degenerates to the Tullock contest with two-sided incomplete information, whose equilibrium is derived by Malueg and Yates (2004). The unique symmetric pure strategy Bayesian equilibrium (x_H^*, x_L^*) is given by

$$x_H^* = \left(\frac{1}{8} + \frac{1}{2}\frac{v_H v_L}{(v_H + v_L)^2}\right) v_H \text{ and } x_L^* = \left(\frac{1}{8} + \frac{1}{2}\frac{v_H v_L}{(v_H + v_L)^2}\right) v_L,$$

where x_H^* and x_L^* are player's equilibrium bid when his type is v_H and v_L respectively.

Last, consider the asymmetric case where one player (e.g. player A) commits to disclose and the other (e.g. player B) decides to conceal information. Denote $\hat{x}_H^*$ and $\hat{x}_L^*$ as player A's bid when his type is v_H and v_L respectively. Similarly, denote $\hat{x}_{ij}^*$ as B's bid conditional on A's type is v_i $(i = H, L)$ and his type is v_j $(j = H, L)$. The equilibrium of this one-sided incomplete information contest is provided by Zhang and Zhou (2016), and they focus on parameters yielding an equilibrium where both players make positive amount of bid. Since our goal is to analyze players' decisions of information sharing, we fully characterize the equilibrium in our two-state framework for all values of v_H and v_L.[4]

Lemma 1 *Suppose player A shares information and B chooses to conceal information. Then there exists a unique pure strategy equilibrium in which player A chooses bid:*

$$\hat{x}_L^* = \left[\frac{\sqrt{v_H} + \sqrt{v_L}}{3v_H + v_L}\right]^2 v_H v_L, \tag{1}$$

[4]The proof closely follows that of Proposition 6 in Zhang and Zhou (2016) and the derivation of the two-type example in Section 5.2 in Wärneryd (2003), and is omitted for brevity.

and

$$\hat{x}_H^* = \begin{cases} \left(\frac{\sqrt{v_H}+\sqrt{v_L}}{3v_L+v_H}\right)^2 v_H v_L & \textit{if } \frac{v_H}{v_L} \le 9 \\ \frac{v_H}{9} & \textit{if } \frac{v_H}{v_L} > 9 \end{cases}. \quad (2)$$

Player B chooses bid according to

$$\hat{x}_{LH}^* = \sqrt{v_H}\sqrt{\hat{x}_L^*} - \hat{x}_L^*, \quad \hat{x}_{LL}^* = \sqrt{v_L}\sqrt{\hat{x}_L^*} - \hat{x}_L^*, \quad \hat{x}_{HH}^* = \sqrt{v_H}\sqrt{\hat{x}_H^*} - \hat{x}_H^*,$$

and

$$\hat{x}_{HL}^* = \begin{cases} \sqrt{v_L}\sqrt{\hat{x}_H^*} - \hat{x}_H^* & \textit{if } \frac{v_H}{v_L} \le 9 \\ 0 & \textit{if } \frac{v_H}{v_L} > 9 \end{cases}.$$

2.2 Decisions to Share Information

Next, we investigate players' incentives to disclose information. Denote player i's equilibrium payoff when he chooses $r_i = S, N$ and the opponent chooses $r_j = S, N$ by $V_{r_i r_j}$. The stage game of information sharing is summarized in Table 1.

		r_B: S	r_B: N
r_A	S	V_{SS}, V_{SS}	V_{SN}, V_{NS}
	N	V_{NS}, V_{SN}	V_{NN}, V_{NN}

Table 1: The Stage Game of Information Sharing.

Given the equilibrium bids characterized in the previous section, players' equilibrium payoffs under different information regimes are

$$V_{SS} = V_{NN} = \frac{1}{4}\left[\frac{v_H}{4} + \frac{v_L}{4}\right] + \frac{1}{4}\left[\frac{v_H^3}{(v_H+v_L)^2} + \frac{v_L^3}{(v_H+v_L)^2}\right] = \frac{5}{16}(v_H+v_L) - \frac{3}{4}\frac{v_H v_L}{v_H+v_L},$$

$$V_{SN} = \begin{cases} \frac{1}{4}\left[1+\frac{v_H}{v_L}\right]\hat{x}_H^* + \frac{1}{4}\left[1+\frac{v_L}{v_H}\right]\hat{x}_L^* & \text{if } \frac{v_H}{v_L} \le 9 \\ \frac{5}{18}v_H + \frac{1}{4}\left[1+\frac{v_L}{v_H}\right]\hat{x}_L^* & \text{if } \frac{v_H}{v_L} > 9 \end{cases},$$

and

$$V_{NS} = \begin{cases} \frac{1}{4}\left[(\sqrt{v_H}-\sqrt{\hat{x}_H^*})^2 + (\sqrt{v_L}-\sqrt{\hat{x}_L^*})^2 + (\sqrt{v_H}-\sqrt{\hat{x}_L^*})^2 + (\sqrt{v_L}-\sqrt{\hat{x}_H^*})^2\right] & \text{if } \frac{v_H}{v_L} \le 9 \\ \frac{1}{9}v_H + \frac{1}{4}\left[(\sqrt{v_H}-\sqrt{\hat{x}_L^*})^2 + (\sqrt{v_L}-\sqrt{\hat{x}_L^*})^2\right] & \text{if } \frac{v_H}{v_L} > 9 \end{cases}.$$

For the remainder of the paper, it is convenient to define $\delta := v_H/v_L$, which can be interpreted as a measure of relative dispersion of winning values. The next lemma compares the equilibrium payoffs for different values of δ.

Lemma 2 (Payoff Comparison) *The equilibrium payoffs V_{SS}, V_{NN}, V_{SN}, and V_{NS} can be ranked as follows.*

(i) $V_{NS} > V_{SS} = V_{NN}$ for all $\delta > 1$.

(ii) There exists a threshold $\overline{\delta} \approx 12.3334$ such that $V_{SN} > V_{NN}$ if $\delta < \overline{\delta}$, and $V_{SN} < V_{NN}$ if $\delta > \overline{\delta}$.

Proof. Dividing V_{SS} and V_{NN} by v_L, we obtain:

$$\frac{V_{SS}}{v_L} = \frac{V_{NN}}{v_L} = \frac{5}{16}(1+\delta) - \frac{3}{4}\frac{\delta}{1+\delta} = \frac{1}{16}\frac{5\delta^2 - 2\delta + 5}{1+\delta}.$$

(i) It remains to prove $V_{NS} > V_{SS}$. Plugging (1) and (2) into V_{NS} and dividing it by v_L yields,

$$\frac{V_{NS}}{v_L} = \begin{cases} \frac{1}{4}\left[\left(\frac{\delta+\sqrt{\delta}}{3+\delta} - 1\right)^2 + \left(\frac{\delta+\sqrt{\delta}}{3\delta+1} - \sqrt{\delta}\right)^2 + \left(\frac{\delta+\sqrt{\delta}}{3+\delta} - \sqrt{\delta}\right)^2 + \left(\frac{\delta+\sqrt{\delta}}{3\delta+1} - 1\right)^2\right] & \text{if} \quad \delta \le 9 \\ \frac{1}{9}\delta + \frac{1}{4}\left[\left(\frac{\delta+\sqrt{\delta}}{3\delta+1} - \sqrt{\delta}\right)^2 + \left(\frac{\delta+\sqrt{\delta}}{3\delta+1} - 1\right)^2\right] & \text{if} \quad \delta > 9 \end{cases}.$$

Case 1: $\delta \le 9$. Carrying out the algebra, we see that $V_{NS} \ge V_{SS}$ is equivalent to

$$\frac{3}{8} \times \frac{1+\delta}{\sqrt{\delta}} + \frac{3}{2} \times \frac{\sqrt{\delta}}{1+\delta} - (1+\sqrt{\delta})^2\left[\frac{\delta - \sqrt{\delta} + 3}{(\delta+3)^2} + \frac{3\delta - \sqrt{\delta} + 1}{(3\delta+1)^2}\right] > 0.$$

It is straightforward to verify that the left hand side is strictly positive for $\delta \in (1, 9]$.

Case 2: $\delta > 9$. Carrying out the algebra, $V_{NS} \ge V_{SS}$ is equivalent to

$$\frac{\delta + \sqrt{\delta}}{(3\delta+1)^2}(3\delta^{\frac{3}{2}} + 2\delta + 1) + \frac{1}{8}(1+\delta) - \frac{2}{9}\delta - \frac{3}{2}\frac{\delta}{1+\delta} < 0.$$

The left hand side of the inequality can be bounded above by,

$$\begin{aligned} LHS &\le \frac{\delta + \sqrt{\delta}}{(3\delta+1)^2}(3\delta^{\frac{3}{2}} + 2\delta + 1) + \frac{1}{8}(1+\delta) - \frac{2}{9}\delta - \frac{27}{20} \\ &= \sqrt{\delta}\frac{3\delta^2 + 2\delta + 1}{(3\delta+1)^2} + \frac{5\delta^2 + \delta}{(3\delta+1)^2} + \frac{1}{8}(1+\delta) - \frac{2}{9}\delta - \frac{27}{20} \\ &\le \sqrt{\delta}\frac{3\delta^2 + 2\delta + 1}{(3\delta+1)^2} + \frac{5}{9} + \frac{1}{8}(1+\delta) - \frac{2}{9}\delta - \frac{27}{20} \\ &= \frac{\delta}{3\delta+1}\sqrt{\delta} + \frac{\delta+1}{(3\delta+1)^2}\sqrt{\delta} + \frac{5}{9} + \frac{1}{8}(1+\delta) - \frac{2}{9}\delta - \frac{27}{20} \\ &< \frac{1}{3}\sqrt{\delta} + \frac{1}{9} + \frac{5}{9} + \frac{1}{8}(1+\delta) - \frac{2}{9}\delta - \frac{27}{20} \\ &= -\frac{7}{72}\delta + \frac{1}{3}\sqrt{\delta} - \frac{67}{120} \le -\frac{7}{8} + 1 - \frac{67}{120} < 0. \end{aligned}$$

The first inequality follows from that fact that $\delta/(1+\delta)$ is strictly increasing in δ. The second inequality follows from $(5\delta^2+5\delta)/(3\delta+1)^2 \leq 5/9$. The third inequality follows from $\delta/(3\delta+1) < 1/3$ and $(\delta+1)/(3\delta+1)^2\sqrt{\delta} < 1/9$ for $\delta > 9$.

(ii) Plugging (1) and (2) into V_{SN} and dividing it by v_L yields,

$$\frac{V_{SN}}{v_L} = \begin{cases} \frac{1}{4}(1+\delta)\delta\left(\frac{1+\sqrt{\delta}}{3+\delta}\right)^2 + \frac{1}{4}(1+\delta)\left(\frac{1+\sqrt{\delta}}{3\delta+1}\right)^2 & \text{if} \quad \delta \leq 9 \\ \frac{5}{18}\delta + \frac{1}{4}(1+\delta)\left(\frac{1+\sqrt{\delta}}{3\delta+1}\right)^2 & \text{if} \quad \delta > 9 \end{cases}.$$

Case 1: $\delta \leq 9$. It can be verified that $V_{SN} > V_{SS}$ is equivalent to

$$\frac{(1+\delta)^2(1+\sqrt{\delta})^2}{5\delta^2-2\delta+5}\left[\delta\left(\frac{1}{3+\delta}\right)^2 + \left(\frac{1}{3\delta+1}\right)^2\right] > 1/4.$$

$$\Leftrightarrow (1+\delta)^2(1+\sqrt{\delta})^2(9\delta^3+7\delta^2+7\delta+9) - \frac{1}{4}(5\delta^2-2\delta+5)(3+\delta)^2(3\delta+1)^2 > 0.$$

It is straightforward to verify that the left hand side is strictly positive for $\delta \in (1, 9]$.

Case 2: $\delta > 9$. Carrying out the algebra, we see that $V_{SN} \geq V_{NN}$ is equivalent to

$$g(\delta) := \frac{5\delta^2-58\delta+45}{(1+\delta)^2}\left(\frac{3\delta+1}{1+\sqrt{\delta}}\right)^2 \leq 36.$$

Notice that $g(\delta) \leq 0$ for $\delta \in [9, \frac{29+2\sqrt{154}}{5}]$ and the above inequality holds. For $\delta > \frac{29+2\sqrt{154}}{5} \approx 10.7639$, it can be verified that $(5\delta^2-58\delta+45)/(1+\delta)^2$ and $(3\delta+1)/(1+\sqrt{\delta})$ are both strictly increasing in δ. Therefore, the left hand side is strictly increasing in δ for $\delta \geq 10.7639$. Combing with $g(11) \approx 5.1700 < 36$ and $g(13) \approx 52.3407 > 36$, there exists a threshold $\overline{\delta} \approx 12.3334$ such that $V_{SN} > V_{NN}$ for $\delta < \overline{\delta}$ and $V_{SN} < V_{NN}$ for $\delta > \overline{\delta}$. ■

Lemma 2 states that player A strictly prefers to conceal information if player B commits to information sharing. The intuition is as follows. Suppose player A also commits to disclose his private information. On the one hand, he loses information advantage directly and will be worse off. On the other hand, due to the symmetric information structures, competition among players is intensified and hence player A will employ a more aggressive bidding strategy.[5] As a result, information sharing is strictly dominated.

However, when the opponent conceals information, player A may benefit from information sharing if δ is small enough. Similarly, information disclosure from player A has two effects. It *improves coordination* (or *softens competition*) between the two players at the expense of losing *information advantage*. When δ is small (large), the former (latter) effect dominates the latter (former). Therefore, sharing (concealing) information is optimal to player A.

[5]To see this, it is useful to consider the situation where types are sufficiently dispersed (i.e., $\delta > 9$) and player A's value is v_L. When player A conceals information, he submits zero bid (i.e., $\hat{x}^*_{HL} = 0$) once he knows the opponent's value is v_H. In contrast, he always submits a positive amount of bid if he discloses information.

Proposition 1 (Equilibrium Information Disclosure Decisions) *If $\delta > \overline{\delta}$, sharing information is strictly dominated for both players. If $\delta < \overline{\delta}$, there exists two asymmetric pure strategy equilibria in which one player discloses information and the other conceals, and one symmetric mixed strategy equilibria in which both players randomize over sharing and concealing information.*

The proof follows immediately from the payoff comparison in Lemma 2, and is omitted. Proposition 1 predicts a threshold of the relative dispersion of winning values between information sharing and no information sharing. This result stems from both the *imperfectly discriminatory* success function and the fact that the size of the winning value is *independent* of players' bids in Tullock contests. To better understand the impact of these two facts, it is useful to compare Proposition 1 to previous results in the literature on information sharing in all-pay auctions and Cournot competition.

Firstly, Proposition 1 provides a stark contrast to Proposition 2 in Kovenock et al. (2015), where information sharing is always strictly dominated under all-pay auction with private values. Since the success function is perfectly discriminatory in all-pay auctions, competition is more intense relative to the Tullock contests, and hence it is more difficult to achieve coordination through voluntary information sharing. In fact, the result in Kovenock et al. (2015) indicates that the cost of losing information advantage always outweighs the benefit of achieving coordination in all-pay auctions.

Secondly, Proposition 1 also contrasts with the possibility result of communication in a Cournot game (e.g., Li, 1985; Shapiro, 1986), where each firm prefers to commit to disclose its verifiable private information of the marginal cost before it chooses quantity. Compared to the framework in this paper where player's value of winning is exogenously given, the total revenue is a function of the aggregate quantity in Cournot competition. This gives the oligopolists additional incentives of achieving coordination on production through information exchange relative to our framework. Therefore, information sharing always arises in equilibrium.

2.3 Optimal Information Disclosure

Now consider the optimal information disclosure problem. A contest designer would like to maximize the expected total revenue or social welfare. Denote X_{SS}, X_{SN}, and X_{NN} as the expected total revenue under different information regimes respectively. Simple algebra yields,

$$\frac{X_{SS}}{v_L} = \frac{X_{NN}}{v_L} = \frac{1}{8}(1+\delta) + \frac{1}{2}\frac{\delta}{1+\delta},$$

and

$$\frac{X_{SN}}{v_L} = \begin{cases} \frac{1}{4}\sqrt{\delta}(\sqrt{\delta}+1)^2\left[\frac{1}{3\delta+1} + \frac{1}{3+\delta}\right] & \text{if} \quad \delta \leq 9 \\ \frac{1}{4}\sqrt{\delta}(\sqrt{\delta}+1)^2\frac{1}{3\delta+1} + \frac{1}{9}\delta & \text{if} \quad \delta > 9 \end{cases}.$$

Proposition 2 (Revenue Comparison) *Among all three information regimes, SS and NN generate the same aggregate revenue to the contest designer, which is higher than that under SN.*

Proposition 2 states intuitively that information asymmetry between players softens competition and hence generates lower expected aggregate revenue in equilibrium.[6] In other words, treating both players equally by either disclosing or concealing information is optimal if the contest designer aims to maximize revenue. This result differs from Fu et al. (2014) in which SS is the designer's optimal policy in a symmetric incomplete-information all-pay auction and Jiao et al. (2017) in which the SN environment is not always dominated by SS for the designer in an asymmetric-information all-pay auction, mainly due to the different features between Tullock and all-pay auction.

Next, we compare total welfare, which is defined as the sum of the expected aggregate revenue and player's expected payoffs. Under SS and NN, they are the same and equal to,

$$\frac{1}{4}(v_H + v_L) + \frac{1}{2}\frac{v_H^2 + v_L^2}{v_H + v_L}.$$

Under SN, it is

$$\frac{1}{4}(v_H + v_L) + \frac{1}{4}\left[\frac{\hat{x}_L^*}{\hat{x}_L^* + \hat{x}_{LH}^*}v_L + \frac{\hat{x}_{LH}^*}{\hat{x}_L^* + \hat{x}_{LH}^*}v_H\right] + \frac{1}{4}\left[\frac{\hat{x}_{HL}^*}{\hat{x}_H^* + \hat{x}_{HL}^*}v_L + \frac{\hat{x}_H^*}{\hat{x}_H^* + \hat{x}_{HL}^*}v_H\right].$$

Proposition 3 (Welfare Comparison) *In terms of social welfare, there exists a threshold $\delta^\dagger \approx$ 23.3867 such that SN outperforms SS and NN if $\delta < \delta^\dagger$, and vice versa if $\delta > \delta^\dagger$.*[7]

The result for welfare comparison is less clear than that for revenue comparison. Because bids are simply transfers between the contest designer and players, social welfare equals the average valuation of the winner. It is obvious that there is no efficiency loss when the two players are of the same type. Hence, the difference of social welfare between symmetric and asymmetric information disclosure stems from the situation where the two players are of different types.

Under symmetric information disclosure (SS or NN), the high type wins with probability $v_H/(v_H + v_L) = \delta/(1+\delta)$ in equilibrium, implying a welfare loss with probability $1/(1+\delta)$. Under asymmetric information disclosure, to see the intuition more clearly, consider the case where $\delta > 9$ and $r_A r_B = SN$. There are two equally likely cases. When $v_A = v_H$ and $v_B = v_L$, the prize is distributed to the high type player with certainty and there will be no loss of allocative efficiency. Therefore, in this case welfare is improved relative to symmetric information disclosure. When $v_A = v_L$ and $v_B = v_H$, the prize is distributed to the high type player with probability $1 - (\sqrt{\delta} + 1)/(3\delta + 1) < \delta/(1+\delta)$, and hence welfare is reduced relative to symmetric information disclosure. Therefore, the welfare comparison depends on which of the two effects dominates, which in turn depends on the size of δ.

[6] Wärneryd (2003) and Einy et al. (2013) establish similar results under the context of common value. With common value contest, it is evident that the most efficient information structure must also minimize total revenue due to the absence of the concern of allocative efficiency.

[7] The proof is similar to that of Proposition 1, and is omitted for brevity.

3 Conclusion

In this paper, we show that in a symmetric Tullock contest with private values, information sharing can be achieved *voluntarily* when player's types are sufficiently concentrated, in contrast to the information withholding result for all-pay auction contests in the literature. Relative to the two symmetric information regimes, the asymmetric information regime is always less effective in collecting revenue, and is more efficient in terms of social welfare when types are concentrated e-nough. This paper leaves open for future research the question of players' incentives to communicate unverifiable information (e.g., cheap talk) after learning the values of the prize.

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