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Abstract

A unique characteristic of crowdsourcing contest is the coexistence of multiple contests and each individual contestant strategically chooses the contest that maximizes his/her expected gain. The competition between contests for contestants significantly changes the optimal allocation of prizes for contest organizers. We show that the contestants with higher ability prefer to single-prize contests while those with lower ability prefer to multiple-prize contests, which makes single-prize contest is no longer the optimal choice for organizers as it was in the context of a single contest. We demonstrate that the organizers may allocate multiple prizes whether they intent to maximize total efforts or highest efforts, and presents the condition under which the multiple-prize approach will be optimal.

Introduction

With the growth of the internet and online communities, crowdsourcing has increasingly become an important strategy for businesses to tap into the wisdom of the public. Crowdsourcing refers to "*the act of a company or institution taking a function once performed by employees and outsourcing it to an undefined (and generally large) network of people in the form of an open call.*" (Howe 2006). The function can be R&D challenges, product design, advertisement planning, software development and others. Crowdsourcers can be Fortune 500 companies, government agencies, charity organizations, or small enterprises and individuals, while crowdsourcees are typically small enterprises and individuals (Howe 2008).

Crowdsourcing is often conducted in a form of contest with prize varying from hundreds to millions of dollars. In a crowdsourcing contest, a crowdsourcer announces a task contest and the associated prize rule, then the public decide whether to participate given the task requirement, his/her capability and prize rules. After the crowdsourcees complete the tasks and submit their results, the crowdsourcer chooses the winner(s) and award prize(s) based on the prize rule. One of the most well-known crowdsourcing contests is organized by Netflix, a movie rental company. It offers a prize of $1 million to the first contestant(s) who can improve its movie recommendation system by at least 10 percent.

A central issue in the design of crowdsourcing contest is the allocation of prizes among contestants. Offering prizes to multiple contestants can encourage participation while offering a single prize to the best contestant can increase competition among the top contestants. A striking result of prior research on multi-person contest is that, if the cost function of the contestants is linear or concave, it is *always optimal* to offer a single prize than multi prizes (Moldovanu and Sela 2001).

However, online crowdsourcing has a unique characteristic: crowdsourcing contests are usually posted on an online crowdsourcing platform that offers multiple crowdsourcing tasks to choose from. For instance, Innocentive.com offers thousands of crowdsourcing contests on R&D challenges, Topcoder.com lists thousands of software development contests, and Taskcn.com receives and posts thousands of Logo designing contests every day. Contestants can browse and compare those task contests for free and then choose to participate in those that are most likely to bring them prize. This characteristic suggests that there exists competition among multiple contests, an issue not considered in prior studies that focus on off-line contests.

The research question of this paper is thus to identify how crowdsourcers should allocate prizes under the presence of multiple competing contests. We find that the allocation of prizes under this condition needs to consider not only the strategic interactions between crowdsourcer and contestants, but also the competition between crowdsourcers. We show that the classic result that, if the cost function of the contestants is linear or concave, it is always optimal to offer a single prize than multiple prizes (Moldovanu and Sela 2001) no longer holds.

Literature Review

Although crowdsourcing contest is still in the early stage, contest itself is not a new idea. In economic studies, contest is defined as economic or social activities in which two participants or more pay money or labor in order to get some prize (Dasgupta and Nti, 1998). Such phenomena are commonly observed in real life, e.g., the promotion and hiring within an organization, new product R&D contest, athletic competitions, and economic competition among nations.

In early studies of the allocation of prize in contests, researchers assume that the contestants are homogeneous, i.e., the contestants don't have significant differences in ability and there is no private information in a contest (Clark and Riis, 1998; Barut and Dan, 1998). However, it might not be the case in reality. Glazer and Hassin (1988) took into account the heterogeneity of contestants and put forward an incomplete information contest model, but they did not obtain an explicit result. Afterwards, Moldovanu and Sela (2001) established a new incomplete information contest model, in which, the contestants had different ability and the ability type was regarded as private information. The cost of each contestant is decided by his ability type and level of efforts. The purpose of the crowdsourcer is to maximize either the total effort of all contestants or the highest effort among all contestants. They proved that when the cost function is linear and concave, the total incentive of a single prize is greater than that of multiple prizes. When the cost function is convex, the incentive of different prize allocation strategies is correlated with the distribution of contestants' ability.

Besides the generalized model of Moldovanu and Sela (2001), recent IS studies have focused on online crowdsourcing contests. J. Yang etc. (2008) studied the difference of prize allocation between different types of tasks by using the data collected from Taskcn.com. According to their statistics, there exist both single-prize and multi-prizes contests in all types of tasks, but there is a difference in proportions of the two depending on task type. For designing contests, the proportion for multi-prizes was comparatively small; while strategy and web contests are usually listed with prizes to multiple contestants. Y. Yang etc. (2009) showed that multi-prizes appear superior to single-prize for all task types. In particular, multi-prizes are more effective in expertise project such as software development than in ideation project such as graph designing. Archak and Sundararajan (2009) gave special attention to the asymptotic behavior of the contest outcome. They demonstrated that when the contestants are risk neutral, single-prize is optimal even if the crowdsourcer needs more than one solution; when the contestants are risk averse, multi-prizes may be optimal and the number of prizes can be more than the desired number of solutions.

Different from the previous research, we study the problem of prize allocation in a unique setting: contest competition. In crowdsourcing contest, competitions are not just among contestants, but also among crowdsourcers as contestants make strategic participation decisions. We show the optimal strategy for crowdsourcers when they facing competition from others. The contest model developed in this paper is based on Moldovanu and Sela (2006), with the standard assumptions of heterogeneity of contestants, risk neutrality, and linear cost function.

The Model of Crowdsourcing Contest

Consider a contest where k prizes are awarded. The value of all the prizes is the same, that is, $V_1= V_2=\ldots= V_k$. We assume $\sum_{i=1}^{k} V_i = 1$ for normalization. There are n contestants. We assume that $k<n$. In the contest, each player i makes an effort x_i. An effort causes a cost denoted by $c_i x_i$, where $c_i > 0$ is an ability parameter. A low c_i means that i has a high ability and vice versa. Abilities are independently drawn from an interval $[m,1]$ according to a distribution function F. We assume F has a continuous density function $f>0$. Note that m is strictly positive. And c_i is private information to i. F and f are common knowledge. The contestants whose effort is higher than or equal to the k highest effort win the prizes.

Assume that all contestants undertake effort according to the function b, and assume that this function is strictly monotonic and differentiable. Contestant i's maximization problem is:

$$\max_{x} (1-F(b^{-1}(x)))^{n-1} - cx$$

Denote by C_1, C_2, …,C_n the identical, independently distributed random variables governing the distribution of the contestants' abilities. Denote by $C_{(1,n)}$, $C_{(2,n)}$,…,$C_{(n,n)}$ the corresponding order statistics, and by $F_{(1,n)}$, $F_{(2,n)}$,…,$F_{(n,n)}$ their respective distribution functions.

According to Corollary 1 of Moldovanu and Sela (2006), each contestant's equilibrium-effort function is given by:

$$x \equiv b_{n,k}(c) = \frac{1}{k}\int_c^1 \frac{1}{t} dF_{(k,n-1)}(t)$$

Let $F_k^n(c)$ denote the probability that agent i with type c meets n-1 competitors such that k-1 of them have lower types, and n-k have higher types. The expected utility of each contestant is given by:

$$U_{n,k}(c, b_{n,k}(c)) = \frac{1}{k} F_1^n(b_{n,k}{}^{-1}(x)) - cb_{n,k}(c)$$

By the Envelope Theorem, it follows that

$$\frac{dU_{n,k}(c, b_{n,k}(c))}{dc} = \frac{\partial U_{n,k}(c, b_{n,k}(c))}{\partial c} = -b_{n,k}$$

Together with the boundary condition $b_{n,k}(1) = 0$, this yields

$$U_{n,k}(c) = \int_c^1 b_{n,k}(s) ds$$

If the crowdsourcer is going to maximize the expected value of total effort, we have

$$R_{n,k} = n\int_m^1 b_{n,k}(c) dF(c) = E\left[\frac{1}{C_{(k+1,n)}}\right]$$

See the proof in Moldovanu and Sela (2006)'s Proposition 2.

If the crowdsourcer is going to maximize the expected value of highest effort, then we have

$$R_{n,k} = \frac{1}{k} E\left[\frac{1}{C_{(k,n-1)}}\right] - \frac{1}{k}\frac{(n-1)!}{(n-1-k)!}\cdot\frac{(2n-1-k)!}{(2n-1)!} E\left[\frac{1}{C_{(k,2n-1)}}\right]$$

See the proof in Appendix.

The Allocation of Prize

Consider two contests. Contest 1 has k_1 prizes, and contest 2 has k_2 prizes. The prize sum of the contests is the same. The interesting question is: which contest will the contestants choose to participate? This is answered by the following result.

Proposition 1. Consider a contest with n contestants. For any number of prizes k_1, k_2 such that $k_1<k_2<n$,

(1) if $U_{n,k_1}(m)<U_{n,k_2}(m)$, then $U_{n,k_1}(c)<U_{n,k_2}(c)$ for all $c\in[m,1)$;

(2) if $U_{n,k_1}(m)>U_{n,k_2}(m)$, there exists a unique $c'=c'(n,k_1,k_2)\in(m,c^*)$ such that:

(a) $U_{n,k_1}(c)=U_{n,k_2}(c)$;

(b) $U_{n,k_1}(c)>U_{n,k_2}(c)$ for all $c\in[m,c')$;

(c) $U_{n,k_1}(c)<U_{n,k_2}(c)$ for all $c\in(c',1]$.

See the proof in Appendix.

That is, if the contestant with the highest ability prefers the contest with a large number of prizes, all the contestants will have the same preference. Otherwise, there exists a certain ability level, which divides the contestants into two groups. The contestants whose ability is higher than that level prefer the contest with the smaller number of prizes; while the contestants with the ability lower than that level prefer the contest with the larger number of prizes. Intuitively, it means that the contest with a large number of prizes is more attractive to less-able contestants.

Now, we assume two crowdsourcers announce two contests at the same time. Contestants regard both contests as an n-participant contest, and decide which one to take. If two contests have the same number of prizes, n contestants divide evenly to two contests, each contest has $n'=\left\lfloor \frac{n}{2} \right\rfloor$ contestants. If $k_1<k_2<n$ and $U_{n,k_1}(m)<U_{n,k_2}(m)$, all the contestants choose contest 2. If $k_1<k_2<n$ and $U_{n,k_1}(m)>U_{n,k_2}(m)$, the number of the contestants who choose contest 1 is given by $n_1=\lfloor nF(c')\rfloor$ the number of the contestants who choose contest 2 is given by $n_2=\lfloor n(1-F(c'))\rfloor$. The ability distribution of contestants in contest 1 is given by $G(c)=\begin{cases}\dfrac{F(c)}{F(c')}, & c\in[m,c'] \\ 1, & c\in(c',1]\end{cases}$, while the ability distribution of contestants in contest 2 is given by $H(c)=\begin{cases}0, & c\in[m,c') \\ \dfrac{F(c)-F(c')}{1-F(c')}, & c\in[c',1]\end{cases}$. We can use the following matrix to describe the firms' payoff with different prize strategies:

		Crowdsourcer 2	
		$k = k_1$	$k = k_2$
Crowdsourcer1	$k = k_1$	R^F_{n',k_1} R^F_{n',k_1}	$R^G_{n_1,k_1}$ $R^H_{n_2,k_2}$
	$k = k_2$	$R^H_{n_2,k_2}$ $R^G_{n_1,k_1}$	R^F_{n',k_2} R^F_{n',k_2}

When $R^F_{n',k_1} > R^H_{n_2,k_2}$ and $R^G_{n_1,k_1} > R^F_{n',k_2}$ (Condition 1) is satisfied, $k = k_1$ is optimal to both firms. When $R^F_{n',k_1} < R^H_{n_2,k_2}$ and $R^G_{n_1,k_1} < R^F_{n',k_2}$ (Condition 2) is satisfied, $k = k_2$ is optimal to both firms. Otherwise, there is no pure strategy equilibrium.

Moldovanu and Sela (2006)'s Proposition 2 states when there is only one contest, the optimal strategy of crowdsourcer is to allocate the entire budget to one prize. However, according to our analysis above, in a multi-contests setting, the situation is more complex. When Condition 1 is satisfied, the single-prize strategy is optimal; when Condition 2 is satisfied, the multi-prizes strategy is optimal. If both conditions are not satisfied, the optimal strategy is a mixed strategy.

The intuition of our analysis is that, while facing a single-prize and a multi-prizes contest, contestants will self-select into two groups. Contestants with higher ability participate in the single-prize contest, while contestants with lower ability participate in the multi-prizes contest. Although the contestants in the single-prize contest have higher ability than those in the multi-prizes contest, the number of the contestants in the single-prize contest can be lower than those in the multi-prizes contest. Since a crowdsourcer's payoff is not only related to the ability level of contestants but also the number of contestants, his payoff could be lower. Therefore, in the multi-contests setting, multi-prizes could be an optimal strategy for crowdsourcers.

Conclusion

We have studied the prize allocation problem of crowdsourcing contest. We prove that as long as there exist multiple contests for contestants to choose, single-prize strategy can not always be optimal, ever under the standard assumptions of heterogeneity of contestants, risk neutrality, and linear cost function. Moreover, we specify the conditions under which single-prize or multi-prizes is optimal. Our research can be regarded as a supplement to Moldovanu and Sela (2001, 2006) and helps crowdsourcers allocate contest prizes more effectively.

Appendix

1. Proof of the Expected Value of Highest Effort

$$\begin{aligned}
R_{n,k} &= \int_m^1 b_{n,k}(c)dF_{(1,n)}(c) = \frac{1}{k}\int_m^1\int_c^1 \frac{1}{t}dF_{(k,n-1)}(t)dF_{(1,n)}(c) \\
&= \frac{1}{k}(F_{(1,n)}(c)\int_c^1 \frac{1}{t}dF_{(k,n-1)}(t)\Big|_m^1 + \int_m^1 F_{(1,n)}(c)\frac{1}{c}dF_{(k,n-1)}(c)) \\
&= \frac{1}{k}\int_m^1 \frac{1}{c}F_{(1,n)}(c)dF_{(k,n-1)}(c) \\
&= \frac{1}{k}\int_m^1 \frac{1}{c}[1-(1-F(c))^n]dF_{(k,n-1)}(c) \\
&= \frac{1}{k}\int_m^1 \frac{1}{c}dF_{(k,n-1)}(c) - \frac{1}{k}\int_m^1 \frac{1}{c}(1-F(c))^n dF_{(k,n-1)}(c) \\
&= \frac{1}{k}\int_m^1 \frac{1}{c}dF_{(k,n-1)}(c) - \frac{1}{k}\frac{(n-1)!}{(n-1-k)!}\frac{(2n-1-k)!}{(2n-1)!}\int_m^1 \frac{1}{c}dF_{(k,2n-1)}(c) \\
&= \frac{1}{k}E\left[\frac{1}{C_{(k,n-1)}}\right] - \frac{1}{k}\frac{(n-1)!}{(n-1-k)!}\frac{(2n-1-k)!}{(2n-1)!}E\left[\frac{1}{C_{(k,2n-1)}}\right]
\end{aligned}$$

2. Proof of Proposition 1

$$\begin{aligned}
U_{n,k}(m) &= \int_m^1 b_{n,k}(c)dc = \int_m^1 \frac{1}{k}\int_c^1 \frac{1}{t}dF_{(k,n-1)}(t)dc \\
&= c\cdot\frac{1}{k}\int_c^1 \frac{1}{t}dF_{(k,n-1)}(t)\Big|_m^1 + \frac{1}{k}\int_m^1 c\cdot\frac{1}{c}dF_{(k,n-1)}(c) \\
&= -\frac{m}{k}\int_m^1 \frac{1}{t}dF_{(k,n-1)}(t) + \frac{1}{k}\int_m^1 dF_{(k,n-1)}(c) \\
&= \frac{1}{k}(1-mE\left[\frac{1}{C_{(k,n-1)}}\right])
\end{aligned}$$

For $E\left[\frac{1}{C_{(k_1,n-1)}}\right]-E\left[\frac{1}{C_{(k_2,n-1)}}\right]>\frac{k_2-k_1}{k_1}\left(\frac{1}{m}-E\left[\frac{1}{C_{(k_1,n-1)}}\right]\right)$ we obtain $U_{n,k_1}(m)<U_{n,k_2}(m)$, otherwise, $U_{n,k_1}(m)>U_{n,k_2}(m)$.

By Moldovanu & Sela (2006)'s Lemma 2, we obtain $U_{n,k_2}(c)-U_{n,k_1}(c)=\int_c^1(b_{n,k_2}-b_{n,k_1})dt>0$ for all $c\in(c^*,\ 1)$

If $U_{n,k_1}(m)<U_{n,k_2}(m)$, for all $c\in(m,\ c^*)$, we have

$$U_{n,k_2}(c)-U_{n,k_1}(c)=\int_c^1 (b_{n,k_2}-b_{n,k_1})dt$$
$$=-\int_c^{c*} (b_{n,k_1}-b_{n,k_2})dt+\int_{c*}^1 (b_{n,k_2}-b_{n,k_1})dt$$
$$>-\int_m^{c*} (b_{n,k_1}-b_{n,k_2})dt+\int_{c*}^1 (b_{n,k_2}-b_{n,k_1})dt>0$$

Therefore, for $U_{n,k_1}(m)<U_{n,k_2}(m)$, we obtain $U_{n,k_1}(c)<U_{n,k_2}(c)$ for all $c\in[m,1)$.

If $U_{n,k_1}(m)>U_{n,k_2}(m)$, that is $\int_m^1 b_{n,k_1}dt>\int_m^1 b_{n,k_2}dt$. By Moldovanu and Sela (2006)'s Lemma 2, we know that $\int_c^1 b_{n,k_1}dt<\int_c^1 b_{n,k_2}dt$ for all $c\in(c*,1)$. Since $b_{n,k_1}(c)$ and $b_{n,k_2}(c)$ is single-crossing, there must exist a unique $c'\in(m,c*)$, such that $\int_c^1 b_{n,k_1}dt=\int_c^1 b_{n,k_2}dt$ for $c=c'$, $U_{n,k_1}(c)<U_{n,k_2}(c)$ for $c\in(c',1)$ and $U_{n,k_1}(c)>U_{n,k_2}(c)$ for $c\in[m,c')$.

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