Performance and Prize Decomposition in Contests

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Abstract

This paper focuses on the effect of additive contest decomposition on performance: winning probabilities and efforts of the contestants. Our main result provides a general sufficient condition for invariance of contest performance to the decomposition of a contest when the sum of the possibly differently valued prizes in the segmented contests is equal to the value of the prize in the original grand contest and the relative prizes in the sub-contests are equal for every contestant. It is shown that this condition is satisfied by the commonly used exponential logistic contest success functions. With these functions the contest designer does not have an incentive to split the prize and create additive, segmented sub-contests. We finally prove that when the additive contest decomposition is asymmetric, contest decomposition may adversely affect the designer; that it, reduce the total efforts of the contestants.

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I. Introduction

The designers of contests are usually concerned about aggregate efforts (investment, influence activities, campaign contributions, rent seeking efforts, lobbying outlays) made by the contestants. The design of contests may focus on the number of contestants and their characteristics (ability, preferences, income), Amegashie (1999), Baye et. al. (1993), the nature of prizes (private or public goods,), Nitzan (1994b), the multi-stage sequential nature of the contest, Gradstein and Konrad (1999) or the contest success function, Epstein and Nitzan (2006), Fang (2002). In this paper we focus on contest design that takes the form of additive contest decomposition; namely the decomposition of a contest into similar sub-contests, such that, for every contestant, the sum of the possibly differently valued prizes in the segmented contests is equal to the value of the prize in the original grand contest. Such decomposition may affect contest performance; that is, the winning probabilities of the contestants and their efforts.[4] We provide conditions for the invariance of performance to contest decomposition and show that these conditions are satisfied by the exponential logistic probability functions that are commonly used in the contest literature.[5] These contest success functions are the only logistic functions that are homogeneous of degree zero. With such contest success functions, the designer of the contest does not have an incentive to split the prize and create additive and symmetric segmented sub-contests. If the contest decomposition is additive but asymmetric, a designer who is interested in maximizing the contestants' efforts may prefer a single grand contest. We illustrate this possibility in the special case of two contestants and the simple lottery logit contest success function.

[4] For example, consider a privatization contest on an oil drilling concession in say, *K* oil fields of a country. One possibility is to assign the grand concession en-block to a single winner who is determined in the contest (an auction). Another possibility is to split the single concession conglomerate auction into some smaller sub-auctions and determine the winners of the different oil-field concessions (or any combination of these concessions) in the different sub-auctions. In our setting, there are constant returns to scale, so the value of the grand concession in the single auction is equal to the sum of the values of the separate concessions contested in the segmented auctions. In this paper we focus on the impact of such segmentation on the contestants' efforts and the governments' receipts, purposely disregarding other regulatory considerations, like enhancing competition by splitting a monopoly into several competing firms or enhancing the efficiency of a governmental firm through privatization.

[5] A special case of these functions is the simple lottery function proposed in Tullock (1980)

II. The Segmented Contests

Consider m risk neutral agents who compete in K different independent contests. In contest k (k = 1,2,..,K) the prize of agent i (i=1,2,..,m) is n_i^k. The agents make efforts to increase their probability of winning. They allocate their efforts (time, expenditures, and resources) between the K different contests. If agent i expends x_i^k (i=1,2,..,m) in contest k (k = 1,2,..,K) , the agents assume that the winning probability of agent i in contest k is $\Pr_i^k = \Pr_i^k\left(x_1^k, x_2^k, ..., x_m^k\right)$. The function $\Pr_i^k\left(x_1^k, x_2^k, ..., x_m^k\right)$ is usually referred to as the contest success function (CSF) in contest k. The expected net payoff of the risk neutral agent i in the K sub-contests is given by:

$$(1) \qquad E^S\left(w_i\right) = \sum_{k=1}^{K} \Pr_i^k n_i^k - \sum_{k=1}^{K} x_i^k, \quad i = 1, 2, ..., m$$

For contestant i the sum of the prizes in the K contests is equal to $n_i = \sum_{k=1}^{K} n_i^k$. Contestant i's stake in the K contests can therefore be written in the following way: $n_i^k = \beta_i^k n_i$ where $\beta_i^k > 0$ *and* $\sum_{i=1}^{K} \beta_i^k = 1$.

The parameters β_i^k, determined by the contest designer, reflect the splitting proportions of the grand contest into a bundle of segmented sub-contests. We consider two contingencies; egalitarian (symmetric) splitting and discriminating (asymmetric) splitting of a grand contest.

Symmetric splitting of a grand contest means that for every k, $\beta_1^k = \beta_2^k = ... = \beta_m^k$. That is, the designer does not discriminate among the contestants by offering differential decomposition of the grand contest to the different participants. If the designer possesses a discrimination power, he may offer participant i a vector $\boldsymbol{\beta}_i = \left(\beta_i^1, \beta_i^2, ..., \beta_i^K\right)$, $\sum_{k=1}^{K} \beta_i^k = 1$, reflecting a certain type of decomposition and at the same time offer another participant j, $j \neq i$, a different decomposition vector $\boldsymbol{\beta}_j = \left(\beta_j^1, \beta_j^2, ..., \beta_j^K\right)$, $\sum_{k=1}^{K} \beta_j^k = 1$.

The expected net payoff of agent i $\left(i = 1, 2, ..., m\right)$ is given by:

(2) $$E^S\left(w_i\right) = \left(\sum_{k=1}^{K} \beta_i^k \, \mathrm{Pr}_i^k \right) n_i - \sum_{k=1}^{K} x_i^k$$

It is assumed that $\frac{\partial \, \mathrm{Pr}_i^k(.)}{\partial x_i^k} > 0$, $\forall j \neq i$ $\frac{\partial \, \mathrm{Pr}_i^k(.)}{\partial x_j^k} < 0$ and that given x_j^k, there exists $\underline{x}_i^k$ such that, for $x_i^k \geq \underline{x}_i^k$, $\forall j \neq i$ $\frac{\partial^2 \, \mathrm{Pr}_i^k(.)}{\partial x_i^{k2}} < 0$ (the latter inequality ensures that the second order conditions are satisfied)[6].

We assume the all players participate in the contest $\left(x_i^k > 0 \quad \forall i, k\right)$. We therefore focus on the unique interior Nash equilibria of the contest. Solving the first order conditions $\left(\frac{\partial E^S\left(w_i^k\right)}{\partial x_i^k} = 0 \right)$ we obtain:

(3) $$\Delta_i^k = \beta_i^k \frac{\partial \, \mathrm{Pr}_i^k}{\partial x_i^k} n_i - 1 = 0, \quad k = 1, 2, ..., K \quad and \quad i = 1, 2, .., m$$

Thus, the first order conditions require that:

(4) $$\frac{\partial \, \mathrm{Pr}_i^k}{\partial x_i^k} = \frac{1}{\beta_i^k n_i}, \quad k = 1, 2, ..., K \quad and \quad i = 1, 2, .., m$$

The expressions in (4) determine the equilibrium efforts of the players and their probabilities of winning the contest.

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[6] The functional forms of the CSF's commonly assumed in the literature, see for example Nitzan (1994a), satisfy these assumptions. We also assume that there is a unique pure strategy Nash equilibrium.

III. Performance Invariance to Symmetric Decomposition

Let us now consider the relationship between the contestants' performance under the single grand (combined) contest where all agents compete for the sum of the prizes in the *K* contests n_i versus the case where they compete separately in the *K* sub-contests, as described above. Under the case of the overall contest, we obtain that the expected net payoff of contestant *i* is equal to,

$$(1') \qquad E\left(w_i\right) = \Pr_i n_i - x_i, \quad i = 1, 2, ..., m$$

where $\Pr_i$ is the probability of winning the contest and x_i is the total effort invested in this contest.

The first order conditions (see (4)), therefore require that:

$$(4') \qquad \frac{\partial \Pr_i}{\partial x_i} = \frac{1}{n_i}, \quad i = 1, 2, .., m$$

Consider the sub-class of the logistic contest success functions, Dixit (1987), $\Pr_i^k = \dfrac{\sigma_i g(x_i^k)}{\sum_{i=1}^{n} \sigma_i g(x_i^k)}, \quad i = 1, 2, .., m, \quad k = 1, 2, ..., K$ where $\sigma_i > 0, \quad g(0) \geq 0$, $g(t)$ increases in *t*[7] and $\dfrac{g(t_i)}{g(t_j)} = g\left(\dfrac{t_i}{t_j}\right)$. Clark and Riis (1998) show that $\dfrac{g(t_i)}{g(t_j)} = g\left(\dfrac{t_i}{t_j}\right)$ is equivalent to $g\left(t_i\right) = t_i^{\alpha}$. The equilibrium ratio between any two winning probabilities in this case is equal to $\dfrac{\sigma_i}{\sigma_j} \dfrac{g(x_i^k)}{g(x_j^k)}$ and the equilibrium relative expenditures between any two groups is equal to $\dfrac{g(x_i^k)}{g(x_j^k)}$.[8] Hence, by assumption and in light of (4),

[7] In this special case we retain the assumption that a contestant's marginal winning probability declines as his effort increases. This requires additional assumptions on the first and second derivatives of the function g(t).
[8] Wärneryd (2003).

(5) $$\frac{\Pr_i^*}{\Pr_j^*} = h\left(\frac{n_i}{n_j}\right) \quad and \quad \frac{x_i^*}{x_j^*} = g\left(\frac{n_i}{n_j}\right)$$

where $h(t) = \sigma_t g(t)$.[9]

In the case of K independent sub-contests, we get (see (5)) that, for $k = 1, 2, .., K$ and any two agents i and j $i, j = 1, 2, .., m$:

(6) $$\frac{\Pr^{*k}{}_i}{\Pr^{*k}{}_j} = h\left(\frac{\beta_i^k n_i}{\beta_j^k n_j}\right) \quad and \quad \frac{x^{*k}{}_i}{x^{*k}{}_j} = g\left(\frac{\beta_i^k n_i}{\beta_j^k n_j}\right)$$

Therefore the ratio between the expected winning probabilities of the contestants *i* and *j* is equal to:

(7) $$\frac{\sum_{k=1}^{K} \beta_i^k \Pr^{*k}{}_i}{\sum_{k=1}^{K} \beta_j^k \Pr^{*k}{}_j} = \frac{\sum_{k=1}^{K} \beta_i^k \Pr^{*k}{}_j h\left(\frac{\beta_i^k n_i}{\beta_j^k n_j}\right)}{\sum_{k=1}^{K} \beta_j^k \Pr^{*k}{}_j}$$

and the relative (total) efforts made by these contestants is equal to:

(8) $$\frac{\sum_{k=1}^{K} x^{*k}{}_i}{\sum_{k=1}^{K} x^{*k}{}_j} = \frac{\sum_{k=1}^{K} g\left(\frac{\beta_i^k n_i}{\beta_j^k n_j}\right) x^{*k}{}_j}{\sum_{k=1}^{K} x^{*k}{}_j}$$

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[9] Examples:

a. Tullock's lottery logit functions: Let $\Pr_i = \frac{d_i x_i}{\sum_{i=1}^{m} d_i x_i}$ for x_i and $d_i > 0$; that is, $g(t) = t$. In this case, in equilibrium, $\frac{\Pr_i^*}{\Pr_j^*} = \frac{d_i n_j}{d_j n_j}$ and $\frac{x^*{}_i}{x^*{}_j} = \frac{n_i}{n_j}$.

b. Tullock's generalized CSF: Let $\Pr_i = \frac{x_i^r}{\sum_{i=1}^{m} x_i^r}$ for $x_i > 0$ and $r \leq 2$; that is, $g(t) = t^r$. In this case, in equilibrium, $\frac{\Pr_i^*}{\Pr_j^*} = \left(\frac{x_i^*}{x_j^*}\right)^r = \left(\frac{n_i}{n_j}\right)^r$.

Using (5), (7) and (8) we obtain:

Proposition: Suppose that $\Pr_i^k = \frac{\sigma_i g(x_i^k)}{\sum_{i-1}^{m} \sigma_i g(x_i^k)}$, where $\sigma_i > 0$, $g(0) \geq 0$, $g(t)$ increases in t and $\forall j \neq i, \quad j,i = 1,2,..,m \quad \frac{g(t_i)}{g(t_j)} = g\left(\frac{t_i}{t_j}\right)$. If $\beta_1^k = \beta_2^k = ... = \beta_m^k$, for all k=1,2,…,K , then

$$\text{(a) } \Pr_i^* = \sum_{k=1}^{K} \beta_i^k \Pr_i^{*k} \quad , \quad \text{(b) } x_i^* = \sum_{k=1}^{K} x_i^{*k} \quad \text{and (c) } E^S\left(w_i^*\right) = E^S\left(w_i^*\right).$$

Proof: See Appendix

By part (a) of the Proposition, if the value of the prize in every sub-contest relative to the value of the grand prize is equal for all the contestants, $\beta_1^k = \beta_2^k = ... = \beta_m^k$ for every k, then the weighted probably of winning the sub-contests is equal to the probability of winning the overall contest. Part (b) of the Proposition establishes that when $\beta_1^k = \beta_2^k = ... = \beta_m^k$ for all k, the total effort incurred by the contestants is invariant with respect to additive contest decomposition. Part (c) of the Proposition implies that the expected payoff of the contestants is the same under the grand contest and its additive decomposition.

Note that $\frac{g(t_i)}{g(t_j)} = g\left(\frac{t_i}{t_j}\right)$ is equivalent to $g\left(t_i\right) = t_i^{\alpha}$ (see Clark and Riis, 1998) thus the CFS is the generalized Tullock function: $\Pr_i^k = \frac{\sigma_i \left(x_i^k\right)^{\alpha}}{\sum_{i-1}^{m} \sigma_i \left(x_i^k\right)^{\alpha}}$.[10] The generalized Tullock probability functions are the only logistic CSF's that result in invariance of the contestants' performance (expected payoffs and efforts) to contest decomposition. This means that under the commonly assumed exponential logistic contest success functions, a designer of contests cannot benefit (increase total efforts of the contestants) by contest decomposition.

[10] Clark and Riis (1998) show that the generalized Tullock probability functions are the only functions that satisfy both homogeneity of degree zero and independence of irrelevant alternatives. An alternative axiomatization of these contest success functions appears in Kooreman and Schoonbeek (1997).

IV. Asymmetric (Discriminative) Distribution of Relative Prizes in the Sub-Contests

Let us consider how asymmetry in the distribution of relative values of the prizes in the sub-contests (the β_i^k's) affects the total amount of resources invested in the contest, $x_i^* = \sum_{k=1}^{K} x^{*k}_i$. Suppose that the contest designer can offer to each contestants different partitions of the grand prize, and contestants are invited to compete on their different (possibly total as well as relative) prizes in the different sub-contests. To simplify our calculations, let us consider the case of only two contestants competing in two contests $i = k = 2$[11]. However, the designer of the contest can now offer each contestant a different partition of the grand prize. So let β_1^1 and $\beta_1^2 = (1 - \beta_1^1)$ denote the personal partition proportions offered to contestant 1 and, similarly, β_2^1 and $\beta_2^2 = (1 - \beta_2^1)$ denote the relative proportions of the grand prize offered to contestant 2.

Now let us allow a change in β_1^1, namely a change in the relative proportion of the value of the grand prize offered to contestant 1 (the proportions of the value of the grand prize as viewed by contestant 2 remain unchanged).

By differentiating the first order conditions (see (3)), we get that the Nash equilibrium efforts satisfy the following conditions:

(9)
$$\frac{\partial x^{*k}_i}{\partial \beta_1^1} = \frac{\dfrac{\partial \Delta_i^k}{\partial x_j^k}\dfrac{\partial \Delta_j^k}{\partial \beta_1^1} - \dfrac{\partial \Delta_j^k}{\partial x_j^k}\dfrac{\partial \Delta^k_i}{\partial \beta_1^1}}{\dfrac{\partial \Delta_i^k}{\partial x_i^k}\dfrac{\partial \Delta_j^k}{\partial x_j^k} - \dfrac{\partial \Delta_j^k}{\partial x_i^k}\dfrac{\partial \Delta_i^k}{\partial x_j^k}}, \quad i \neq j, \quad k = 1, 2$$

Rewriting (9) together with (3) and (4), and adding together the efforts of the contestants in the sub-contests $x_1^{*1}, x_1^{*2}, x_2^{*1}$ and x_2^{*2}, we obtain that (see appendix for more detailed calculations),

[11] Generalizing the setting to a larger number of contestants and contests would not change the results.

(10) $$\frac{\partial X^*}{\partial \beta_1^1} = \frac{\partial \Pr_1^1}{\partial x_1^1}\frac{1}{\beta_1^1 A}\left(\frac{\partial^2 \Pr_2^1}{\partial x_1^1 \partial x_2^1} - \frac{\partial^2 \Pr_2^1}{\partial x_2^{12}}\right) + \frac{\partial \Pr_2^1}{\partial x_2^1}\frac{1}{\left(1-\beta_1^1\right) A}\left(\frac{\partial^2 \Pr_2^2}{\partial x^{22}_2} - \frac{\partial^2 \Pr_1^2}{\partial x^2{}_2 \partial x_1^2}\right)$$

where $X^* = x_1^{*1} + x_1^{*2} + x_2^{*1} + x_2^{*2}$ and $A = \left(\frac{\partial^2 \Pr_2^1}{\partial x^{12}_2}\frac{\partial^2 \Pr_1^1}{\partial x^{12}_1} - \frac{\partial^2 \Pr_1^1}{\partial x_1^1 \partial x_2^1}\frac{\partial^2 \Pr_2^1}{\partial x_2^1 \partial x_1^1}\right)$. Notice that since $\frac{\partial^2 \Pr^1{}_2}{\partial x^1{}_2{}^2} < 0$, $\frac{\partial^2 \Pr^1{}_1}{\partial x^1{}_1{}^2} < 0$, and $\frac{\partial^2 \Pr^1{}_2}{\partial x^1{}_1 \partial x^1{}_2} = -\frac{\partial^2 \Pr^2{}_1}{\partial x^2{}_2 \partial x^2{}_1}$, $A > 0$.

Notice that a change in β_1^1 has an ambiguous effect on the total amount of resources invested in the contest because $\frac{\partial \Pr_1^1}{\partial x_1^1} > 0, \frac{\partial^2 \Pr_2^1}{\partial x^{12}_2} < 0$ and $\frac{\partial^2 \Pr_2^1}{\partial x_1^1 \partial x_2^1} = -\frac{\partial^2 \Pr_1^2}{\partial x_2^2 \partial x_1^2}$.

Let us consider the special case of Tullock's lottery logit function where $\Pr_i = \frac{x_i}{x_i + x_j}$. Under this contest success function, we obtain that if $\beta_1^1 > \beta_2^1$, then $\frac{\partial X^*}{\partial \beta_1} < 0$ and if $\beta_1^1 < \beta_2^1$, then $\frac{\partial X^*}{\partial \beta_1^1} > 0$. This means that, with the lottery logit function, total efforts are maximal when $\beta_1^1 = \beta_2^1$. That is, the designer of the contests does not have an incentive to create differential (asymmetric) sub-contests because the design of a discriminating system of sub-contests reduces the total efforts of the contestants.

V. Conclusion

We have studied contest performance under symmetric and asymmetric contest decomposition that preserves the contest success function and the group of contestants, allowing different additive net prizes in the sub-contests. Such contests are common in open, nationwide lobbying games, political contests or R&D races, where the designer often splits a grand prize (budget), however, the potential contestants voluntarily decide how to allocate their efforts between the sub-contests. We established sufficient conditions for the invariance of contest performance to such contest decomposition and showed that these conditions are satisfied by the commonly used exponential logistic contest success functions; the only logistic functions that are homogeneous of degree zero. With these functions a contest designer, who is interested in maximizing the contestants' total efforts, does not have an incentive to split the prize and create symmetric and additive segmented sub-contests. Contest decomposition may adversely affect the designer; that it, reduce the total efforts of the contestants, when the additive segmented sub-contests are asymmetric; that is, when the distribution of the relative values of the prizes vary across the contestants. In particular this is the case when there are two contestants and two sub-contests and the contest success function is Tullock (1980) simple lottery function.

Finally note that further research is needed to take into account additional considerations that were disregarded in our analysis. In particular, one could explore the effect of contest decomposition on performance when one allows increasing returns to scale, risk averse contestants or splitting the prize as well as the group of contestants in the grand contest.

VI. Appendix

Proof of Proposition:

The proof of part (a) of the Proposition is directly obtained from (6), (7) and (8).

To prove part (b), we have to compare the expenditure in the grand contest to the total expenditure in the segmented contests. Combining (4) with $\Pr^k{}_i = \frac{\sigma_i g(x^k{}_i)}{\sum_{i=1}^{m} \sigma_i g(x^k{}_i)}$ yields:

(A1) $$\frac{\sigma_i \frac{\partial g\left(x_i^k\right)}{\partial x_i^k} \sum_{v=1, v\neq i}^{m} \sigma_v g\left(x_v^k\right)}{\left(\sum_{i=1}^{m} \sigma_i g\left(x_i^k\right)\right)^2} = \frac{1}{\beta_i^k n^k{}_i},$$

Consider $\beta_i^k x_i^k = x_i^T$, where x_i^T denotes the expenditures in the single grand contest. Substituting x_i^T into (A1) yields:

(A2) $$\frac{\sigma_i \beta_i^k \frac{\partial g\left(x_i^k\right)}{\partial x_i^k} \sum_{v=1, v\neq i}^{m} \sigma_v g\left(x_v^1\right)}{\left(\sum_{i=1}^{m} \sigma_i g\left(x_i^k\right)\right)^2} = \frac{\sigma_i \frac{\partial g\left(\beta_i^k x_i^T\right)}{\partial x_i^k} \sum_{v=1, v\neq i}^{m} \sigma_v g\left(\beta_v^k x_v^2\right)}{\left(\sum_{i=1}^{m} \sigma_i g\left(\beta_i^k x_i^T\right)\right)^2}$$

Using (4') together with (A2) and $\frac{x_i^*}{x_j^*} = g\left(\frac{n_i}{n_j}\right)$, we obtain

(A3) $$\sum_{k=1}^{K} \beta_i^k x_i^{*k} = x_i^*$$

which completes the proof of part (b).

In light of (1) and (1’), the proof of part (c) of the Proposition is directly implied by parts (a) and (b).

QED

Calculations that yield equation (10)

(A4) $$\frac{\partial x^{*1}_{\ 1}}{\partial \beta_1^1} = -\beta_2^1 \frac{\partial^2 \Pr_2^1}{\partial x^{12}_{\ 2}} \frac{\partial \Pr_1^1}{\partial x_1^1} \frac{1}{\beta_1^1 \beta_2^1 A};$$

(A5) $$\frac{\partial x^{*1}_{\ 2}}{\partial \beta_1^1} = \beta_2^1 \frac{\partial^2 \Pr_2^1}{\partial x_1^1 \partial x_2^1} \frac{\partial \Pr_1^1}{\partial x_1^1} \frac{1}{\beta_1^1 \beta_2^1 A}$$

(A6) $$\frac{\partial x^{*2}_{\ 1}}{\partial \beta_1^1} = \left(1-\beta_2^1\right) \frac{\partial^2 \Pr_2^1}{\partial x^{22}_{\ 2}} \frac{\partial \Pr_1^2}{\partial x_1^2} \frac{1}{\left(1-\beta_2^1\right)\left(1-\beta_1^1\right) A}$$

(A7) $$\frac{\partial x^{*2}_{2}}{\partial \beta_1^1} = -\left(1-\beta_2^1\right) \frac{\partial^2 \Pr^2_{\ 1}}{\partial x^2_{\ 2} \partial x^2_{\ 1}} \frac{\partial \Pr^2_{\ 1}}{\partial x^2_{\ 1}} \frac{1}{\left(1-\beta_2^1\right)\left(1-\beta_1^1\right) A}$$

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