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Rent-seeking contest when the prize increases with aggregate efforts

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Abstract. The objective of this article is to investigate contests in which efforts are productive. Tullock's standard rent-seeking model is extended by making the rent itself increase with the aggregate efforts. A positive externality is thereby introduced into the contest, because a contender's private effort in quest of the rent generates a benefit for other contenders. Coupled with a negative externality presented in the standard rent-seeking model, the net effect on the social efficiency of the contest is *a priori* ambiguous. It is shown that the extended contest generates socially wasteful, excessive aggregate efforts.

1. Introduction.

Many economic and social phenomena can be explained as contests in which players compete by expending effort to increase their probability of winning a prize, that is, rents. Examples include R&D rivalry and patent competition, electoral competition, wars of attrition, elimination tournaments, and so on. A central result of the theory of contests is that the winner-takes-all contest involves socially wasteful efforts.[1] Each player expends resources to increase his or her probability of winning the prize, and therefore, ignores negative externalities imposed on competitors. Most of these works have assumed that the size of the prize is exogenously given and that efforts are non-productive.[2] In circumstances in which efforts are purely for redistribution, the assumptions may generate a valid prediction on the social inefficiency of contests. In other circumstances in which those efforts have some productive aspects, however, the prediction may have to be modified.

The purpose of this article is to investigate contests in which the size of rent is endogenously determined. In particular, the size of rent is assumed to increase with aggregate efforts. This assumption is made to capture two related features of contests: first, efforts may be at least partly productive, and second, the size of the the rent may increase with efforts. Examples of these features are discussed later in this section.

The efficiency of the contest is *a priori* ambiguous. On the one hand, there is a strong incentive to expend resources since it increases the size of the rent. It aggravates the usual negative externalities. On the other hand, there may be incentives for under-efforts because each player does not expect to receive the full return for his effort. In other words, there are spillover benefits to competing players and, thus, positive externalities in efforts. This works to generate a socially deficient amount of aggregate efforts.

We need a framework for calculating the net effect of these two externalities. This issue may be set aside as an empirical question because the net effect depends on detailed specifications of a model. Nonetheless, it would be quite interesting to explore the significant features of contests that determine the inefficiency of aggregate efforts.[3] For an analytic tractability, most theoretical and applied works have simply assumed that the rent is predetermined and efforts are non-productive. If one can show the direction of net effects, at least in a certain class of contests, then it would help us to evaluate properly the efficiency conclusions of those works.

The present article reconsiders the basic rent-seeking model by Tullock (1980) which has been the basis of numerous works on rent-seeking models. In Section 2, the model is extended with endogenously determined rents, and it is analyzed to show that the equilibrium level of aggregate efforts is always greater than the socially efficient level. Thus, even when efforts are productive by increasing the size of rents, the contest leads to social waste.[4] Section 3 examines a more general model to obtain a sufficient condition for this socially inefficient level of excessive efforts. In Section 4, the issue of rent dissipation is addressed, and an appropriate modification of its measure is proposed for the present model. Section 5 includes concluding remarks.

Before presenting the model, consider examples of productive efforts and endogenously determined rents. Recall that the present model tries to capture two related features of contests: first, efforts may be at least partly productive, and second, the size of the rent may increase with those efforts.

Posner (1992) argues that expenditures on litigation are not necessarily wasteful from a social standpoint, since they increase the probability of a correct decision by giving the tribunal more information.[5] The high-stakes segment of the legal profession is another illustration of the case in which the social value of the prize depends at least partly on effort. Well-defined property rights, for instance, are an important precondition for economic activity, and clearly in some cases the efforts of talented patent attorneys lead to a more sharply defined set of rights. Murphy, Shleifer, and Vishny (1991) take the case of traders in financial markets. Trading probably raises efficiency since it brings security prices closer to their fundamental values. It might even indirectly contribute to growth if more efficient financial markets reduce the cost of capital.[6] Tirole (1988) also contends that when air-travel prices and entry on routes were regulated in the United States, airlines competed for customers (the rent) by offering lavish services.[7] This type of rent-seeking behavior was not entirely wasteful, because customers enjoyed the services. All of these examples share the first feature (productive efforts) of the contests which this article attempts to capture.

Frank and Cook (1993) consider singers competing for the contract to record a popular compact disc. The return to a participant if he or she lands this contract is the revenue from the sale of copies. Each consumer's reservation price for the compact disc is related to its quality. If consumers' expected quality increases with aggregate efforts, then the expected revenue available to this seller will be increasing with them as well. Hillman (1991) considers the case in which contestants can seek to increase the value of their enterprise by influencing protection or trade liberalization decisions and restricting access of foreign goods to the domestic market.[8] The level of protection achieved by an industry is determined by the total effort made by industry interests in seeking political influence.[9] Tullock (1980) describes his rent-seeking game as a lottery for a prize, the rent, for which the players are competing. Players buy lottery tickets to affect their probability of winning. In Tullock's model, these expenditures are retained by the lottery, that is, ticket expenditures are not added to the prize. If a part of ticket expenditures is added to the prize, the expected size of rent increases with aggregate efforts.

Another example is the R&D investment to obtain a monopoly right. Investments are productive if knowledge generated by all contestants have spill-over effects on the monopoly. The monopoly's profit increases with total investments. In such R&D contests, the innovator is typically unable to appropriate the full surplus from his or her investment. This will tend to depress investment in research and development.[10] On the other hand, aggregate expenditures on R&D tend to be excessive in comparison with the cooperative optimum. Each firm considers only its own marginal benefit from the investment and does not take into account the reduction it imposes on the expected value of the other firms' investment.[11] The net effect is *a priori* ambiguous.

2. Analysis

Consider a contest in which N players compete to win a prize R. Players are indexed by $i = 1, \ldots, N$. Player i's effort, $e_i \in R_+$, increases the probability, p^i, that he or she will win the prize. The effort, or outlay, is measured in the same unit as the prize. The probability takes the symmetric, logit form as Tullock (1980) used:

$$p^i = \frac{1}{N} \quad \text{if } e_j = 0 \text{ for all j.}$$
$$= \frac{e_i}{[\Sigma\, e_j]} \quad \text{otherwise.} \qquad (1)$$

Further assume that R is an increasing function of aggregate efforts. Under this specification, every player's effort is productive, not just the winner's one. Since the main result of this article is to show the social inefficiencies of the contest, this specification makes the result stronger. The player i's payoff function U^i can be written as

$$U^i(e_1, \ldots, e_N) \equiv \frac{e_i}{[\Sigma e_j]} R(\Sigma e_j) - e_i . \qquad (2)$$

The contest can be analyzed as a game $\Gamma = \{N, \{e_i \in R_+\}, \{U^i\}\}$. The solution concept used in this article is the symmetric (pure strategy) Nash equilibrium. Before analyzing the equilibrium, consider the cooperative optimum of aggregate efforts as a benchmark.

Definition 1. The socially efficient amount of aggregate efforts, denoted by E^*, is defined as a maximizer of the social surplus: $E^* \equiv \underset{z}{\operatorname{argmax}}\ R(z) - z$.

The following assumptions are made to ensure that this maximization problem has a unique interior solution.

Assumption 1. $R(z)$ is twice continuously differentiable.
Assumption 2. $R(z) \geq 0$, $R' > 0$, $R'' < 0$, and $R'(z) > 1$ as $z \to 0$.
Assumption 3. There exists a finite, positive $\bar{E}$ such that $R(\bar{E}) - \bar{E} = 0$.

The following lemma is a direct consequence of Assumption 2 and Assumption 3.

Lemma. (i) *There exists a unique* E^* *such that* $0 < E^* < \bar{E}$.

(ii) *For all* $z \in (0, \bar{E})$, $W(z) \equiv R(z) - z > 0$.

Proof. Omitted.

The main result of this section is Proposition 1.

Proposition 1. *In the contest* Γ *with endogenously determined rents, the amount of aggregate efforts is greater than the social optimum (that is,* $E > E^*$*). Thus, the contest always generates social waste.*

Proof. The first-order condition for this maximization problem is

$$\frac{\partial U^i}{\partial e_i} = \frac{[(R + e_i R')(\Sigma\, e_j) - e_i R] - (\Sigma\, e_j)^2}{(\Sigma\, e_j)^2} = 0.$$

Denote the symmetric equilibrium by $(e, \ldots, e)$. Denote the amount of aggregate efforts in equilibrium by E, that is, $E \equiv Ne$. By substituting e for e_j for all j, the first-order condition can be rewritten as $(R + eR')E - eR - E^2 = 0$. By dividing it by e, I obtain $RN + R'E - R - EN = 0$. Rearranging gives us $(N - 1)[R(E) - E] + E[R'(E) - 1] = 0$. Define

$$\Phi(z) \equiv (N - 1)[R(z) - z] + z[R'(z) - 1]. \qquad (3)$$

Then, at the symmetric equilibrium E, Φ has a value of zero (i.e., $\Phi(E) = 0$).

First, I show that the contest Γ has a unique equilibrium value of the aggregate efforts. Observe that $\Phi(E^*) = (N - 1)[R(E^*) - E^*] + E^*[R'(E^*) - 1] = (N - 1)[R(E^*) - E^*] > 0$. Also observe that $\Phi(\bar{E}) = \bar{E}\,[R'(\bar{E}) - 1] < 0$. Because $\Phi'(z) = N[R'(z) - 1] + zR''(z) < 0$ for all $z \in [E^*,\infty)$ and $\Phi(z)$ is continuous, by the intermediate value theorem, there exists a unique E that satisfies $\Phi(E) = 0$. There is no other equilibrium value of aggregate efforts because $\Phi(z) > 0$ for all $z < E^*$.

Next, compare the relative size of the equilibrium efforts E and the social optimum E^*. From the fact that $\Phi(E^*) > \Phi(E) = 0$ and $\Phi'(z) < 0$ for all $z \in [E^*,\infty)$, I obtain $E < E^*$. Q.E.D.

To provide an intuition to Proposition 1, rewrite each party's payoff function as follows:

$$\begin{aligned} U^i &= \frac{e_i}{\Sigma e_j} R(\Sigma e_j) - e_i \\ &= \frac{e_i}{\Sigma e_j} \{R(\Sigma e_j) - \Sigma e_j\} \end{aligned}$$

Let $e^* \equiv \frac{1}{N} E^*$. Starting at the social optimum in which $e_j = e^*$ for all j, a marginal change in e_i does not change the value of the curled bracket by the envelope theorem. However, it does increase the party i's chance of winning the social net surplus because the probability is increasing in e_i. Therefore, every player has an incentive to increase his own effort from the socially optimal level so that the equilibrium generates an excessive amount of aggregate efforts.

3. Generalization

This section considers a more general model of rent-seeking by assuming that, for positive r,

$$\begin{aligned} p^i &= \frac{1}{N} \qquad \text{if } e_j = 0 \text{ for all j.} \\ &= \frac{e^r_i}{[\Sigma e^r_j]} \quad \text{otherwise.} \end{aligned} \tag{4}$$

where the parameter r represents the marginal return to efforts.[12]

The player i's payoff function U^i can be rewritten as

$$U^i (e_1, \ldots, e_N) \equiv \frac{e^r_i}{[\Sigma e^r_j]} R(\Sigma e_j) - e_i \,. \tag{5}$$

The general contest can be analyzed as a new game $\Gamma^r = \{N, \{e_i \in R_+\}, \{U^i\}\}$ indexed by r. It has been shown in the literature that the existence of a stable equilibrium depends on the value of r.[13] In particular, when r is less than a critical value, such an equilibrium exists. It is shown in this article that the efficiency of the contest also depends on the value of the exponent r.

The equilibrium effort will be a function of r. For clarity, I drop the index r in writing the equilibrium. Denote the symmetric equilibrium by $(e, \ldots, e)$ and aggregate efforts in equilibrium by $E \equiv Ne$. To guarantee the existence of such an equilibrium, the range of r must be restricted.

Assumption 4. $0 < r \leq \bar{r}$, where $\bar{r} \equiv 1 + \dfrac{[1 - R'(\bar{E})]}{N - 1}$.

Note that $\bar{r} > 1$. Under this assumption, each player's expected payoff at the symmetric equilibrium will be non-negative.[14]

Proposition 2. *If r is not too small, the general contest also generates social waste. Formally, there exists r^*, with $0 < r^* < 1$, such that for any $r > r^*$, the contest Γ^r induces the aggregate equilibrium efforts E which are greater than E^*.*

Proof. The first-order condition for the player i's maximization problem is

$$\frac{\partial U^i}{\partial e_i} = \frac{[(re_i^{r-1}R + e_i^rR')(\Sigma e_j^r) - re_i^{r-1}e_i^rR] - (\Sigma e_j^r)^2}{(\Sigma e_j^r)^2} = 0.$$

By substituting e for e_j for all j, the first-order condition can be rewritten as:

$$(re^{r-1}R + e^rR')Ne^r - re^{2r-1}R - N^2e^{2r} = 0.$$

By dividing it by e^{2r-1} and using the fact $E = Ne$, I obtain $rRN + ER' - rR - EN = 0$. Rearranging gives us $r(N - 1)[R(E) - E] + E[R'(E) - 1] + (N - 1)E(r - 1) = 0$.

Define

$$\Phi^r(z) \equiv (N - 1)[rR(z) - z] + z[R'(z) - 1].$$

Then, at the symmetric equilibrium E, Φ^r has a value of zero (i.e., $\Phi^r(E) = 0$).

Observe that $\Phi^r(E^*) = (N - 1)[rR(E^*) - E^*]$. Define r^* such that $\Phi^{r^*}(E^*) = 0$. That is,

$$r^* = \frac{E^*}{R(E^*)}$$

Note that $0 < r^* < 1$. If $r > r^*$, then $\Phi^r(E^*) > 0$.

Now, fix $r \in (r^*, \bar{r}]$. First, I show the existence and uniqueness of the equilibrium aggregate efforts. For any $z < E^*$, $\Phi^r(z) \equiv (N - 1)[rR(z) - z] + z[R'(z) - 1] > 0$ because $[rR(z) - z] > 0$ when $r > r^*$ and $[R'(z) - 1] > 0$ for $z < E^*$. Therefore, any value less than E^* cannot be an equilibrium.

Note that $\Phi^r(\bar{E}) \equiv (N - 1)[rR(\bar{E}) - \bar{E}] + \bar{E}[R'(\bar{E}) - 1] < 0$ from the definition of $\bar{r}$. For all $z > E^*$, $\dfrac{d\Phi^r(z)}{dz} = (N - 1)[rR'(z) - 1] + [R'(z) - 1] + zR''(z) < 0$ when $r < \bar{r}$. Since $\Phi^r(z)$ is continuous, by the intermediate value theorem, there exists a unique E satisfying $\Phi^r(E) = 0$.

Now, compare the relative size of the equilibrium efforts E and the social optimum E^*. Since $\Phi^r(E^*) > 0$ and $\Phi^r(z)$ is decreasing for $z > E^*$, $E > E^*$ is obtained. Q.E.D.

Proposition 2 shows that the social inefficiency depends on the value of the parameter r. When r is very small, the positive externalities can dominate the negative externalities so that the aggregate effort level can be less than the social optimum.

Corollary. (i) *If* $r < r^*$, *then* $E < E^*$ (*under-efforts*).

(ii) *If* $r = r^*$, *then* $E = E^*$ (*social optimum*).

4. Rent Dissipation

The rent-seeking literature has been concerned with the relationship between total rent-seeking outlays in equilibrium and the value of contested rent. The ratio D between these two values is called the extent of rent dissipation. Formally, $D \equiv \frac{\Sigma_i e_i}{R}$, where $(e_1, \ldots, e_N)$ is a Nash equilibrium in pure strategies. In the basic rent-seeking contest (with $r = 1$ in Tullock's model), the rent is totally dissipated when the number of rent seekers is sufficiently large. In small number contests, however, the rent is not fully dissipated. There are other reasons why the extent of rent dissipation is incomplete: risk aversion, uncertainty about the award of the rent, asymmetry in the competitors' rent valuations, endowments, attitudes toward risk or lobbying capabilities, and timing of moves. (See Shmuel Nitzan, Modeling Rent-Seeking Contests, 1993 for more discussion and references)

In the group rent-seeking contests, rent dissipation is usually reduced due to free riding incentives (Nitzan (1991a)). When the contested rent has public good attributes, there are similar incentives for under-dissipation of the rent (Katz, Nitzan, and Rosenberg (1990), Ursprung (1990)). The present article identifies another reason why the extent of rent dissipation is incomplete -- when the size of the rent is endogenously determined, in particular, when it is increasing with total efforts. In this case, however, the traditional measure of the extent of dissipation is generally unsatisfactory in measuring of the efficiency implications of contests. A modification is proposed as follows.

Consider a symmetric Nash equilibrium in pure strategies with $e = e_j$ for all j. Define $E = Ne$. Denote the net social surplus in equilibrium by $W(E) \equiv R(E) - E$, and the net social surplus at the social optimum by $W^* \equiv R(E^*) - E^*$.

Definition 2. The measure of the extent of rent dissipation is defined by

$$D \equiv \frac{W^* - W(E)}{W^*}.$$

This definition of dissipation rate is consistent with the definition in the existing literature when R is pre-determined. The numerator represents the degree of social waste in the contest. The measure can be rewritten as:

$$D = \frac{(E - E^*) - (R(E) - R^*)}{W^*}.$$

Propositions 1 and 2 show that the first term in the numerator is positive. Since $R(\cdot)$ is increasing in aggregate efforts, the second term in the numerator also is positive. Because the value of the whole numerator is positive from the definition of W^*, it implies that $(E - E^*) > (R(E) - R^*)$.

To illustrate the extent of rent dissipation in the present model, consider an example of the contest with a particular functional form for $R(z)$.

An Example: Consider a contest with $R(z) = 2\sqrt{z}$.

Assumptions 1, 2, and 3 are satisfied with this specification. It can be easily shown that $E^* = 1$, $R^* = 2$, $W^* = 1$, $r^* = 1/2$, and $\bar{E} = 4$. When $r = 1$, it can be shown that the equilibrium aggregate efforts $E = \frac{1}{N^2}(2N - 1)^2$, $W(E) = R(E) - E = \frac{1}{N^2}(2N - 1)$, and $D = 1 - W(E) = \frac{1}{N^2}(N - 1)^2$. Note that $0 < D < 1$, and D is increasing with N. As $N \to \infty$, thus, $D \to 1$. If $N = 2$ as well as $r = 1$, then $E = \frac{9}{4}$ and $D = \frac{1}{4}$.

In the general model with $r \in (r^*, \bar{r}] = (½, 1 + \frac{1}{2(N - 1)}]$, it can be shown that $E = \frac{1}{N^2}[2Nr - (2r - 1)]^2$, and $W(E) = R(E) - E = \frac{1}{N^2}[(2N - 1) - 4(N - 1)^2(r^2 - r)]$, and $D = \frac{1}{N^2}(N - 1)^2(2r - 1)^2$. Note that $0 < D < 1$, and D is increasing both with r and with N.

The analysis of this example illustrates that the contest with an endogenously determined rent still generates qualitatively similar results as those obtained from the standard pure rent-seeking models. In particular, the extent of rent dissipation increases with the number of contenders and with the parameter r representing marginal returns to efforts.

5. Concluding remarks

This article investigates contests in which the size of rent is endogenously determined, and in particular, in which the size of rent increases with aggregate efforts. Although the net effect of this extension depends on detailed specifications of a contest, this article manages to show that, at least in a certain class of contests based on Tullock's classic model, the rent-seeking effects dominate, and thus, social waste results.

One of the main insights of the rent-seeking literature is that, in quest of rents, players expend excessive efforts, and thus, it generates social waste. This article shows that the important insight is not undermined by the fact that efforts are productive by increasing the size of rents. Most of the theoretical and applied works in the rent-seeking literature have assumed that efforts are pure rent-seeking and socially wasteful. An implication of this article is that the assumption of pure rent-seeking activities is not so critical to their predictions.

An interesting future research agenda is to examine whether this observation is robust to several possible extensions of the model, for instance, uncertainty about the award of the rent, asymmetry in the competitors' rent valuations, endowments, attitudes toward risk or lobbying effectively, and timing of moves.

Notes

[1] The research on rent-seeking was initiated by the works of Tullock (1967), Krueger (1974) and Posner (1975). This early literature focuses on full-dissipation of rents, while recent literature identifies conditions under which rents are partially dissipated. For more discussion of this dissipation issue, see Section 4.

[2] There are few exceptions. Appelbaum and Katz (1986) study a three-player game where the rent setter (a regulator offering a rent to firms) is himself a rent seeker (seeking the support of consumer-voters). Gradstein (1992) supplements a basic contest with an exogenous function relating the *value* of the rent to the rent seekers' efforts. Ursprung (1990), and Riaz, Shogren and Johnson (1991) endogenize the rent seekers' *valuation* of the rent.

[3] This article tries to contribute to the literature by proposing an alternative perspective to an unresolved issue -- to establish the relevant normative criterion against which surplus-seeking endeavors can be evaluated. Rowley (1991) maintains that the *ex ante* distinction between surplus and waste, profit and rent, is obscure without detailed institutional information. In the present model, not all of expenditures constitute waste. Some parts of them are ex ante welfare-enhancing, and others are welfare-reducing.

[4] In the existing literature, rent-seeking behavior is by definition socially wasteful (see Buchanan (1980)). The present article considers a contest -- an extension of Tullock's rent-seeking model, and investigates whether the contest generates social waste, and thus whether the model of the present article can be classified as a rent-seeking model. This article provides an affirmative answer.

[5] Posner (1992: pp. 546-565).

[6] Murphy, Shleifer, and Vishny (1991: p. 506).

[7] Tirole (1988: p.77).

8 I assume that there is only one winner becoming a monopoly, and that he or she receives the benefit from protection. Hillman investigates, however, the case in which the *ex post* market structure allows several firms, that is, political activity yields a public-good-type benefit in the form of increased protection for all firms in the industry.

9 Denote the political activity of firm i by a_i, and denote by P the domestic tariff-inclusive price of the industry output. The level of protection increases with aggregate political activity A undertaken by N firms in the industry, such that $P = P(A) = P(\Sigma a_i)$, where $P'(A) > 0, P''(A) < 0$. This specification is that all individual contributions to the collective benefit associated with political influence are reflected in the aggregate contribution.

10 Hartwick (1984) shows that firms underinvest in R&D due to the spillover effects. Firm *i*'s unit production cost is $c(x_i, \Sigma_{j\neq i}x_j)$ with $c_1 < 0$ and $c_2 < 0$.

11 Dasgupta and Stiglitz (1980), and Hartwick (1982) show that, without spillover, an excessive duplication results.

12 Baye, Kovenock, and de Vries (1993) interpret r as a measure of returns to scale: the case $0 < r < 1$ represents decreasing returns, while $r > 1$ represents increasing returns to aggressive bidding or efforts.

13 In the original Tullock's model with (5) and with N = 2, a pure strategy symmetric Nash equilibrium exists when $0 < r \leq 2$, while it does not when $r > 2$. See Baik and Shogren (1991), and Baye, Kovenock, and de Vries (1993) for further discussion.

14 If the size of rent is predetermined (that is, $R' = 0$), and N = 2, then $\bar{r} = 2$. This result has been observed in Baik and Shogren (1991) and Baye, Kovenock, and de Vries (1993).

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