The social costs of monopoly and regulation: a game-theoretic analysis

William P. Rogerson*

The theory of rent-seeking is that monopoly profits attract resources directed into efforts to obtain these profits and that the opportunity costs of these resources are a social cost of monopoly. This article shows that monopoly rents remain untransformed to the extent that firms are inframarginal in the competition for them and thereby earn profits. Different fixed organization costs can produce inframarginal firms. In a situation where a monopoly franchise is periodically reassigned, the incumbent may possess an advantage in the next year's hearings. This also results in untransformed rents.

1. Introduction

■ Over the last fifteen years contributions of a number of authors to a variety of different fields in economics (Tullock, 1967; Krueger, 1974; Posner, 1975) have demonstrated the utility of the concept of rent-seeking both for making predictions and for drawing welfare judgments about a broad range of economic activities. The basic theory of rent-seeking is that the existence of an opportunity to obtain monopoly profits will attract resources into efforts to obtain monopolies, and the opportunity costs of these resources are social costs of monopoly as well. For example, suppose that a regulatory board meets every period and assigns the monopoly franchise for an industry to one of a competing number of entrants; the successful firm then earns π dollars in monopoly profits for that period. The theory of rent-seeking suggests that firms will in the aggregate spend some fraction of π dollars competing for the franchise by hiring lawyers, making presentations, etc. To the extent that these resources are misallocated, they represent a social cost of monopoly in addition to the normal deadweight loss.

Posner (1975, p. 812) asserts that firms' expenditures will tend to be equal to π:

> If ten firms are vying for a monopoly having a present value of $1 million, and each of them has an equal chance of obtaining it and is risk neutral, each will spend $100,000 (assuming constant costs) on trying to obtain the monopoly. Only one will succeed and *his* costs will be much smaller than the monopoly profits, but the total costs of obtaining the monopoly—counting losers' expenditures as well as winners'—will be the same as under certainty.

The major purpose of this article is to show that this is a more sweeping statement than is warranted. Section 2 establishes the accounting identity that the firms' expected aggregate profits from the regulatory game are equal to the untransformed rents. Therefore, asking whether some rents are not transformed is equivalent to asking whether profits are

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* Stanford University.

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earned in the regulatory game. This article shows that there are at least two respects in which firms can be inframarginal and thus earn profits.

First, different firms may face different fixed organization costs in forming an organization and acquiring the necessary information to participate in the rent-seeking process. For example, a firm which has participated in other regulatory hearings concerning related technologies might experience almost no start-up costs. The extreme case of differential start-up costs is the case where n firms have no fixed costs and all other firms have infinite fixed costs. Section 3 shows for this case that firms' expectations are less than π and approach π as n goes to ∞. Section 4 shows, more generally, that to the extent there are differential fixed costs, firms' expenditures will be less than π. Firms with low fixed costs possess a scarce resource and these inframarginal firms earn rents.

Second, firms may be inframarginal with respect to incumbency. Last year's franchise holder may well possess an advantage in this year's hearings because it has been able to establish a relationship with its regulators or to obtain extra information. Because potential entrants would perceive their chances of success as smaller, such an incumbency advantage might be expected to reduce entrants' expenditures in vying for the monopoly and thus reduce the social costs of monopoly. Posner (1975) correctly pointed out that an incumbency advantage would also make the prize worth more and thus encourage expenditures.[1] The accounting identity of Section 2 sheds light on the net effect of these two factors by shifting the focus from expenditures to profits. Section 3 shows that the incumbent in such a game could well earn positive discounted profits, even if an infinite number of potential entrants with identical fixed costs exist. To the extent that this occurs, rents remain untransformed.

One response to these two factors would be to push Posner's arguments one stage further back. The existence of an incumbent and/or differential fixed costs is exogenously given in this model. If firms competed to gain an initial incumbency advantage or firms spent money to lower their fixed costs in anticipation of the regulatory game, we might observe untransformed rents' being competed away at this earlier stage. Two points should be noted. First, many regulatory agencies are created to regulate firms already in existence. Second, the rent transformation argument requires that firms anticipate the size of rents being competed for. Williamson (1977) was the first to make this point. He argues that "whether the full-transformation or incomplete-transformation scenario is the more accurate, one depends in the final analysis on the computational powers of economic agents in relation to the degree of complexity and uncertainty with which they are expected to contend" (p. 721). Pushing the competition further and further back in time increases the uncertainty with which agents can estimate rents and thus makes them less likely to be competed away.

Finally, in Section 5 it is shown that a unique degree of incumbency advantage maximizes firms' expenditures and furthermore that the maximizing degree of advantage varies in predictable ways with other observable characteristics of the game. This knowledge is not particularly interesting for the regulatory game where the degree of advantage is not necessarily changeable and goals such as obtaining information may be as important as minimizing expenditures. However, it is argued that the model can be interpreted as an R&D game where the successful innovator in one period has an advantage in the pursuit of subsequent innovations. The degree of this advantage can be affected by the government through changes in trade secrets legislation and disclosure requirements on government-sponsored research. The results of this section suggest a manner in which

[1] See Section III.7. For example, on p. 824 Posner states: "Consider, for example, a market that is a natural monopoly. . . . [Social] costs can be reduced, however, by a rule limiting entry. . . . But the rule is not very satisfactory. . . . [T]he more efficient the rule at keeping out new entrants at low cost to the monopolist, the greater will be the expected value of having a natural monopoly—and, hence, the greater will be the resources that firms expend on trying to become the first to occupy a natural monopoly market."

government might want to offer differing degrees of incumbency advantage across differing industries, depending on the value of certain observable characteristics of the industries.

2. The general case

■ We wish to model the idealized situation where n firms compete for the right to operate a monopoly franchise which generates profits. At the start of each period, a government agency assigns rights to the franchise for that period. Firms spend money attempting to influence this decision.

Formally, we construct an n-person infinite period game. There are n states; let state j be the state where firm j is currently the monopolist. Let x_{ij} be the amount of money spent by firm i when state j occurs. The state space and firms' strategies are stationary. They are not dependent on t. A firm's probability of obtaining the franchise will clearly depend upon its and others' lobbying expenditures. It may also depend upon the state of the world. For example, a firm's chances of success may be greater if it is the monopolist, because it now has greater knowledge and expertise or because it has established a relationship with its regulators. Let f_{ij} be the probability of firm i's succeeding in state j; f_{ij} is a function of $(x_{1j}, \ldots, x_{nj})$. It must be true for every $(x_{1j}, \ldots, x_{nj})$ that

$$\sum_{i=1}^{n} f_{ij} = 1 \text{ for all } j \tag{1}$$

$$f_{ij} \geq 0 \text{ for all } i, j. \tag{2}$$

Let π be the profits that the successful firm earns in a period by operating the franchise.

Firm i selects the strategy vector $(x^*_{i1}, \ldots, x^*_{in})$. That is, firm i spends x^*_{ij} if state j occurs. Let θ_{ij} be firm i's probability of success in state j with the given strategies:

$$\theta_{ij} = f_{ij}(x^*_{1j}, x^*_{2j}, \ldots, x^*_{nj}). \tag{3}$$

Let θ be the matrix with (i, j) entry of θ_{ij}:

$$\theta = [\theta_{ij}]. \tag{4}$$

By (1) and (2) θ is a stochastic matrix. The associated stochastic process is the one that determines which firm will be the monopolist for each period.

Such a matrix always has a steady-state solution—a vector $\gamma = [\gamma_1, \ldots, \gamma_n]$ such that

$$\text{(i) } \gamma_i \geq 0 \text{ for all } i \tag{5}$$

$$\text{(ii) } \sum_{i=1}^{n} \gamma_i = 1 \tag{6}$$

$$\text{(iii) } \gamma = \theta\gamma. \tag{7}$$

The steady state may not be unique; as well, the stochastic process may actually converge to some sort of cycle. However, at a minimum, the average of the cycle which the stochastic process converges to equals one of the steady states. Therefore, one of the steady states describes the long-run average probability distribution which the stochastic process will exhibit. (Which steady state does this depends on the initial point.) Long-run expected values for this process are therefore calculated by using one of the steady-state distributions. See Gantmacher (1960) for a complete discussion of these points.

Before stating and proving the main theorem of this section, more notation needs to be introduced. Let θ^t_{ij} be the probability of firm i's becoming the monopolist in period t, given that firm j is currently the monopolist. That is, θ^t_{ij} is the (i, j) entry of θ^t. Let R^t_{ij} be the expected profit to firm i in period t, given that the world is currently in state

j. These returns can be defined recursively as follows:

$$R^1_{ij} = \theta_{ij}\pi - x^*_{ij} \tag{8}$$

$$R^t_{ij} = \sum_{k=1}^{n} \theta^{t-1}_{kj} R^1_{ik}\,, \qquad t = 2, 3, \ldots . \tag{9}$$

Assume that all firms calculate the value of the game by summing discounted expected profits with firm i using the discount rate c_i. Let V_{ij} be the value of the game to firm i in state j:

$$V_{ij} = \sum_{t=1}^{\infty} c_i^{t-1} R^t_{ij}\,. \tag{10}$$

Finally, let S_j be the surplus of π over total firm expenditures which occurs in state j:

$$S_j = \pi - \sum_{i=1}^{n} x^*_{ij}\,. \tag{11}$$

We can now prove the accounting identity for this game. The long-run expected surplus that this game generates is a nonnegative weighted sum of the values $\{V_{ij}\}$.

Theorem 1. Let γ be a steady-state solution to θ. Then

$$\sum_{j=1}^{n} \gamma_j S_j = \sum_{i=1}^{n}\sum_{j=1}^{n} \gamma_j (1 - c_i) V_{ij}\,. \tag{12}$$

Proof. The value functions must all satisfy

$$V_{ij} = R^1_{ij} + c_i \sum_{k=1}^{n} \theta_{kj} V_{ik}\,. \tag{13}$$

Sum this over indices as required, using (7). *Q.E.D.*

The value of the game to every player must always be nonnegative if we assume that the strategy of doing nothing at zero cost is available to each player. Therefore, the right-hand side of (12) is nonnegative and so is the left-hand side. As a result, the long-run expected surplus of π over total expenditures is nonnegative.

Note that V_{ij} is the present discounted value to player i from being in state j. Therefore, $(1 - c_i)V_{ij}$ is the "annual value" of this multiyear value and $\sum_{i=1}^{n} (1 - c_i)V_{ij}$ represents the aggregate annual profits for the firms in state j. Equation (12) therefore states that the long-run expected surplus (left-hand side) equals the long-run expected annual aggregate profits (right-hand side). That is, expenditures fall short of π to the extent that firms make positive expected profits.

3. A special case: no fixed costs

■ The remainder of the article deals with a special case where the f_{ij} functions are given a particular functional form. This section makes the additional assumption that fixed costs of entry into the game are zero for $n + 1$ firms and infinite for all others. Let f_{ij} be given by

$$f_{ij}(0, \ldots, 0) = 0 \tag{14}$$

and by

$$f_{ij}(x_{1j}, \ldots, x_{n+1,j}) = \begin{cases} \dfrac{\beta x_{ij}}{\beta x_{jj} + \sum\limits_{k \neq j} x_{kj}}, & i = j \\ \dfrac{x_{ij}}{\beta x_{jj} + \sum\limits_{k \neq j} x_{kj}}, & i \neq j \end{cases} \tag{15}$$

for every $(x_{1j}, \ldots, x_{n+1,j}) \neq 0$, where β is some real number greater than or equal to 1. Each firm's chance of obtaining the franchise is simply the proportion of total lobbying expenditures that it accounts for weighted by 1 if it is not currently the monopolist and by β if it is the current monopolist. For any fixed vector of expenditures $(x_{ij}, \ldots, x_{n+1,j})$ it is easy to see that f_{ij} decreases in β for $i \neq j$ and increases in β for $i = j$. Therefore, to the extent that β is greater than 1, the current monopolist has an advantage in regulatory hearings to determine the next franchise holder. All potential entrants receive equal treatment. Each firm faces the same return function if it becomes the monopolist. This is, therefore, in some sense the simplest specification of a case where the monopolist has an advantage.[2] As well, assume that each firm uses the same discount rate, c.

We shall use the Nash equilibrium concept.

Definition. The strategy vectors $\{x_1^*, \ldots, x_{n+1}^*\}$ are equilibrium strategies if for every i and j, x_i^* satisfies

$$V_{ij}(x_1^*, \ldots, x_i^*, \ldots, x_{n+1}^*) = \sup_{x_i \in R_+^{n+1}} V_{ij}(x_1^*, \ldots, x_i, \ldots, x_{n+1}^*). \tag{16}$$

That is, x_i^* must maximize $(V_{i1}, \ldots, V_{i,n+1})$ given others' behavior. Note that the domain of x_i is R_+^{n+1} (where $R_+ = [0, \infty)$). In particular, the firm always has the option of doing nothing at zero cost and zero return.

A possible criticism of this definition is that it does not allow firms to consider nonstationary strategies. A nonstationary strategy for firm i would be an infinite vector of n-tuples $(x_i^1, x_i^2, \cdots)$, where x_i^t is the n-tuple representing firm i's strategy at time t. Fortunately, an equilibrium in the game where firms are restricted to stationary strategies is also an equilibrium in the game where firms are allowed to choose nonstationary strategies. If firm i observes all the other firms' choosing a stationary strategy, it finds itself facing a stationary dynamic program and can do no better by using a nonstationary strategy than a stationary one. (See Denardo (1967) for proof of this.) Therefore, the equilibrium defined above is more robust than the formal definition indicates.

Recall from (13) that the return functions are particularly simple—a firm's probability of winning is not affected by which of the others is the monopolist so long as they all spend the same. Therefore, we might hope for a particularly simple sort of equilibrium to occur; each firm's strategy is one number, x_e, if it is an entrant and another number, x_m, if it is the monopolist. We shall call this a symmetric equilibrium.

Definition. An equilibrium $\{x_i^*\}_{i=1}^{n+1}$ is a symmetric equilibrium if there exist two numbers x_e and x_m such that for every i and j

$$x_{ij}^* = \begin{cases} x_e, & i \neq j \\ x_m, & i = j \end{cases}. \tag{17}$$

The major result of this section is the constructive proof of the existence and uniqueness of such a symmetric equilibrium. Since each player has the same strategy and it only varies as he is the entrant or monopolist, it will be seen that all of the variables indexed

[2] It is possible to solve the game explicitly when each x_{ij} is weighted by some constant β_{ij}. However, it is not clear how to interpret this more general specification so the simpler model is presented.

by (i, j) will only assume two values. We shall employ the notational convenience of indexing them by "e" or "m" for the state of being the entrant or the monopolist, respectively.

Theorem 2. The unique[3] symmetric equilibrium for $n \in \{1, 2, 3, \cdots\}$ is:

$$x_e = \frac{\beta n \pi}{an^2 + 2bn + 1} \tag{18}$$

$$x_m = \left(n - \frac{n-1}{\beta}\right) x_e , \tag{19}$$

where

$$a = c(2\beta - 1) + (1 - c)\beta^2 \tag{20}$$

$$b = c + (1 - c)\beta. \tag{21}$$

Other variables assume the following values (uniquely):

$$\theta_e = \frac{1}{\beta n + 1} \tag{22}$$

$$\theta_m = \frac{\beta n + 1 - n}{\beta n + 1} \tag{23}$$

$$V_e = \frac{\pi}{(1 - c)(an^2 + 2bn + 1)} \tag{24}$$

$$V_m = [(1 - c)(\beta^2 - (2\beta - 1))n^2 + 2(1 - c)(\beta - 1)n + 1]V_e . \tag{25}$$

Proof: See the Appendix.

The untransformed rents are equal to

$$\pi - nx_e - x_m . \tag{26}$$

It is easy to show that $nx_e + x_m$ increases with the number of firms, n. As n goes to infinity, aggregate expenditures are

$$\frac{2\beta - 1}{\beta^2 - c(\beta - 1)^2}\pi. \tag{27}$$

This number equals π when β is 1, equals 0 when β goes to ∞, and decreases for values of β in $[1, \infty]$. Therefore, untransformed rents are always positive. They are smaller if there are more potential entrants. If the incumbent has no advantage, untransformed rents go to zero as n increases. However, to the extent that there is an incumbency advantage, a progressively higher floor is created for the size of untransformed rents which bounds them strictly away from zero.

The duality between untransformed rents and firms' profits provides the intuition for these results. The accounting identity proven in Theorem 1 for this particular example is

$$\pi - nx_e - x_m = (1 - c)(nV_e + V_m). \tag{28}$$

That is, untransformed rents equal the annualized expected present discounted value of the n entrants and one incumbent from playing the game. As n increases, competition drives the aggregate values of the entrants, nV_e, to zero. However, to the extent the incumbent has an advantage, even an infinite number of potential entrants cannot reduce his discounted expected profits to zero.

[3] For the case $c = 0$ (when the world ends after the first period) the symmetric equilibrium is in fact the unique equilibrium. Therefore, although it has not been shown that the symmetric equilibrium is the unique equilibrium for the case of $c \geq 1$, the solution is a generalization of the unique solution for the one-period case.

4. A special case with fixed costs

■ **The sources of incomplete rent transformation.** This subsection uses the same functional form for the f_{ij} functions as Section 3, but relaxes the particular assumption about fixed costs made in Section 3. A firm with positive fixed start-up costs will participate in the hearings if and only if V_e exceeds its costs. Firms with progressively larger fixed costs will join the game and thereby reduce V_e until entry is no longer profitable. Formally, assume that there are N possible participants in the game, where N can be ∞. Index members of the set by i in such a way that firms with lower fixed costs have lower index numbers. Let $F(i)$ be firm i's fixed costs. Then n^* is an equilibrium number of nonincumbent firms (for a total of $n^* + 1$ firms) if two conditions are satisfied. First, every firm must make nonnegative profits as a nonincumbent (or there must be no nonincumbent players):

$$n^* = 0 \qquad \text{or} \qquad F(n^* + 1) \leq V_e(n^*). \tag{29}$$

Second, any other firm which contemplated entering the game would make negative profits (or all $N - 1$ firms are nonincumbent players):

$$n^* = N - 1 \qquad \text{or} \qquad F(n^* + 2) > V_e(n^* + 1). \tag{30}$$

Since V_e is decreasing in n, continuous, and zero in the limit and since F is nondecreasing, it is easy to see that an equilibrium number of nonincumbent players always exists and is unique.

With nonzero fixed costs, annualized fixed costs now need to be included in the rent transformation equation. If there are n nonincumbent firms, the surplus of π over expenditures is

$$\pi - nx_e(n) - x_m(n) - (1 - c) \sum_{i=1}^{n+1} F(i), \tag{31}$$

which, by the accounting identity of (26) is equal to

$$(1 - c)[nV_e(n) + V_m(n) - \sum_{i=1}^{n+1} F(i)]. \tag{32}$$

Expression (32) can be divided into two terms as follows:

$$(1 - c)[\sum_{i=1}^{n+1} (V_e(n) - F(i))] + (1 - c)[V_m(n) - V_e(n)]. \tag{33}$$

The first term of (33) represents annualized rents accruing to firms which are inframarginal with respect to fixed costs. As in any situation generating inframarginal rents, smaller numbers of firms with low fixed costs will increase the amount of inframarginal rent earned by them.

The second term of (33) represents the annualized rents accruing to the incumbent because of his incumbency advantage. From Section 3, $V_m(n) - V_e(n)$ is always greater than or equal to $\lim_{n\to\infty} V_m(n)$[4] which is positive. In fact, $\lim_{n\to\infty} V_m(n)$ can be made arbitrarily close to $\pi/(1 - c)$ by increasing β.

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[4] To see this it is sufficient to show that $(\partial/\partial n)[(V_m(n) - V_e(n))] \leq 0$. From Theorem 2,

$$\frac{\partial}{\partial n}(V_m(n) - V_e(n)) = \frac{-\beta n^2 + (\beta - 1)n + 1}{(an^2 + 2bn + 1)^2}\pi,$$

which can be shown to be negative.

□ **Comparative statics of fixed cost.** In this subsection the effect of an increase in all firms' fixed costs is considered. Since the equilibrium number of players is a nonincreasing function of the level of fixed costs, the results of Section 3 imply that the surplus of π over $nx_e + x_m$ is a nondecreasing function of the level of fixed costs. As fixed costs rise, the smaller number of players results in less rent transformation into annual expenditures.

Although lowering fixed costs increases the amount of π eaten up by annual expenditures, this does not fully describe the transformation process. Fixed expenditures should also be considered as rent transformation, if they are actually made. When fixed organizational costs suddenly drop for an existing regulatory process, existing firms which joined the regulatory game previously cannot retroactively reduce their fixed expenditures. The only effect will be to induce marginal firms to enter the game. Therefore, aggregate expenditures on fixed costs will rise along with expenditures on annual costs, and the surplus of π over total expenditures will fall. When fixed organizational costs suddenly rise for an existing regulatory process, existing firms will not have to pay more fixed costs or be induced to leave the game. Obviously no new firms will be induced to enter, and, as a consequence, expenditures on fixed costs will not change. Therefore, the surplus of π over total expenditures will rise.

Finally, we need to compare two regulatory processes which have always had different fixed costs of entry but are similar in other respects. In this case, the decrease in fixed costs and increase in annual expenditures work in opposite directions, and no unambiguous prediction concerning the effects on the amount of rent transformation is possible. Two examples illustrate this. First, consider a case where $n + 1$ firms have zero fixed costs, and the remainder of the firms have infinite fixed costs. Lowering fixed costs corresponds to making n larger. In this case firms' profits are $nV_e(n) + V_m(n)$. This sum decreases in n. Therefore, as fixed costs drop (rise) the amount of rent transformation increases (decreases). Second, consider a case where fixed costs fall only for inframarginal firms, but remain unchanged for the marginal firm and extramarginal firms. It is clear that the equilibrium number of firms, V_e, and V_m are not affected. Therefore, total profits of all firms rise, and the amount of rent transformation increases.

In summary, when comparing two existing regulatory processes with different fixed costs, the process with lower fixed costs will have more players and higher annual expenditures. However, if costs are calculated by including annualized fixed costs, either process might exhibit larger expenditures and thus more rent transformation.

5. Comparative statics of β[5]

■ Corollary 1 summarizes the effects of β on aggregate expenditures.

Corollary 1. There exists a function,

$$\gamma: \{1, 2, 3, \ldots, N-1\} \times [0, 1] \rightarrow [1, \infty],$$

such that

$$\begin{aligned} \text{(i)}\quad \beta < \gamma(n, c) &\Rightarrow \frac{\partial}{\partial \beta}(nx_e + x_m) > 0 \\ \beta = \gamma(n, c) &\Rightarrow \frac{\partial}{\partial \beta}(nx_e + x_m) = 0 \qquad (27) \\ \beta > \gamma(n, c) &\Rightarrow \frac{\partial}{\partial \beta}(nx_e + x_m) < 0 \end{aligned}$$

[5] For simplicity of presentation, the case where $n + 1$ firms have zero fixed costs and all others have infinite fixed costs is formally considered. To the extent that reducing β induces entry, reducing β might be generally more desirable. The qualitative propositions of this analysis, however, are unchanged.

$$\text{(ii)}\ \frac{\partial \gamma}{\partial n} < 0 \tag{28}$$

$$\text{(iii)}\ \frac{\partial \gamma}{\partial c} > 0. \tag{29}$$

Proof. From Theorem 2 we can write

$$\frac{\partial}{\partial \beta}(nx_e + x_m) = \frac{-2n^4(1-c)\beta^2 + 2n^3(1-c)\beta + 2n^3 + cn^2}{(an^2 + 2bn + 1)^2}. \tag{30}$$

From this, it follows that if we define

$$\delta(\beta, n) = \frac{\beta n^2(\beta - 1) + \beta n - n}{\beta n^2(\beta - 1) + \beta n + 1}, \tag{31}$$

then

$$\text{(i)}\ c \gtreqless \delta \quad \text{according as} \quad \frac{\partial(nx_e + x_m)}{\partial \beta} \lesseqgtr 0, \tag{32}$$

$$\text{(ii) for every } (\beta, n) \in (1, \infty) \times \{1, 2, 3 \cdots\}, 0 \le \delta(\beta, n) < 1, \tag{33}$$

$$\text{(iii)}\ \frac{\partial \delta}{\partial \beta} > 0, \quad \frac{\partial \delta}{\partial n} > 0. \tag{34}$$

Define γ implicitly by

$$c = \delta(\gamma(c, n), n).\ Q.E.D. \tag{35}$$

The effect of β on aggregate expenditures can be conceptually separated into a short-run and long-run effect. In the short run increasing the incumbent's advantage increases the incumbent's chances of winning and reduces the attractiveness of expenditures for everyone. However, in the longer run the prize of winning is more attractive, because the incumbent finds it easier to maintain his position; this should increase firms' expenditures. Result (i) is that the long-run effect dominates for small values of β, but eventually aggregate expenditures begin to fall with β.

Result (ii) says that increasing the number of players in the game reduces the relative influence of the long-run effect. The reasons for this are not clear. *A priori* reasoning suggests any result could be possible. Result (iii) is more intuitive; as all firms discount the future more heavily, the influence of the short-run effect becomes larger.

6. Applications

■ A theory of regulation which assumes that no rents are transformed would suggest that the regulator be careful to set π as low as possible to minimize deadweight loss in the regulated market. A theory which takes rent transformation into account, but which assumes that all of the firms' expenditures have no social value, simply adds another reason for setting π close to zero. However, at least some of the expenditures by firms may be socially useful. For example, firms may spend money on designing better products or generating useful information for the regulatory agency in the process of competing with one another. This view provides a rationale for choosing π to be positive. The regulator is essentially funding firms' expenditures from participating in the regulatory process through choosing π to be greater than zero.

In this model, the regulator views its choice of π and its choices of rules and procedures which affect β and the level of fixed costs as one coordinated plan to maximize social surplus.[6] The aggregate level of expenditures can be directly affected by choosing π. Therefore, the goals of the regulator in choosing β and the level of fixed costs should be

[6] Of course, various equity considerations are also likely to be important.

to (i) increase the fraction of rents transformed and (ii) alter the patterns of expenditures in ways which increase their social usefulness. The rationale for the first goal is that, for a given level of aggregate expenditures, increases in the fraction of π transformed allow π to be chosen smaller and thus deadweight loss in the regulated market to be reduced.

The first goal suggests that a regulatory process should be designed so that the assignment procedure is as competitive as possible; as many potential entrants as possible should be encouraged to participate and, especially if there are many entrants, the incumbency advantage should be as low as possible. The second goal, however, may conflict with the first. For example, if there are increasing returns to scale in preparing a well-planned service or a well-designed product, increasing the fixed costs of at least some potential entrants (possibly by simply arbitrarily excluding all but a small number) could alter the pattern of expenditures in a desirable manner. Although aggregate expenses would fall, average expenses per firm would rise.

This article can also be interpreted as modeling certain aspects of the R&D process. At the beginning of each period, firms each decide how much money to spend on R&D for that period. A firm's probability of discovering a profitable new product increases as its expenditures increase and decreases as its competitor's expenditures increase. The expected revenues of the firm therefore depend on the expenditures of that firm relative to all other firms. Furthermore, success in the past period gives a firm a head start in this period's R&D. The size of β measures the size of this advantage.

Government has some control over the size of β in an industry. Trade secrets legislation and disclosure rules for government-funded research clearly affect β. By having more stringently enforced trade secrets legislation or by not requiring firms operating under government contracts to make their research public, the government grants the winning firm an increased advantage relative to its opponents in the next round. Note that the role of trade secrets legislation is distinct from any role the government may play relating to the appropriability of an invention. (Firms cannot copy an invention if some aspect of it is secret.) In the model, this second effect simply amounts to ensuring that the winning firm actually receives π. The first effect of increasing β is separate.

Corollary 1 shows that a unique level of β exists which maximizes R&D expenditures. Furthermore, it increases with the discount rate and decreases with the number of firms. Therefore, if the government wanted to use trade secrets legislation as a spur to innovative activity,[7] it might choose different levels of enforcement in different types of industries. For example, trade secrets legislation may be more important in smaller industries as an incentive for innovative activity. As regards the discount rate, if we hold the time discount rate over continuous time constant and increase the rate of innovative activity, we shorten the length of each period and thus increase the discount rate in our discrete model. Therefore, this model suggests that industries characterized by rapid innovative activity need stricter trade secrets legislation and fewer disclosure requirements on government-sponsored research to induce greater R&D effort than industries characterized by a slower pace of innovative activity.

Appendix

Proof of theorem 2

■ Only an outline of the proof is given here. A complete proof appears in Rogerson (1981).

[7] Of course, government would not necessarily desire to stimulate R&D effort in all industries. To evaluate whether increased R&D expenditures would be welfare improving and then to determine an optimal value for β would require explicit modeling of the R&D production function so that such factors as potential duplication of effort and economies of scale could be taken into account. See Scherer (1980) for a discussion of market structure and R&D and for references to other sources. This article simply identifies how government might use trade secrets legislation as a spur to innovative activity.

The standard approach for calculating a symmetric Nash equilibrium is followed. First we characterize firm i's optimal strategy, given fixed strategies of the other firms. Then we solve for a strategy vector of the required form such that firm i will choose it, given that other firms have chosen it.

The functional equation of dynamic programming (Denardo, 1967) is used to characterize firm i's optimal choice. Let the other firms' choices be given by $\{x_j^*\}_{j \neq i}$. Suppose that firm i chooses x_{ij} in state j and that y_j is the present discounted value to firm i, given it is in state j. Firm i's choice of strategy determines the transition probabilities. We shall write $\theta_{ij}(x_{ij})$ to show this dependence. The immediate expected payoff to firm i is the expected return from winning minus its expenditure:

$$\theta_{ij}(x_{ij})\pi - x_{ij} . \tag{A1}$$

As well, firm i will find itself in state k with probability $\theta_{ij}(x_{ij})$ next period. The expected present discounted value of this is

$$(1 - c) \sum_{k=1}^{n+1} \theta_{kj}(x_{ij})y_k . \tag{A2}$$

Let $g_{ij}(x_{ij}, y_1, \ldots, y_{n+1})$ denote the total present discounted value of state j to firm i, which is the sum of these two terms. The functional equation of dynamic programming says that x_i^* is an optimal strategy for firm i with associated values $(y_i^*, \ldots, y_n^*)$ if and only if for every $j = 1, \ldots, n + 1$,

$$\text{(i)} \quad x_{ij}^* \text{ maximizes } g_{ij}(x_{ij}, y_1^*, \ldots, y_{n+1}^*) \text{ over } x_{ij}^* \in [0, \infty]$$

and

$$\text{(ii)} \quad y_j^* = g_{ij}(x_{ij}^*, y_1^*, \ldots, y_{n+1}^*).$$

Part (i) states that x_{ij}^* must maximize g_{ij}, since g_{ij} determines the value of state j to firm i. However, y_j^* is supposed to be this value. Therefore, (ii) must also hold.

It is now straightforward (at least conceptually, if not algebraically) to write out explicitly the g_{ij}'s and solve for a symmetric equilibrium.

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