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AN EVALUATION OF FEDERAL POLICIES CONCERNING JOINT VENTURES FOR APPLIED RESEARCH AND DEVELOPMENT*

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Current federal policies toward interfirm cooperation in research and development are designed to maximize society's use of available technology. Models of industry resource allocation behavior demonstrate that these policies are detrimental to the formation of risk sharing consortia for the development of new technology. The reason is that current policies often deprive applied research and development activities of their appropriability.

Analytical results suggest that, if appropriability is maintained, an underinvestment in applied research and development can be corrected, in most cases, simply by permitting firms to share the benefits and costs of projects in proportion to firms' investments. A permissive governmental posture may be particularly effective for industries consisting of a large number of firms with some firms relatively larger than others. Industries consisting of small numbers of relatively equal size firms may require government as a participant in consortia for applied research and development (appropriable but risky R&D activities).

(RESEARCH AND DEVELOPMENT; GOVERNMENT; ENGINEERING; ECONOMICS)

1. Introduction

In an earlier paper [6], we investigated the effectiveness and efficiency of alternative policy instruments directed at stimulating industry's joint investment in basic (*inappropriable*) research. We developed a model of an industry where each firm could allocate its investable resources between two types of investment opportunities: one representing inappropriable joint research and the other representing appropriable research or nonresearch (e.g., plant, building) investment. We established what would be rational for each firm and used this to determine the industry's equilibrium allocation of resources to the inappropriable joint research. It was shown that this equilibrium allocation was less than Pareto optimal. Consequently, it was concluded that in correcting the underinvestment in inappropriable research and development activities, it is not sufficient on the part of the government simply to permit interfirm cooperation. Our model permitted us further to assess the effectiveness of two conventional methods of stimulating inappropriable R&D: provision of seed money (i.e., outright grants) and provision of matching subsidies (or tax incentives). We demonstrated that provision of seed money is counterproductive (except in rather special circumstances) and that while matching subsidies are effective, they are not cost efficient. Thus, at present, government does not really have an effective and efficient instrument for stimulating basic (inappropriable) research.

In this paper, we consider the case of joint ventures for applied research and development (appropriable R&D) and we evaluate existing government policies concerning such ventures. However, the above results from our previous paper are crucial to the discussion here, since, as we shall show, existing policies often convert appropriable R&D into inappropriable R&D.

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2. A Project Share Model

Technically, the situation of underinvestment in appropriable, but risky, R&D occurs only when the expected monetary payoff of an R&D project is positive, but its size and risks are beyond the reach of each individual firm in an industry. An R&D project of this type is "lumpy" (that is, it calls for a sizable minimum investment), and for risk averse firms the incremental expected utility of the payoff from the total project is zero or negative. Formally, let us define these conditions as below:

Let

C be the minimum initial investment required for the particular appropriable and risky R&D project.

$\tilde{Z}$ be the uncertain return from the project (expressed in terms of its present value) accruing to the investing firm(s).

$\tilde{X} = \tilde{Z} - C$ be the net profit of the firm from the project. $\tilde{X}$ is also expressed in terms of its present value and is a random variable.

W_i be the initial wealth of firm i.

$u_i(W_i + X)$ be the utility function of firm i in the pertinent range of values of X. u_i is assumed to be concave with respect to X, since each firm is assumed to be risk averse.

From the foregoing remarks, it is clear that our project satisfies the following two conditions,

$$E(\tilde{X}) > 0 \quad \text{and} \tag{1}$$

$$E\left[u_i(W_i + \tilde{X})\right] < u_i(W_i) \qquad \text{for all } i. \tag{2}$$

Now, our concern is whether, when interfirm cooperation is permitted, a group of rational self-interested firms in this industry will decide to cooperate and share the costs, benefits and risks of the project.

Samuelson [8] has shown that when condition (1) is satisfied, and when the utility function of a firm is concave, there is some positive fraction of the project (assuming both costs and benefits are shared in the same proportion) that is acceptable to the firm, i.e., there exists at least one $p_i > 0$ such that

$$E\left[u_i(W_i + p_i\tilde{X})\right] \geqslant u_i(W_i). \tag{3}$$

If $\bar{p}_i$ is the maximum fraction of the project acceptable to firm i, then $\bar{p}_i$ is a value such that

$$1 > \bar{p}_i > 0 \quad \text{and} \tag{4}$$

$$E\left[u_i(W_i + \bar{p}_i\tilde{X})\right] = u_i(W_i). \tag{5}$$

The project will be acceptable to the industry G (consisting of firms $1, 2, \ldots i, \ldots, g$) on a cooperative basis if

$$\sum_{i \in G} \bar{p}_i \geqslant 1. \tag{6}$$

Assuming that there are no special costs of cooperation, when the condition stated in (6) is satisfied, we can presume that a consortium will form to share the costs and benefits of the project and that the underinvestment will be corrected. In other words, for R&D projects for which (6) is satisfied in the pertinent industry, it would suffice for the government simply to allow such a consortium to form and exist.

Note that when condition (6) is satisfied, we are not suggesting that the resultant consortium will be necessarily industry-wide. When the industry-wide sum of the $\bar{p}_i$'s substantially excceds one, individual firms may be more concerned about identifying the *optimal share* (p_i^*) which would maximize their expected incremental utility from

the project, i.e., p_i^* is such that

$$E\left[u_i(W_i + p_i^* \tilde{X})\right] - u_i(W_i) \geq E\left[u_i(W_i + p_i \tilde{X})\right] - u_i(W_i) \qquad \text{for all } p_i \qquad (7)$$

that is,

$$E\left[u_i(W_i + p_i^* \tilde{X})\right] \geq E\left[u_i(W_i + p_i \tilde{X})\right] \qquad \text{for all } p_i\,. \qquad (8)$$

Thus, when $\sum \bar{p}_i$ is substantially greater than one (as is likely to be the case for many risky projects), individual firms would want to get together with only a subgroup of other firms in the industry and negotiate project shares as close to the individual p_i^*'s as possible. Thus, in general, we do not expect industry-wide R&D consortia for risk-sharing ventures.

Only in cases in which the condition in (6) is not fulfilled, it may be necessary for government to accept a share of the project such that

$$P_E \geq 1 - \sum_{i \in G} \bar{p}_i \qquad (9)$$

where P_E represents government's share. As before, the assumption is that each participant (including government) would share in the benefits of the project, in proportion to the participant's share of the initial investment.

Of course, in some cases it may be necessary for the government to participate in a consortium even though condition (6) is satisfied. This may happen either (a) when the transaction costs of industry-wide cooperation are prohibitive, or (b) when most firms in the industry are insistent upon taking a share very close to the optimal share p_i^* or no share at all, and $\sum_{i \in G} p_i^* < 1$.

We can deal with these cases respectively by (a) defining "the relevant industry" appropriately, and (b) equating $\bar{p}_i$ with p_i^*. When we talk about the satisfaction of condition (6) in the rest of this paper, we imply the pertinent qualifications mentioned here.

On the basis of this simple model, the posture for a prudent policy towards cooperative ventures for appropriable R&D seems quite clear. Government should identify specific appropriable R&D projects that are socially desirable but privately unacceptable and should encourage the relevant industry to form suitable interfirm or industry-government consortia to share the benefits and risks of the project in proportion to participants' shares of the initial costs.

Readers familiar with available empirical studies of cooperative R&D may be skeptical of the above model and policy recommendation. On the basis of the British experience with research associations (RAs), documented by the Center for Study of Industrial Innovations (CSII) [2] and by Johnson [7], one can conclude that RAs have failed to be an effective source of far reaching technological developments. Generally, RAs have not funded highly risky projects necessary to achieve technological breakthroughs. Empirical evidence indicates no significant difference between the probabilities of technical completion of projects funded by RAs and those independently funded by private firms. In fact, CSII [2] found that whereas private industry spends 80% of its allocation to R&D on development projects (the results of which are appropriable and risky), RAs spend almost 80% of their R&D budgets on "research projects" (which have a higher degree of inappropriability). These percentages are generally confirmed by Wolek's [9] study of R&D consortia in the United States. Thus, prima facie, it seems that interfirm consortia have failed to correct an underinvestment in applied research and development.

Another point that is evident from the available empirical studies is that, contrary to the assumption in our model, RA financing is seldom based on the principle of proportional sharing of costs and benefits. In fact, most RAs operate as nonprofit organizations and are consequently barred from providing dividends to participating firms.

The point is that studies such as CSII [2], Johnson [7], and Wolek [9] have focused primarily on industry-wise RAs. Because of (1) their industry-wide nature, (2) the initial government grant (seed money) to start the RAs, and (3) their typical organizational structures, RAs concentrate primarily on *inappropriable* R&D activities. This is true even when RAs are involved in short-term, directly applicable work since the resulting product and process improvements are to be disseminated freely. Thus, the industry behavior observed by CSII, Johnson and Wolek is not relevant to the model described in this paper. Instead, it is exactly the behavior explained by the model in our previous paper [6].

The difficulty is that adequate empirical studies of joint ventures among a few firms (i.e., not industry-wide) for specific appropriable but risky R&D projects are simply not available. This does not mean that such joint ventures for risk sharing do not exist. The Industrial Research Institute [4] has identified several examples including development of shale oil technology, hydrocarbon research, inter-industry emission control programs, etc., where joint ventures among a few firms have been negotiated. However, where such joint ventures do take place, industry executives are reluctant to disclose any details because of concern for trade secrets. More significantly, industry executives are often afraid to admit the existence of such joint ventures because of the potential for antitrust actions.

In fact, an empirical validation of our model in this paper seems unlikely since in the United States, current government policies toward interfirm or industry-government collaboration are hardly in line with the prescription of the model. The fact is that existing policies toward cooperative R&D have not been consciously developed with the intention of reducing private underinvestment in R&D. Instead they have evolved from policies designed to meet the needs and concerns of an earlier era. The net result of this evolution is that these policies seem to maximize society's use of available technology. However, below we explain why and how these policies are detrimental to the formation of risk sharing consortia for the development of new technology.

3. An Evaluation of Current Policies

3.1. *Policies Toward Interfirm Cooperation*

Ever since the days of the Sherman Act, for example, almost any interfirm cooperation is subject to a review by the Department of Justice for its potential or actual anticompetitive effect. Consequently, the Antitrust Division of the Department of Justice has had the greatest influence in the development of governmental policies toward R&D consortia.[1] The Antitrust Division is rarely concerned with the impact of its decisions on future allocation of resources, or on the development of new technology; its primary concern is to minimize existing or future monopoly.[2] Thus, in most

[1] In any event, private firms contemplating joint ventures for R&D are ordinarily quite fearful of potential antitrust action. This is well documented by the articles of Cuthbert, Socolofsky, Swan, etc. in a report published by The Commerce Technical Advisory Board [3].

[2] Of course, official statements from the Antitrust Division (or, for that matter, any government department) always insist that an interfirm collaboration in R&D is not a *per se* violation of antitrust laws. A

cases involving interfirm cooperation for appropriable R&D activities, the U.S. government has typically taken one or more of the following actions:

(i) It has taken members of a consortium to court for violation of antitrust laws, often after years of cooperation, cross licensing, patent pooling, etc. In such cases, the courts have typically signed cease and desist decrees and ordered the firms to make their patents available to all qualified competitors at "reasonable" (i.e., nominal) costs.

(ii) It has obtained injunctions against large firms in an industry (often meaning firms accounting for one or two percent of industry sales) to bar them from any cooperation with other large firms in their industry.

(iii) It has allowed cooperation with the condition that the research findings and/or patents resulting from such cooperation be available to other firms in the industry (including those who do not participate in the consortium) at a "reasonable" or nominal cost.

Indeed, all three of these measures make sense from a monopoly minimization point of view, if one is concerned only about the monopoly over already developed technology. However, as Arrow [1] has pointed out, there is an inherent conflict between optimal use of available technology and optimal development of new technology. Policies that attempt to maximize society's use of available technology will necessarily reduce the incentive for investment in new technology. The fact is that when research findings and patents resulting from a consortium are made available to everyone, including firms not participating in the consortium, as required by action (iii) above, the basic character of the joint investment opportunity is changed from appropriability to inappropriability. Consequently, in a consortium that accepts the condition laid down in action (iii) above, resource allocation behavior of the member firms will be given by the model in our earlier paper [6]. As indicated in the summary of our results from that paper, inappropriable R&D activities are likely to be underinvested in, even on a cooperative basis. Furthermore, government, at present, does not really have an effective and efficient instrument to stimulate inappropriable R&D. In fact, it can be shown [5] that in most cases industry's allocation of resources to an inappropriable R&D activity is smaller than that to an appropriable activity, other things remaining unchanged. In other words, existing government policy towards cooperation for appropriable R&D seems to increase the underinvestment in R&D rather than to decrease it.

Interestingly enough, members of an industry facing innovative competitors may welcome current government policy and the consequent reduction in their R&D allocation, since such a cooperative arrangement also means an "insurance" for each participating firm against the risk of other members' innovation.[3] If any participating member does (entirely on his own) develop a patentable technology that is remotely related to the purposes and efforts of the cooperative arrangement, it seems most likely

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typical policy assertion also reads, "Antitrust enforcement policy is not inflexible. It does not ignore the nation's needs and problems. It has an affirmative as well as a prosecutive side" [3, p. 6].

On the other hand, most antitrust enforcement officers take the position that the law concerns itself with the traditional notion of anticompetitiveness (i.e., with the effect on the production and sale of the product of an industry) rather than with the anticompetitive effect on the allocation of resources to R&D. This is precisely what Thomas Kauper, former Assistant Attorney General in charge of the Antitrust Division, implied when he said, "I do not want to have any understanding that the Division has some authority under which it would say this is anticompetitive but to heck with it, it is in the public interest anyway" [3, p. 70]. Our study of the history of antitrust actions and decrees shows no evidence of concern for the future allocation of resources to R&D activities on the part of antitrust enforcement officers.

[3] Kauper [3, pp. 61–64] provides several examples of industry-wide agreements requiring competitors to grant each other royalty-free or inexpensive licenses. He claims that the effect and purpose of these

that the consortium will claim, and the courts will uphold, the rights to that technology! Thus, no member of a consortium guided by current government policy has an incentive to develop new technology, on its own, in areas that are related to the purposes of the joint venture. In other words, as far as allocation of resources to the development of new technology is concerned, current government policy toward interfirm cooperation in appropriable R&D seems to *encourage* anti-competitive behavior as it attempts to minimize the possibility of anti-competitive effects in the use of research findings and/or patents resulting from a cooperative venture.

In the foregoing paragraph, we have discussed existing government policies toward *interfirm* cooperation for appropriable R&D. We now turn to policies concerning industry-government cooperation.

3.2. *Policies Toward Industry-Government Cooperation*

In situations in which the government has determined that an industry's allocation to appropriable R&D activities (either by firms acting independently of one another, or through permissible interfirm consortia) will be socially suboptimal, the United States government has often chosen to allocate its tax dollars to, and to participate in, consortia with willing firms.

By our analysis (see equation (9) above), such an arrangement would be very desirable, provided that government and participating firms retain the appropriable nature of the R&D activities and share the resultant benefits and risks in proportion to their respective investments.

Unfortunately, benefit sharing in proportion to participants' investments is not the current policy of the U.S. government. Historically, the U.S. government has been involved in industry-government cooperation in R&D primarily for defense and space technologies developed in the early fifties and sixties. By their very nature, these technologies had to be developed for exclusive and total use by the U.S. government. Unfortunately, government policies developed in that context have persisted in civilian technology areas (although now government's primary intention ought to be to stimulate appropriable but risky R&D). As a result, by tradition, when the U.S. government participates in an R&D activity, even if it contributes only a small fraction of the total investment, the government holds the title to any resulting patents. The only difference is that now it promises to license them to any qualified applicant at a reasonable cost. This policy is familiarly known as the "Title Policy" of the U.S. government for its participation in industry-government consortia.

Similar to antitrust policies toward interfirm cooperation, the Title Policy also has the effect of depriving a joint investment opportunity of its appropriability. Consequently, under the Title Policy, an industry's investment in appropriable R&D is generally less than what it would have been without any government intervention at all. Fortunately, the language of PL 95-224, signed into law by President Carter on February 2, 1978, suggests that the Title Policy may undergo a dramatic revision in the near future. This law promises that in suitable cases of industry-government cooperation for R&D, member firms may negotiate (with designated government administra-

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agreements was to prevent members of the agreements from gaining a competitive advantage from innovative activities, and conversely, to protect the members from any competitive disadvantage from each other's innovations. Such arrangements protect members from the normal competitive risks of noninnovation. Ironically, government decrees against antitrust violators have required that such cross licensing be made available to all firms in the industry as a restitution for the violation! Kauper's argument suggests that industry would welcome such decrees since they would be insured against noninnovations.

tors) the final disposal of patent rights resulting from such cooperation. While the language is encouraging, industry seems not to be convinced of the government's intention. Until industry begins to trust the policy implied in PL 95-224, and believes that the Title Policy is dead, the current underinvestment in appropriable R&D is likely to persist.

In addition to enforcing the Title Policy, in most cases of industry-government cooperation, the U.S. government includes a "background patent release" clause. This clause requires that if a firm participating in an industry-government consortium has patent rights essential for the exploitation of the results of the consortium's R&D, the participating firm shall make those rights available to the user(s) of the consortium's results at a "reasonable" (nominal) cost. This policy is commonly referred to as the "Background Patent Release Policy" (BPRP).

Empirically, there is considerable evidence that because of BPRP, firms with strong patent positions are reluctant to participate in industry-government consortia for civilian research. (See the Commerce Technical Advisory Board report on Industry Collaboration in Energy R&D [3].) Firms that do not have strong patent positions may nevertheless be prepared to participate in an industry-government consortium. However, it can be shown that as they participate in such consortia, these firms will reduce their allocation of resources to R&D activities that may have some potential for yielding relevant background patents. In fact, extending the model in our previous paper [6], Joglekar [5] has shown that firms participating in an industry-government consortium in the presence of BPRP will allocate a lower level of resources to applied research and development than they would have allocated independently.

In short, we believe that current government policies toward cooperation for appropriable R&D are often counter-productive. That is, they tend to increase the underinvestment in appropriable but risky R&D, rather than to reduce it.

3.3. *Policies Toward Concentrated and Fragmented Industries*

Particularly in the context of appropriable but risky R&D, many policy makers and scholars in the United States believe that concentrated industries (i.e., those consisting of a small number of large firms) come closer to socially optimal levels of investment than the nonconcentrated industries do. These policy makers believe that fragmented industries (consisting of a large number of small firms) fall considerably short of their socially optimal levels of investment in appropriable but risky R&D. Thus, for example, the U.S. government seeks to encourage and underwrite joint R&D in industries such as cotton and leather but is wary of cooperation among automobile manufacturers and seeks injunctions against such cooperative efforts.

In order to verify whether such government actions are justified, let us develop our simple model further and assess the impact of industry concentration (or fragmentation) on the feasibility of the development of an industry consortium for risky but appropriable R&D without any government intervention.

The satisfaction of the condition in equation (6) in §2 depends upon the specific form of the probability distribution of returns from the project and the utility functions of the firms. For adequately general results, we should consider a series of likely forms of these functions. For illustrative purposes, we shall consider only a situation where

(i) $\tilde{X}$ is distributed normally with mean μ and standard deviation σ, and

(ii) the incremental utility function for firm i is given by

$$u_i(W_i + x) - u_i(W_i) = \frac{1}{r_i}(1 - e^{-r_i x}) \tag{10}$$

where r_i is the local risk aversion parameter for firm i.

Now substituting this utility function in (5), $\bar{p}_i$ will be given by

$$E\left[\frac{1}{r_i}(1 - e^{-r_i\bar{p}_i\tilde{X}})\right] = 0 \tag{11}$$

and after simplification,

$$\bar{p}_i = 2\mu/(r_i\sigma^2). \tag{12}$$

Hence, the condition in equation (6) will be satisfied if

$$\sum_{i=1}^{g} \bar{p}_i = \frac{2\mu}{\sigma^2}\left[\frac{1}{r_1} + \frac{1}{r_2} + \cdots + \frac{1}{r_i} + \cdots + \frac{1}{r_g}\right] \geqslant 1 \tag{13}$$

that is, if

$$\sum_{i\in G} \frac{1}{r_i} \geqslant \frac{\sigma^2}{2\mu}. \tag{14}$$

Thus, if (14) is satisfied, the project (with mean benefits μ, and standard deviation of the benefits, σ) will be acceptable to the industry on a cooperative basis.

3.4. *An Analysis*

Now we can analyze the effect of industrial structure on the satisfaction of (14) and consequently on the acceptability of a socially desirable applied research and development project (i.e., an appropriable but risky R&D activity).

We shall only consider the popular assumption that the more wealthy a firm is, the less risk averse it is. Let risk aversion be a linearly decreasing function of the initial wealth of a firm. That is,

$$r_i = r_0 - \rho W_i \tag{15}$$

where r_0 is the risk aversion of a firm with zero wealth, and ρ is a constant. We assume that $\rho > 0$ and

$$r_0 - \rho W_i > 0 \qquad \text{for all } i. \tag{16}$$

That is, all the firms we are dealing with (including the largest firms) are strictly risk averse.

Now consider a homogeneous industry such that

$$\left.\begin{aligned} r_i &= r_j = r \quad \text{and} \\ w_i &= W_j = W_G/g \end{aligned}\right\} \qquad \text{for all} \quad i, j \in G. \tag{17}$$

For this industry the left-hand side of (14), LHS14, can be rewritten as

$$\begin{aligned} \text{LHS14} &= \frac{g}{r_0 - \rho(W_G/g)} \quad \text{i.e.,} \\ \text{LHS14} &= \frac{g^2}{r_0 g - \rho W_G}. \end{aligned} \tag{18}$$

Differentiating (18) w.r.t. g we have

$$\frac{\partial(\text{LHS14})}{\partial g} = \frac{r_0 g^2 - 2\rho W_G g}{(r_0 g - \rho W_G)^2}. \tag{19}$$

The expression in (19) will be negative only if

$$2\rho \frac{W_G}{g} > r_0, \tag{20}$$

that is, only if we expect that a firm with twice as much wealth as the average firm in our homogeneous industry would actually prefer risk rather than being risk averse. But, by our assumption, even the largest firm is risk averse.

Hence, the expression in (19) must be positive. That is, LHS14 must be an increasing function of g, the group size (even after assuming total industry wealth W_G to be independent of g). Of course, for a given project, the right-hand side of (14), i.e., RHS14, is a constant.

It follows then that the larger the number of firms involved in a group, the more likely it is that the condition stated in (14) will be satisfied. In other words, *the larger the number of members in an industry, the more likely it is that a socially desirable R & D project, characterized by appropriability and risk, will be acceptable on a cooperative basis.*

This conclusion stands in direct contradiction to the popular belief that concentrated industries (which often means those involving small numbers of firms) come closer to socially optimal levels of investment in risky R&D.

In the light of the discussion below, this contradiction suggests that we need a clearer definition of the term "concentrated" industry and a better understanding of the exact circumstances under which the popular belief may be valid.

To understand the effect of group heterogeneity on the acceptability of a socially desired, appropriable, but risky R&D project, consider an industry G consisting of two firms i and j with initial wealths W_i and W_j respectively ($W_i > W_j$).

Using (14) and (15), we can say that a project with normally distributed benefits (with mean μ and standard deviation σ) will be acceptable to G if

$$\frac{1}{r_0 - \rho W_i} + \frac{1}{r_0 - \rho W_j} \geqslant \frac{\sigma^2}{2\mu}. \tag{21}$$

Let H denote a comparable homogeneous group, also consisting of two firms, each with initial wealth W such that

$$W = \frac{W_i + W_j}{2}. \tag{22}$$

It follows from (14) and (15) that a similar project would be acceptable to H if

$$\frac{2}{r_0 - \rho W} \geqslant \frac{\sigma^2}{2\mu}. \tag{23}$$

It can be shown that the left-hand side (LHS) of (21) is greater than the LHS of (23). To show this we define

$$W_i - W = W - W_j = \Delta. \tag{24}$$

Then

$$\text{LHS21} = \frac{1}{r_0 - \rho(W + \Delta)} + \frac{1}{r_0 - \rho(W - \Delta)} = \frac{2(r_0 - \rho W)}{(r_0 - \rho W)^2 - (\rho\Delta)^2} \quad \text{and} \tag{25}$$

$$\text{LHS23} = \frac{2}{r_0 - \rho W} = \frac{2(r_0 - \rho W)}{(r_0 - \rho W)^2}. \tag{26}$$

Since

$$(r_0 - \rho W)^2 \geqslant (r_0 - \rho W)^2 - (\rho\Delta)^2, \tag{27}$$

it follows that

$$\text{LHS21} \geqslant \text{LHS23}. \tag{28}$$

Since the right-hand sides of (21) and (23) are identical, it follows that a heterogeneous group G is more likely to satisfy condition (14) than the homogeneous group H. The result can be generalized for industries involving more than two firms.

It follows that if by industrial concentration we mean heterogeneity (as measured by wealth of firms, for example), then industrial concentration does lead to an allocation of resources to appropriable but risky R&D that is closer to social optimality.

Thus, our analysis indicates that industries consisting of a large number of firms as well as industries consisting of some large firms and other relatively small firms may be able to correct their underinvestment in appropriable R&D through interfirm cooperation without government participation. In other words, it seems unnecessary that R&D programs in industries such as cotton and leather should receive special support from the government. On the other hand, industries consisting of a small number of relatively equal size firms may need industry-government consortia to undertake their risky R&D ventures.

4. Conclusion

Our results in this paper suggest that underinvestment in applied research and development (appropriable but risky R&D) can be corrected, in most cases, by permitting firms to share the benefits and risks of projects in proportion to the firms' investments. Such a permissive posture may be particularly adequate in industries consisting of a large number of firms with some firms relatively larger than others. Industries consisting of a small number of relatively equal size firms may need government as a participant in their consortia for risky R&D.

In any case, for interfirm or industry-government collaboration to work, it is important that the appropriable nature of the applied research and development activities be maintained. However, current government policies toward R&D consortia are designed to maximize society's use of available technology. These policies tend to convert appropriable R&D into inappropriable R&D. Consequently, they are detrimental to the development of new technology.

New legislation such as PL 95-224 may help to remedy this situation, provided its implementation is guided by administrators who understand and appreciate the analysis and conclusions presented here.

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