

Deep-space unique requirements for radio system stability are going to continue to be pushed far beyond those needed for near-earth use. The most constraining is the  $10^{-17}$  radio system stability need for gravitational wave detection on deep-space spacecraft via the doppler signature on the radio link. Such gravitational wave detection is not feasible when orbiting near a large massive body such as the earth. Therefore, it must be done from deep space.

In general, though, one can expect deep-space and near-earth space communications technology to evolve together. Deep-space will push the signal-to-noise and stability limits more. Near-earth will push the bandwidth and frequency allocations more. Both will see major advances in the next 15 yrs.

### 3.3 Working Group on Economics and Investment

#### ECONOMIC ISSUES IN THE DEVELOPMENT OF NEW TECHNOLOGY: THE ROLE OF GOVERNMENT IN SATELLITE COMMUNICATIONS RD&A [1]

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#### Introduction

In this paper I describe the way economists understand the research, development, and applications (R&D) process [2] and highlight the economic issues that are important in any discussion of the role of government intervention in that process. In particular I address the following fundamental questions. What is the appropriate allocation of resources to R&D? Can private markets achieve this allocation unaided, or is government intervention desirable? If intervention is called for, what form should it take and how extensive should it be? Finally, are some current forms of government intervention undesirable and, if so, how can they be corrected?

I begin with an analysis of a generic industry, since that is the form of most of the literature, but near the end I will relate the general principles to the satellite communications industry and to some of the specific questions that have been raised with me. I apologize up front for the rather wordy and extensive analysis, but I did not know how much of the economics was common knowledge among the participants in this symposium, how much had been previously digested by policy analysts and engineers in this specific industry, or whether I had to start from beginning principles in economics. I chose to start somewhere in the middle with a leaning toward the beginning since much of what is relevant has only recently been discovered and analyzed in economic research.

The paper is organized the way economists think about the issues surrounding R&D. First, after defining some essential preliminary concepts, I describe what is known about R&D in a purely market environment with no government intervention. The purpose of that analysis

is to understand how the allocation of resources by the private sector, both to the R&D effort and to the dissemination and adoption of innovations, would differ from that which is socially desirable or from that which is desirable from the industry's point of view [3]. When any market's performance is significantly different from that which is socially optimal, economists say there is market failure. As we will see, the R&D market exhibits many characteristics associated with market failure.

I also look at many of the current methods of intervention nominally used to correct market failures. The purpose is to try to understand when intervention is desirable and what it can accomplish. In some cases, the situation is made worse off with intervention; in other cases, it is improved. In the R&D process there are no uniformly best answers so that it is important to understand the various possibilities in order to judge their expected efficacy in particular applications.

Second, I look at the economics of public sector R&D and at two instances of increased inefficiencies due to public sector participation in the R&D process. In particular, I consider the impact of regulation, such as practiced by the Federal Communications Commission (FCC), and the impact of government opportunism as represented by the inability of the public sector to commit to long-term agreements.

Finally, I present the logical conclusions of this analysis as it applies to the satellite communications industry and its and the government's R&D efforts. To slightly overstate the case, I find only limited support for continued government R&D in this industry. In particular, if I had to narrow my choice of recommendation to one of (1) continue business as usual with another NASA program beyond but similar to the Advanced Communications Technology Satellite program (ACTS), or (2) do that research within NASA necessary to support its own and other public sector needs or (3) no further intervention, I would choose (2) with some bias toward (3).

**ACKNOWLEDGEMENT:** I have drawn heavily on the work of many others in the preparation of this paper, but have been mostly guided and informed by the excellent survey of Jennifer Reinganum (1986) on the current state of the art in the economic theory of R&D and by the provocative and persuasive historical and policy analysis of Nancy Rose (1986). The paper by Rose should be required reading for all the participants in this symposium.

### **The Economics of Private Sector R&D**

In this section I briefly summarize the current understanding of the economics of R&D in the private sector that I consider of some relevance for this symposium. I concentrate on principles and generic findings, leaving the specific applications to satellite communications until later [4].

## Key Concepts

The two key forces that determine whether too little or too much is spent on R&D by the private sector when left alone are (1) appropriability, the capability of an innovating firm or organization to capture the benefits from the innovation, and (2) externalities, those benefits and costs from innovative activities that fall to firms and organizations other than the innovator. The extent and character of these forces is shaped by (3) rivalry, the number and character of the innovator's domestic and international competitors, and (4) information dispersion, who knows what about the technology, future markets, and benefits. Let us look at each of these four concepts in turn.

### Appropriability

A successful new technology, embodied in a production technique or a product or a service, confers benefits either directly to those using it or indirectly to those whose costs are reduced because of it. A major determinant of the extent of innovative activity by a firm is its expectations about its ability to convert those benefits into profits. However, appropriating those benefits in the form of profits can be problematical since there are many ways in which information about the innovation may leak to others who can then share in the benefits. Employees changing employers, patent descriptions being "slightly modified," and reverse engineering are just some of the ways information finds its way to others. Once the information is available, competitors can and will adopt the innovation and, thereby, share in the benefits with the original innovator. While this may seem obvious, how much of the benefits an innovator can appropriate has a profound effect upon the extent and scope of his R&D activity and, therefore, ultimately on the rate of innovations available to society.

When a firm allocates resources to R&D, it naturally weighs only its own costs and benefits in its decisions. The fewer benefits it thinks it can appropriate, the lower its incentive to commit valuable resources to innovative activities. Because of this reduced incentive, the firm's allocation may be less than is desirable from society's point of view. This is illustrated in Figure 3-22 using the economist's traditional diagram matching (marginal) [5] benefits and (marginal) costs. The full benefits from the R&D effort are given by  $MB^F$ . The optimal level of R&D effort in that figure is  $X^O$ , the effort at which marginal benefit equals marginal cost. However, because the firm can only appropriate  $MB^P$ , it will choose  $X^P$  where its private marginal benefit equals its marginal cost. One measure of the social loss from this inappropriate allocation of resources is the area of the shaded triangle. This is the area cost-benefit analyses purport to measure.

Of course, once a beneficial innovation has been discovered, it is then desirable from a social point of view to disseminate it quickly and widely. But if the innovator can appropriate all the benefits then it is the monopoly owner of the rights to the innovation and has an incentive to disseminate it slower and much less widely in order to be able to price it higher. Appropriability is good before the innovation is discovered, but nonappropriability is preferred afterward.

Appropriability tugs public policy in two directions. To encourage the socially desirable pace of innovative effort the winner, the one who discovers the successful innovation, should have exclusive rights to its benefits. To encourage the socially desirable pace of innovation dissemination, the winner should have no exclusive rights to the benefits of the innovation. The policy tension comes from trying to achieve both these goals simultaneously. This can, however, be done only if information is perfect and all benefits and costs (the functions  $MB^F$  and  $MC$  in Figure 3-22) are known to the policy maker.

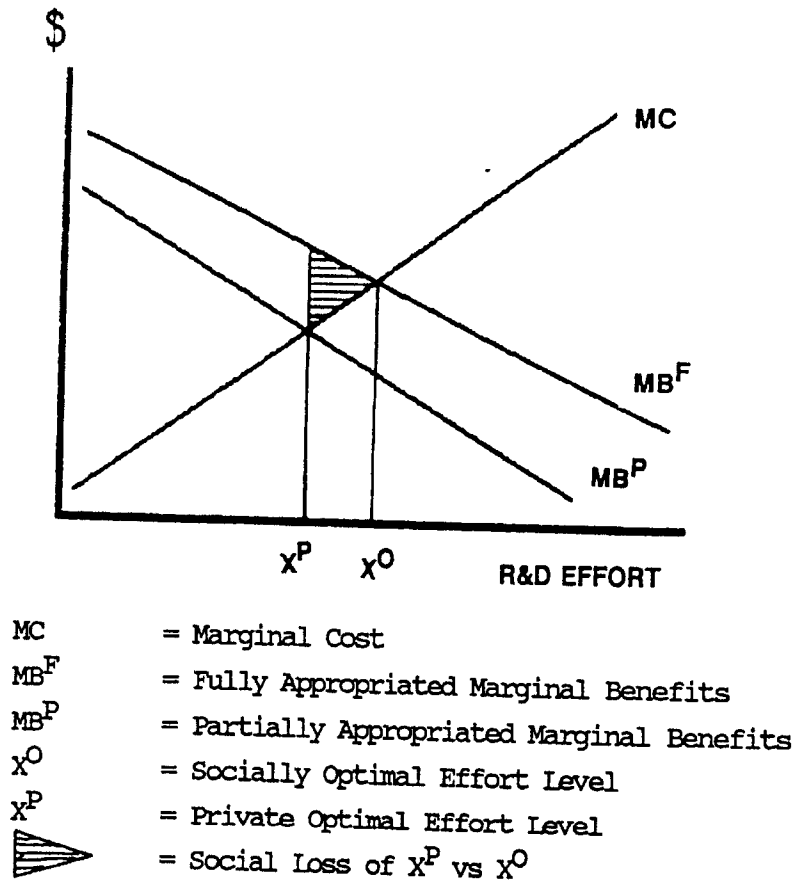


FIGURE 3-22 Appropriability, One Firm

### Externalities

Externalities are the costs and benefits unavoidably conferred on others through one's actions; the classic example is pollution. In the analysis of R&D, externalities take two major forms. The first, which tend to be positive, are those benefits which are nonappropriable (sometimes called spillovers) including those ubiquitous productivity gains conferred on the economy at large that are generally used to justify government subsidies to R&D. These benefits can and do flow across

international boundaries. Another form of positive externalities, important to the communications industry, are called network externalities by economists and refer to those situations in which the benefits to any adopter of a new technology increase as the number of adopters increases. The classic examples include videocassette recorder (VCR) technology (the fewer who adopted Beta, the worse off Sony was) and shared communications technologies.

The second class, called common pool externalities, is more subtle but just as important in the analysis of private sector R&D. The more any one firm invests in R&D the more it increases the probability that it will discover the next innovation before its rivals — otherwise, one presumes, it would not increase its effort. But the higher the probability that it will be first, the lower the probability that its rivals will be first [6]. This is illustrated in Figure 3-23 where  $MC$  and  $MB^F$  represent the firm's own marginal cost and benefit from its own R&D effort. The marginal cost it imposes on others [7] is  $Z(x)$  which must be added to  $MC$  to yield the true social marginal cost of this firm's effort. The firm will choose  $X^P$  to maximize its profits while it would be socially desirable to have it choose  $X^O$ . The social loss is given by the area of the shaded triangle. Just as farmers will allow their cattle to overgraze the commons and oil producers will overuse a common pool, so will competitive firms overspend on R&D efforts in the sense that they will not take into account the negative effect their expenditures have on the expected benefits of their rivals. This is undesirable from both the industry's and society's point of view since it is the aggregate expected benefits that is important: the losers' profits or losses count just as much as the winners' do.

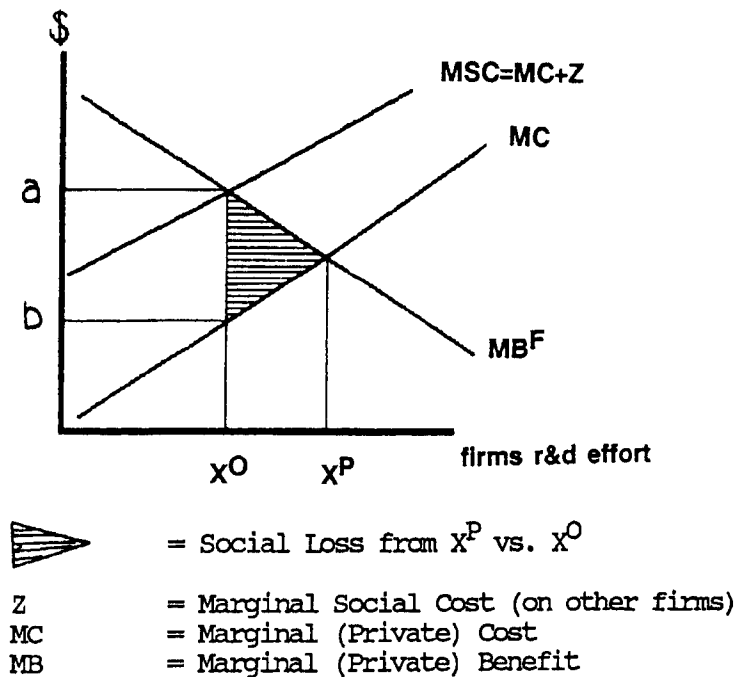


FIGURE 3-23 Common Pool Effect, Many Firms

## Rivalry

A key element in the above discussion of appropriability and externalities is the fact that the behavior of any market oriented firm is conditioned by the extent to which there are others so involved. A firm with no competitors, or a consortium of all the firms in an industry, can appropriate all the benefits of an innovation (subject to its ability to price-discriminate among users) and has no rivals to provide negative common pool externalities. A firm with many competitors, or in a situation in which entry into the industry is easy, is likely to be faced with extensive negative externalities and can appropriate few benefits if it is the winner. Of course the losers will be able to benefit from the positive externalities that the winner cannot appropriate.

The reaction of one's rivals to any firm's R&D strategy is important to gauge, and it is the expected equilibrium situation, when all firms have reacted, that we use to predict the extent of R&D efforts by any industry. Further, if there are international rivals then one must take into account their reactions and strategic policies if one is not to be misled by naive analysis. As we will see below, strategic policies which seem to be appropriate for a firm or an industry under the assumption that rivals will just react passively may be totally inappropriate if the rivals also react aggressively and strategically [8]. Modern game theoretic analysis has provided many insights which can help in the analysis of these issues.

## Information Dispersion

It is important to recognize that information is, by the very nature of the R&D enterprise, incomplete and dispersed among the many participants. This fact constrains what one can hope to accomplish with government policies aimed at R&D efforts, since one must choose the policy before it is known what the innovations will be, how commercially successful they might be, how much engineering remains to be done to create a viable prototype, and so forth. To emphasize this remember that externalities, whether negative or positive, are of fundamental importance in evaluating R&D policy. But there are no markets for externalities and therefore no objective measure of their effect. In Figure 3-22, we would need to know the curves MC and  $MB^F$  (the social benefits) to determine the optimal level of R&D effort. But market evidence can only assist in the measurement of MC and  $MB^P$  (the private benefits). In Figure 3-23 it may be possible to closely approximate  $MB^F$  and MC using market data, but we need to know MSC to compute the optimal level of effort. One might ask the involved parties for their information. But asking self-interested parties to evaluate the size of the benefits they confer on others or the costs they bear through externalities will inevitably yield large numbers about which any self-respecting economist should be very skeptical, especially if government subsidies rise as the reported number grows. This dispersion of information means that traditional cost-benefit analyses are infeasible since the requisite data do not exist. In this situation the policy maker cannot just estimate social costs and benefits and then implement a policy for which benefits outweigh costs. At best the numbers calculated will be statistics which bear a minimal relationship to the real facts; at worst the numbers will be totally misleading.

Nontraditional methods will have to be developed to deal with the fact that direct measurement of costs and benefits is not possible. The appropriate strategy is to create the institutions that provide the best chance of channeling the self-interested behavior of the private and public sector to produce the best outcome. This is not a strategy that public policy has pursued in the past, but it is one that I am convinced must be considered now to avoid unintended and undesired consequences. I discuss some examples later.

### Is There Market Failure in R&D?[9]

Taking the key concepts developed above we can summarize the expected performance of the unregulated marketplace under a laissez-faire policy regime; that is, in a situation in which there is absolutely no intervention by the public sector. We will describe the performance in relationship to two benchmarks: 1) What would be done if the industry were able to cooperate and coordinate the various R&D efforts of each of its firms (this benchmark identifies the interests of the industry), and 2) what would be done if society wanted to allocate its resources efficiently. Benchmark 2 is especially important since deviations from socially desired performance are a primary justification for intervention in the marketplace.

### Allocation of Resources to R&D

In a competitive industry with evenly sized firms and with free entry, we can predict from the theory that R&D expenditures will be too high relative to that allocation which is best for the industry as a whole; that is, aggregate industry profits will be lower than they could be if a single entity could coordinate the activities of all the firms. There will be too many firms, because entry will occur as long as there are profits to be made, and each will spend too much from an industry point of view because, in deciding its own allocation of resources to R&D, it ignores its effect on reducing the marginal benefit of research to others (the common pool problem) [10]. On the other hand, one cannot predict from theory alone whether R&D expenditures will be too high or too low, in a competitive industry, relative to the socially efficient allocation, especially if, as seems typical, the innovator cannot appropriate enough of the benefits of his research [11].

Nonappropriability tends to reduce innovative effort by leading to underspending on R&D. The common pool problem tends to expand innovative effort by leading to overspending on R&D. In Figure 3-24, the balancing of these forces is illustrated for four extreme cases. If both appropriability and common pool effects are low then private effort will be smaller than is socially desirable. If both appropriability and common pool effects are high then private effort will be larger than socially desirable. In the other two cases, one cannot determine the direction of the inefficiency without further evidence. In this case, how these forces balance out to create a market equilibrium allocation and how that compares to the socially efficient allocation is an empirical question

that is fraught with difficulties (especially if we don't know or can't agree on the social value of the innovation).

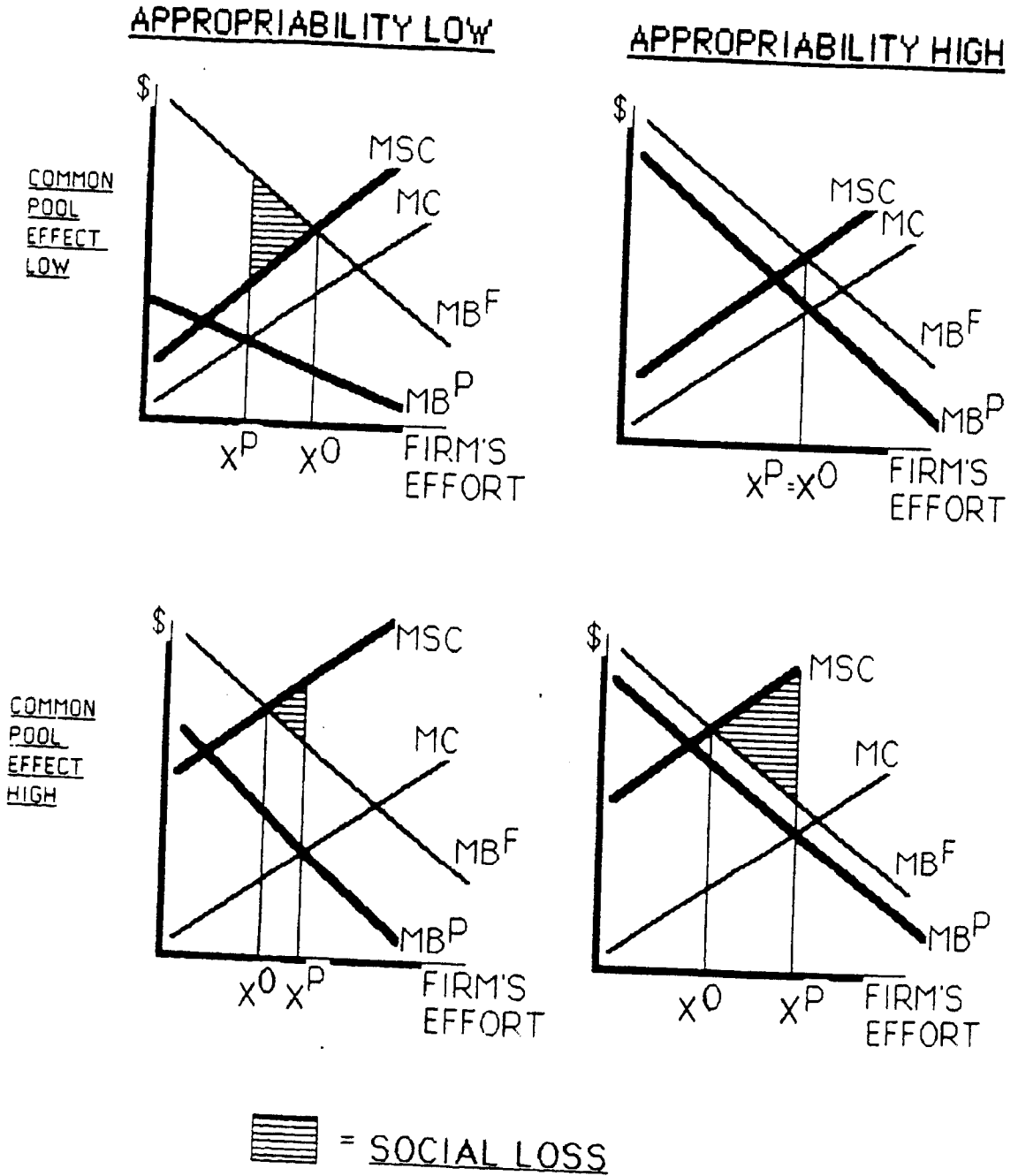


FIGURE 3-24 Effects Combined



A second factor that affects the R&D performance of the unimpeded marketplace is the relative importance of fixed, or sunk, costs and variable costs in the R&D process. As Dixit (1986) notes, the common pool effect (my probability of winning declines because you try harder) acts not only on the expected benefits to each firm but also on the expected costs. The sooner someone wins, the lower are the total R&D costs to the industry and society. Of course, only the flow costs (costs that stop as soon as the R&D project is ended, such as the wages of scientists and engineers who can be transferred to another project) are ended, since fixed costs (such as laboratory setup costs when the laboratory has no other use) are spent at the beginning of the process, by definition. If my rivals' flow costs are less important than their fixed costs, then the externality I impose on them by spending on my R&D (which raises my probability of winning and lowers their probability of winning) is greater since it then acts primarily on benefits only. They cannot save their fixed costs if I win, but they do lose future benefits. If their flow costs are more important than the externality I impose by spending is lessened. If I win they lose future benefits, but they also save future flow costs.  $Z(x)$  is therefore smaller. This has at least two implications for the performance of the market. First, other things being equal, the more important are the setup costs relative to the flow costs of any R&D project, the more are resources allocated to R&D efforts likely to be greater than is socially efficient (because pool effects are likely to swamp the nonappropriability effects). Second, other things being equal, if there are a few well established firms in the industry whose R&D flow costs are somewhat lower than those of potential entrants[12] then the common pool effect will be stronger and allocations to research expenses will be greater than in a newly emerging industry with many relatively equal firms [13].

A third factor often mentioned in the context of space applications as a contributing factor toward underinvestment by the private sector in R&D is risk. In particular, it is a favorite argument of many that "since industry supports only short-term low-risk research, the government should do long-term high-risk research." From an economist's point of view this statement is both factually and theoretically wrong. It is factually wrong since the private sector does support long-term high-risk research. There are many examples, but the most obvious current ones are in biotechnology and fusion research. Many private funds, either indirectly from venture capitalists or directly from the capital market through stock offerings, have been allocated to basic and applied research in these areas, even though the expected time of the first positive payoff is a long way off. The statement is theoretically wrong since when the private sector does not support specific projects, solely for risk reasons, it is probable that the public sector should also not support such projects [14]. In the private sector, the stock market constantly evaluates likely winners. Technical analysts are really well informed not only about the R&D but also about its probable commercial value. Rejection of a project by the private capital markets is a strong signal about its weaknesses that should not be ignored. For the government to pick up these projects, more is required than the observation that the private sector is risk-averse. A second reason why the statement is theoretically wrong rests on the observation that competent risk-management is easier if one

is dealing with a collection of small projects rather than only one very big project. The public sector has a tendency to opt for big projects, in order to get them funded by Congress. Thus government management of R&D leads to more risky portfolios of projects than private sector management. If the project is deemed undesirable by private sector financiers and insurers there is every reason to believe that public sector management will make things worse. One can only conclude that pleas for government support "to avoid risk" are made because accurate measurement is difficult [15]. Strong skepticism should greet these claims.

To summarize, leaving risk to the side where it belongs, the higher is the ability of the winner to appropriate the benefits of innovations, the smaller the common pool effect, and the more established are the firms in the industry, the more is the allocation of resources to R&D likely to be larger than is socially efficient. The less the ability to appropriate, the larger the common pool effect, and the newer the industry, the more likely it is that the market allocation of resources to R&D is smaller than is socially desirable. To know precisely whether there is market failure and, if so, whether there is over- or underinvestment in R&D requires more information than is contained in the models without further precision in the parameters. In particular, specific industry information and specific technology information is needed [16]. But objective measures are difficult to obtain using conventional procedures [17] because the manipulation of information is a powerful strategy in the manipulation of market and political processes.

#### Dissemination and Adoption

Appropriation of the benefits in an unrestricted marketplace comes in two forms: use of the innovation by the discoverer to increase his profits and, if patent protection is available, the sale or licensing of the innovation. If the (marginal) costs of dissemination are small then it is socially efficient for all to learn about the successful innovation rapidly. However, the incentives of both self-use and licensing operate to inhibit rapid dispersion of the details of innovations. For example, in the absence of involuntary externalities, if an industrial research lab licenses an innovation it can generally get more from the sale of the licenses than the cost savings of the firms it sells to, leaving all downstream firms (those who are licensees and those who aren't) worse off than before the innovation [18].

Even when the innovation is publicly known and freely available, if there is any uncertainty about the net benefits that would accrue to an adopting firm, it may be optimal for a firm to wait until others adopt. This effect is magnified when the extent of the benefits depends on whether this new innovation is an "industry standard" which creates network externalities. Thus, from society's point of view, adoption rates are generally lower than desirable. However, from the industry's point of view, if the returns to any one firm decline as the number of adopters increases, as will be the case in an oligopolistic industry without network externalities, then adoption will occur too fast since each firm will ignore its impact on the others [19].

## Summary

Is there market failure in R&D? Look at Table 3-11 and Figure 3-24. The unavoidable fact is that unconstrained markets almost certainly inefficiently allocate society's resources to R&D. Further, unconstrained markets almost certainly inefficiently allocate resources to the dissemination and adoption of new technology. What we don't know is whether too much or too little is allocated. In any case it is clear that achieving efficiency simultaneously in both R&D and dissemination is highly unlikely. The ability of the winner in the R&D race to appropriate the benefits is necessary to achieving an efficient allocation of resources to society's R&D effort, but is clearly counter to efficient dissemination. Referring to Table 3-11 we can see that if both appropriability and common pool effects are small then one should stimulate private R&D efforts. But if one does this by increasing appropriability (e.g., by setting up a patent system), then one is moved into the situation in Cell 2 of Table 3-11. But then dissemination should be stimulated, thereby moving one back to Cell 1. Another problem, hinted at in Note 16, is that the relevant policy can change as a technology develops and an industry matures. Difficulties arise when trying to alter policies which were once appropriate but are no longer so. These types of tensions have been a primary motivation for the search for methods and social policies that can improve on the performance of the market; but all such policies have been compromises at best. We examine some in the next section.

TABLE 3-11. Is There Market Failure in R&D?

	Low Appropriability	High Appropriability
	1	2
Common Pool Effect Small	R&D too low Dissemination OK	R&D may be high or low Dissemination too slow
	3	4
Common Pool Effect Large	R&D may be high or low Dissemination OK	R&D too high Dissemination too slow

## **What Interventions Are Desirable to Correct Market Failure?**

For ease of exposition and to focus discussion on principles, I categorize interventions into three basic types. The first type includes subsidies, either direct or indirect, to the private sector for R&D activities. Included in this category are lower capital costs (such as subsidized interest rates), tax incentives (such as accelerated depreciation schedules), entry restrictions, and direct payments (such as a contribution to an industry consortium). The second type is

institutional and includes patents and antitrust legislation dealing with research joint ventures. The third is direct government expenditures on specific R&D. This would include such programs as the NASA Advanced Communications Technology Satellite (ACTS) and mobile satellite communications.

In evaluating the arguments for intervention to correct market failure it is important to keep two facts clearly in mind. First, while it is often true that the interests of the industry and the interests of society coincide, we have noted cases in which they diverge in exactly opposite directions. Second, the fact that there is market failure does not mean that an independent, unbiased, outside observer can measure the extent of that failure and the size of the appropriate correction, prior to the discovery, development, and demonstration of the innovation, without asking the interested parties for information they have an incentive to withhold or distort. Both facts are important to the correct filtering of all qualitative and quantitative arguments for market intervention.

#### Direct Support

If it were possible for an independent analyst to know and measure everything necessary to evaluate market failure [20], then it would be possible to construct a public policy which ensured the efficient allocation of resources to the R&D process. In particular, a combination of subsidies for R&D costs to all firms in the industry, a prize for the winner, and a limit on entry into the industry would expand the resources devoted to R&D if that were desired. Taxes, or reduced credits, on R&D would cause a contraction if that were desired instead. To encourage the rapid dissemination of an innovation whose costs of adoption are less than the social benefits to be obtained, one can use a combination of a public announcement of the details of the discovery, production subsidies for adoption, and antitrust regulation to enforce competitive pricing. The opposite policies will retard dissemination of any innovation whose adoption costs outweigh its benefits. Of course, if one knew enough to implement such a policy accurately then one would know enough to calculate exactly what the resource allocation should be and simply implement it by fiat. But no one can know enough. Use of these policies, then, requires guessing, based on as much objective evidence as possible, whether the private marketplace for R&D has overspent or underspent. In those cases where the facts are obvious (Cells 1 and 4 in Table 3-11), some direct support is justified, although the exact amount required will be indeterminate. In those cases in which the facts are not sufficient to determine whether action is justified, it may be best to simply do nothing. A more activist alternative is the design and development of other, more indirect, solutions which elicit the information required in an incentive-compatible manner.

#### Institutional Solutions

Because of the inability to objectively and accurately estimate the externalities in the private markets for future innovations, less direct methods to correct market failure have been used. I refer to these as institutional solutions since they involve changing the rules of the

game. Rather than trying to choose a particular outcome, this approach allows the particular situation to interact with the institution to determine the result, which means that the policy maker does not need to know or measure benefits or costs to affect the end allocation of resources to R&D. Two institutions have been commonly suggested: patents and research joint ventures. The former establishes property rights over an innovation, which increases the ability of the innovator to appropriate the benefits and reduces the rate of dissemination. The longer the patent life, the more pronounced these effects. Much effort has gone into trying to calculate the optimal patent life. It should be obvious that the answer depends on the particular parameters of the industry at issue and that again we are confronted with the lack of accurate data. Further, patents are clearly a compromise, a second-best solution to the problem.

The other institutional solution that has been suggested is a revision in the antitrust laws to allow research joint ventures (RJVs). Recent analyses of this form of R&D management suggest that, as one should expect, they are a mixed blessing [21]. To see the intuition behind this remark, let us consider two cases. First, suppose the value of the innovation is the same to the RJV as it would be to an individual winner (referred to as the case of winner-take-all). This would occur if appropriability were high. In this case, RJVs tend to restrict both the development and dissemination of the innovation, relative to what would occur in the absence of the RJV. Expenditures on R&D will be smaller (since RJVs avoid the common pool externality) and dissemination slower (in an attempt to capture more profits for the RJV) than when research is done by independent research units. For the second case, suppose the value of the innovation is larger to the RJV than to an individual winner. This would occur if individual firms would find it difficult to appropriate the benefits of an innovation if other firms in the industry can quickly discover and adopt it also. In this case, RJVs will tend to increase the R&D effort by raising appropriability, but the reduction in the common pool effect will counteract this effect. The RJV may help overcome market failure in the second case, but it is not at all certain. Taking both cases together, RJVs raise appropriability and lower the common pool effect. On net, the effect on R&D is best when there is low appropriability and worst when there is high appropriability. The effect of the RJV on dissemination is likely to be bad (slow it down) in all cases.

#### Government R&D

Little research has been done on the appropriate use of government funded and managed research as an effective way to correct for market failure in R&D, but it is possible to apply the principles we have discussed. Unless the level of government effort in this area is so extensive as to be totally inefficient, the private sector will still find it in its interest to pursue its own programs (perhaps at a reduced level) and the common pool problem will still exist. Publicly managed R&D will not displace all private R&D, and total R&D will still be larger than is efficient unless, because of nonappropriability problems, the private sector would severely underallocate resources in the absence of government support [22].

Dissemination will be better if the government is the winner in the R&D effort, as long as it does not try to profit from the licensing. But subsidized efforts to encourage adoption of the government innovation can cause the private sector to postpone further investment in R&D beyond this current innovation, causing a decline in future social benefits, a classic example of an unintended outcome [23]. An example of this was the extensive government encouragement of the adoption of light water reactors for nuclear power, which clearly caused a reduction in research on alternatives in a way that now seems detrimental. Of course, slower adoption can be more efficient from society's point of view if it encourages further explorations of substitute technologies that might be foregone by the private sector. For example, the (probably unconscious) restraint in the adoption of early satellite communications technology involving low- and medium-altitude satellites was in retrospect a good thing since it prevented the waste of resources spent on that development, which would have become obsolete with the development of geostationary facilities [24].

Estimation and measurement problems, including the incentives for both the private and public sector to exaggerate the facts in favor of their own interests, cause the same problems for efficient government R&D efforts as for direct involvement. Unless the case for this type of intervention is obvious, as it is for generic research in emerging industries, it is probable that the appropriate level and type of expenditure will be miscalculated. If it is not obvious that the private sector will seriously underspend on R&D (from a social point of view) then direct R&D by the government is not an appropriate solution for market failure [25].

#### What Interventions Are Desirable to Promote International Industrial Competitiveness[26]

It has become popular in industries at the cutting edge of technology development and manufacture to argue for special consideration and support of R&D because of foreign competition. Such pleas have occasionally been heard from the satellite communications industry even though sales continue to be made to Japan, Europe, and Latin America. There is ample evidence that other countries promote their own industries in this way, and it is widely believed that this works to the disadvantage of U.S. firms and, perhaps, U.S. consumers. In this section we look at the validity of this position and whether or not the existence of foreign competition provides a sufficient rationale for government intervention in the marketplace.

In analyzing this type of intervention it is important to keep in mind that the primary purpose is strategic. That is, the role of government policy is to promote the interest of the U.S. firms in an industry and not the entire world. Because the reasons are strategic, one must carefully consider the reactions of one's competitors in the evaluation of any policy. Concentration on only the first move will be misleading and can leave the analyst proposing a policy that could be worse for U.S. industry than no policy at all.

Strategic policies can be successful if and only if there are profits to be appropriated from innovation [27]. Such policies work by altering the domestic firms' behaviors in ways that they cannot coordinate privately among themselves. Faced with this different behavior, foreign competitors then react. The ultimate equilibrium can leave the domestic firms with higher profits than would occur if no policy were implemented [28].

The first question that must be answered is whether we should pursue a policy that induces an expansion in foreign R&D or a contraction. If appropriability is low then the former can provide increased externalities to domestic consumers in the form of less expensive products and to domestic firms who can take advantage of second-mover benefits. If appropriability is high then the latter provides reduced common pool effects and raises the expected benefits (profits) of domestic R&D efforts. Industry is inclined to argue the latter is most important, so let us examine policies aimed at reducing foreign R&D.

To do so we must anticipate how the other country will react to changes in our R&D effort. We consider two possible responses: (1) they do nothing or (2) they also act strategically. If the other country follows the first response, a laissez-faire policy toward their R&D, their firms can be influenced to lower their R&D efforts by an expansion of our efforts, because of the common pool effect. (An expansion in our effort lowers their expected benefits from their efforts, which lowers the return to their R&D, which causes them to allocate their funds elsewhere.) The expansion in our effort can be encouraged through the adoption of the appropriate government policies. If the other country follows the second policy of strategic reaction, then the policy prescription is more complicated and depends on the relative importance of the common pool effect on their R&D process vis-a-vis their ability to appropriate the benefits of their, and our, R&D. In particular, if the common pool effect is small and appropriability is high then an expansion of our R&D efforts may simply cause them to expand theirs (our expenditure does not diminish their expected returns by much, if they win they get to keep the benefits, and if we win they get little); our policy in this case should be to encourage reductions in our R&D expenditures. If appropriability is low we should expand our R&D. If they expand their R&D, even if they win, we can gain by appropriating the results of their research. If they contract their research we also gain. The appropriate policies for international strategy are summarized in Table 3-12 for the case in which the opponents are strategic [29].

An interesting implication of this analysis, and one that should make policy makers pause, is that the policies that are appropriate to correct market failures are exactly opposite to those appropriate for international strategy. For example, with high appropriability if the fixed costs of research are important then the required policy to correct market failure is to contract R&D to reduce the common pool externality, but the appropriate strategic policy is to expand our R&D effort if we constitute a large fraction of the international R&D effort. Dixit (1986) points out the dilemma most forcefully: "As an important country in the R&D business, we should be significantly concerned about the negative common

pool externality, and therefore vary of promoting our effort level. If we practice total laissez-faire, ... rivals might use strategic commitment ... and benefit at our expense. If we want to seize the strategic initiative for ourselves, the right policy depends on the relative importance of flow and sunk costs of R&D. If flow costs dominate, our strategic incentive is to tax our R&D [30]. If sunk costs dominate, then as a large country we may want to promote our R&D for strategic commitment. But that is just the case when the common pool problem is at its most serious, and corrective motives suggest taxing our R&D." As with the measures designed to correct market failure, the decision to promote or retard depends on quantitative details of the industry.

TABLE 3-12 Summary of International Policies

	Low Appropriability	High Appropriability
	1	2
Common Pool Effect Small	Expand R&D	Contract R&D
	3	4
Common Pool Effect Large	Contract R&D	Expand R&D

In Table 3-13, the tensions between policy correctives for market failure and policy initiatives for international strategy are highlighted for the situation that seems most relevant for the satellite communications industry. Only in one situation is there a clear case, from society's point of view, for government involvement: low appropriability and low common pool effects [31]. Otherwise, the economic case for intervention to promote our interests in international markets does not seem to be very strong, since gains in strategic benefits are counterbalanced by losses due to market failure.

TABLE 3-13 Summary of Market Failure and International Policies  
(Top Policy for Market Failure; Lower Policy for International)

	Low Appropriability	High Appropriability
Common Pool Effect Small	Expand R&D Expand R&D	Expand R&D Contract R&D
Common Pool Effect Large	No Action Contract R&D	Contract R&D Expand R&D



## The Economics of Public Sector R&D

The inefficient allocation of resources to R&D is not always due to market failure. Indeed, there exist public sector policies which lead to increased inefficiencies since government as an active participant can amplify, rather than correct, market failures. When one identifies such government failure, the obvious best solution is to eliminate the policies that are causing the problem. But in some cases those policies exist for reasons other than the promotion of R&D [32] and cannot be easily dismantled. In compensating for government failures in R&D there are, to date, no general principles that can be applied. One must decide on a case-by-case basis whether correction of inefficiencies created by particular government regulations or procedures requires an expansion of R&D allocations or a contraction. Let us look at two examples.

### Regulatory Inefficiencies

If, in the absence of government interference, an industry would be monopolized then society may choose to regulate it to promote social welfare. One unintended aspect of this regulation can be to prevent entry by others into this business. Another is the effect on R&D. A regulated monopolist can appropriate only those benefits that the regulators do not capture by forcing lower prices, and monopolists are not subject to the common pool problem. Therefore, regulation probably leads to an underinvestment in R&D and dissemination by the regulated monopolist. Thus, policies which promote dissemination but still reward the monopolist for R&D are reasonable in this situation. This R&D policy would not only continue to encourage R&D but could also create conditions that might encourage new entrants to the industry (and the possible elimination of the monopoly and the need for inefficient regulation) once that became technologically feasible. The early history of government sponsored R&D in satellite communications can be rationalized on these grounds as an alternative to the monopoly position of AT&T [33].

Another example of the creation of market failure by government regulation can be traced to the way in which the FCC regulates orbital and spectrum allocations. In a very important paper, Macauley (1986) estimates that inefficient spectrum allocations distort input choices (specifically, inputs are 20-27 percent more hardware intensive, heavier, and spectrum saving than is efficient) as well as technical change (the emphasis is 10 percent too high on spectrum saving technologies) [34]. To correct this inefficient resource allocation one would use a policy that either allocated the spectrum more efficiently or emphasized R&D that was oriented toward weight reduction. This would not only increase the first-order efficiency of satellite configurations, it would also have a significant second-order effect on savings in launch allocations [35]. Unfortunately, much of NASA's ACTS program seems to have been oriented in just the wrong direction with its emphasis on the development of spectrum saving technologies [36].

### Government Opportunism

In this section, I consider a justification for government intervention in R&D which arises when the government will be a sole, or major, consumer of the new technology [37]. If the government could act like major private sector consumers and make commitments to future use and payments, or if it could act like small consumers and simply accept the price it faces to use the new technology, there would be no problem since the market could treat the government like any other consumer and could coordinate the early expenditure of R&D resources with a judicious use of futures contracts [38]. But the government is not just another consumer, and it is rarely willing or able to commit to futures contracts. In particular Congress is often opportunistic and willing to breach any contract, whether written or not, if the politics are favorable. For example, it is always quick to react if unanticipated cost savings occur in the production of a product it is buying and will try to renegotiate for a lower price to capture most of the savings for itself. From a myopic point of view this can be rationalized as representing the current interests of their constituents and is usually politically popular. But from a longer term view this opportunism operates against the interests of the public, by discouraging efforts to find cost savings, and leaves society worse off than if Congress were able and willing to commit itself. The reason is simple and can be illustrated with the stylized example which follows.

The private sector is rational and, in making decisions, will anticipate the future reactions of the public sector if those are important to the firm's interests. Suppose, for example, that a firm is weighing two strategies it might adopt in proceeding with a new technology development program. Suppose further that it knows the resultant output from that program cannot be profitable if its products are only sold to private sector firms. The first strategy it is considering involves a low R&D effort with the virtually certain outcome that a version of the technology will be available for the government but at a cost that few in the private sector will be willing to pay to purchase the product. The second strategy involves a high R&D effort with the possible (but not guaranteed) outcome that a low cost version of the technology will be discovered and that goods and/or services derived from it could then be sold at a lower price than under the first strategy but at a higher profit that allows recovery of more than the extra R&D costs. The other possible outcome associated with the high R&D effort is that the same version of the product will be available as in the low R&D strategy. In weighing these two strategies, the most realistic assumption that the firm can make about future government behavior is that, no matter which technology it ends up with, it will be able to sell to the public sector only for a small "reasonable" profit. Given these expectations, the firm calculates that the extra expenditures required to follow the high R&D strategy will not be worth the risk even if successful. The firm therefore chooses the first strategy, and society ends up with a high cost technology that is adopted by few private firms and paid for with government consumption at a high price. Examples of this undesirable outcome abound.

To carry this example further, suppose the firm believes the public sector will commit itself not to be opportunistic and to be willing to allow a higher profit if the firm is successful in discovering a low cost alternative. The firm will now calculate that the higher expected profit makes the higher investment in R&D worth the risk. If the low cost alternative is not found, the outcome is the same as under no commitment. If the low cost alternative is found, the outcome is better for the firm, the government, and taxpayers, even if the firm's profits are higher than "reasonable." The important fact is that if the firm expects and gets public sector restraint, both the public and private sectors can be better off if the low cost alternative occurs since, even if the firm collects "excessive" profits, the cost to the government can be less than in the high cost outcome. Expecting government restraint, the firm will make the R&D investment; expecting no restraint, it won't make the high R&D investment since it has nothing to gain. Therefore, with restraint all are better off [39].

If restraint is better for both producer and government but the political process will not allow it, there is a case for some other form of intervention to rescue the benefits that are lost because of this political failure. One possibility is the development and codification of fairness properties in government contracting [40]. Another possibility is for the government to invest in the R&D itself. Any policy which promotes R&D would also be appropriate. Whatever policy is followed it should reduce the profit margin needed by the firm (in the low cost outcome) so as to provide an incentive to allocate R&D resources to the search for a better technology. Of course, this will be more costly to the public than if a commitment could be made to allow the firms larger profit margins on their sales to the public sector when their costs are lower than anticipated, but it may be the best that can be done subject to the noneconomic incentives of the political process.

### Summary and Recommendations

In this section I apply the principles and findings of the previous sections to draw out conclusions and recommendations about the appropriate future role of government in the satellite communications industry. To do so one must first specify the relevant characteristics of that industry today and in the near future. I will leave it to others to collect and verify the relevant data and will simply sketch some obvious observations. The private sector of the satellite communications industry consists of a number of well established firms including (not exclusively) GTE, Hughes, GE-RCA, and TRW. While international competition does exist, the U.S. firms, NASA, and DOD are a major fraction of the total worldwide R&D effort in this field. With virtually no information at all, although it is undoubtedly discoverable, I am willing to assume that flow costs, and not sunk costs, are a major part of the R&D expenditures. As indicated in the text I remain agnostic with respect to externalities and appropriability since the self-interest of the reporting parties casts doubt on the quality of the data.

Government-industry interactions have been and continue to be an important fact of life in the communications satellite industry. Major inputs, such as spectrum and orbital position, are allocated by the government in a political context and, therefore, in a way that results in inefficiencies in satellite communications systems designs and utilization. The government has been a direct participant in R&D. Further, it seems likely that government will be the major consumer of the newer developing technology in the mobile satellite communications area.

### Recommendations

#### Interventions Directed to the Industry

As a major country in international R&D in this and other areas we should expect the negative common pool externality to be important and should therefore be reluctant to expand our aggregate (the combination of private plus public) effort level in R&D beyond that which the market would choose. This conclusion is reinforced by the fact that this is a well established industry in which the current incumbents seem to have a significant advantage over potential entrants. Thus, to correct market failure, the appropriate policy seems to lean more toward retarding research and development efforts rather than subsidizing or expanding them.

If we want to seize the strategic initiative in the international sphere, our appropriate strategy depends on the importance of flow costs in R&D. If, as I have assumed, they are a large fraction of the total R&D costs then the strategic initiative is to further inhibit R&D in this area. If fixed costs are more important then, since we are a large country in this area, strategic considerations suggest expansion of our R&D effort. But then the common pool effect is large, which suggests contraction of our R&D effort.

The policy interventions indicated to correct market failure and those indicated to initiate strategic positioning in the international arena seem to offset one another. The economic case for the strong promotion of R&D seems not to be there. Further, on international strategic grounds one must be wary of policies to retard or contract R&D. Therefore, the natural conclusion is to recommend no intervention at all. Sharper empirical estimation of the appropriate parameters might be able to overturn this neutral recommendation if the data are trustworthy, but the maintained hypothesis must be that no intervention is needed.

#### Government R&D

The finding that direct support to the industry appears unwarranted does not mean that no R&D should be carried out by the government or that no R&D policy should be pursued. Our analysis has indicated two areas in which government intervention appears justified.

*Regulation Failure.* We have seen that the inefficient regulation by the FCC of the spectrum has caused a distortion in the pattern of R&D in commercial satellite communications. In particular, it has caused too

much effort to be devoted to spectrum conserving technologies and not enough effort to be devoted to hardware and weight reducing activities. Further, NASA's ACTS program has emphasized and not corrected this misallocation of R&D resources. Assuming that the FCC procedures are not changed, it might be appropriate for the government to either fund R&D hardware-reducing technologies or to provide selective credits to private activities in this direction [41].

*Government Opportunism.* For those enterprises in which the government will be a major or sole consumer of the technology, such as in the Deep Space Network (DSN) or in rural applications of mobile satellite communications, it is appropriate for it to contribute to R&D efforts to avoid the economic problems created by the existence of political opportunism and the inability to commit to socially optimal futures contracts.

Having decided that the government should encourage and finance R&D, it is not at all obvious that the government needs to actually do the research; perhaps it would be better simply to sponsor it in the private sector. The economic arguments we have seen do not address this choice. There is, however, historical experience which suggests some conclusions [42]. In particular, government R&D and government promotion of technology for commercial purposes frequently fails. Both the supersonic transport (SST) and the Space Transportation System (STS) were engineering successes and economic failures. The public sector seems to be capable of achieving well-specified, targeted, noneconomic goals such as landing a man on the moon. It seems to be less successful at programs which pursue economic goals, perhaps because it is unwilling or unable to end projects that are no longer promising, or because the ultimate users' interests in those projects are not well represented in the design process, or because it has inherent difficulty in effecting unit cost reductions in the goods and services it is expected to produce [43].

### **New Institutions**

I have argued that estimation and measurements that evaluate the costs and benefits of future R&D are either nonexistent or highly suspect. Ways must be found to arrive at a more balanced picture of the situation. Typically those who provide the hardware, the designers and builders, make the case: the users are not yet organized [44]. In the private sector this imbalance is corrected by the bottom line, the ultimate requirement to not lose money, which means that the (expected) users' needs must be anticipated. In the public sector there is no such ultimate accounting, and, therefore, the political process can be myopic and designer oriented without penalty [45]. This suggests that the appropriate policy strategy might be the elimination of cost-benefit analysis as the policy vehicle and the development of new institutions to decide when and at what level the public sector should involve itself in R&D. If a very small part of the public expenditure on hardware R&D were spent instead on organization R&D, the ultimate social impact and benefits from the hardware could be significantly increased.

In the area of spectrum regulation, it is obvious to most who have carefully considered it that new methods for spectrum allocations are long overdue. Many economists have argued for an assignment of property rights which would allow markets to be the institution that rations use[46] Others, including myself, would favor a more custom design approach which would accept the fact that the information required to make good decisions is dispersed (and not in the hands of the regulators) and that any implementation and allocation must be done subject to the constraints imposed by the incentives of the potential users to manipulate the information. With the results of recent research in economics, such design of institutions is now a feasible enterprise[47].

For government R&D entered into to minimize the problems of commitment and in which the government will not be the only consumer, both industry and Congress must be willing to develop new institutions to deal with the facts of joint ventures. We already have examples of arrangements that don't work. The Clinch River breeder reactor project split industry and government contributions roughly 50-50 initially. However, no further private contributions were required, and, as a result, the utilities had no incentive to control costs or to stop the project if it became inefficient to continue. The result of that arrangement was absolutely predictable. The optimal sharing rules for long-term high technology joint private-public ventures need to be investigated. They must include the conditions under which R&D is to be abandoned as well as conditions for cost and benefit sharing. It is highly likely that some custom designing of institutional rules will be indicated.

#### Final Thoughts

It is important for both the public and private sectors to remember that, although the first-order effect of government participation and help can be positive and desirable, by the time all the higher order effects work themselves out (including industry's responses, assorted rent-seeking activities [48], and foreign responses) both the industry and the public can be worse off than if there were no intervention. Apparently bad policies can have desirable consequences. A recent example of this is the contraction of the U.S. steel industry due to the decision of the public sector not to subsidize the domestic firms' struggle against foreign competition. Although this appeared to be a bad policy, since heavy unemployment occurred, the industry is now leaner and is actually selling products to Japan and others. It is highly probable that the short-term costs of unemployment and reallocation of resources will be more than covered by the long-term gains. On the other hand, apparently good policies can have undesirable consequences. Examples of this can be easily found. For instance, the communications satellite industry is now paying a high price, in delayed launches and redesign costs, for the launch subsidies it was initially satisfied to receive on the STS Shuttle.

Commercially successful technology must be efficiently developed and economically sound. The potential benefits of an application are of no use to anyone if they are not able to be utilized [49]. As is most forcefully argued in Rose (1986, p.61), "Perhaps the most important lesson

from the rich histories of technology development is that the government's frequent success in mobilizing resources to make major technological advances does not imply an aptitude for the development of commercially successful technologies. Technology may be forced, but economically successful technologies are more elusive." Economic success requires both that the technology works, that it is needed, and that it can be offered at a price that will be acceptable to buyers, yet high enough to yield a profit [50]. The public sector has demonstrated an ability to make technology work, but it is the private sector that has demonstrated an ability to find the technology that is desired by users in the general public. We should rely on our strengths and provide minimal interference in the marketplace. For those times for which interference is necessary, we must design better institutions so that the interventions can be more efficiently managed. Research and development of organizations appropriate for the management of the inevitable private-public partnership in R&D of leading-edge technologies is as important as is the R&D itself if society is to maximize its benefits.

#### NOTES

- [1] I have had very helpful conversations with William Gates, David Porter, and William Weber of the Jet Propulsion Laboratory, with Thomas F. Rogers of the Sophron Foundation, and with Jennifer Reinganum of Caltech. They have provided insights, encouragement, and corrections. They are not responsible for any remaining errors.
- [2] I will adopt the definition that R&D begins with basic research but proceeds beyond to the implementation of a demonstration project (prototype).
- [3] A socially desired allocation is an economically efficient one; that is, one in which no one can be made better off without making anyone else worse off. If one allocation is more efficient than another, then in moving to the first allocation all the winners can compensate all the losers and still be better off. There is, of course, no guarantee that the compensation will actually be paid. The allocation that is desirable from the industry point of view is the one that maximizes industry profits. This can be different from the socially desired allocation, especially if the industry possesses some market power.
- [4] Much of this material can be found in more detail in Kamien and Schwartz (1980) and Reinganum (1986). The interested reader is strongly encouraged to peruse those references.
- [5] Marginal benefit is the extra benefit derived from increasing an activity by one unit. Technically, it is the (partial) derivative of benefits with respect to the level of an activity. Marginal costs are similarly defined.

- [6] All probabilities must sum to 1, the size of this "common pool."
- [7] Let  $p_i(x_i, x_{-i})$  be the probability that  $i$  is first when  $i$ 's effort is  $x_i$  and when the other's efforts are  $x_{-i}$ . Let  $B^i(x_i)$  be the benefit  $i$  receives for a level of effort  $x_i$  if  $i$  is the winner. Then the impact of  $j$  on other firms is  $z(x_j) = \sum_{i \neq j} [\partial p^i(x) / \partial x_j] B^i(x_i)$ .
- [8] A good example of the importance of predicting one's rivals' reactions can be found in the competition between the Shuttle and Ariane.
- [9] This section relies heavily on the excellent survey of Reinganum (1986).
- [10] As indicated earlier, the extent of overspending can be sizable although very difficult to measure with traditional methods.
- [11] This is a classic example of a situation in which the interests of the industry and the interests of society can be opposed.
- [12] Economists call these inframarginal firms. These are firms who garner economic rents, or opportunity profits, since they are more efficient than potential entrants. Two reasons for such an advantage might be learning-by-doing effects and previous innovative successes. There are others.
- [13] This effect is countered by the fact that an established firm with a large market share, in an effort to prolong its capture of the flow of benefits from past innovative success, will invest less and adopt slower than potential entrants who have nothing to lose. This is another example of the countervailing forces that seem to haunt any attempt at a straightforward economic analysis of R&D.
- [14] For a more complete and careful exposition of the reasons, the interested reader should consult Doherty (1987).
- [15] Using the high-risk argument, a supplicant can, reasonably honestly, simultaneously claim massive potential benefits from a project and an inability to justify privately investing in the project. The former is a statement about the upper end of the support of the probability distribution of likely rewards (the maximum possible return from the best case scenario); the latter is a statement about the expected value of the returns and the lower end of the support of the probability distribution (the worst case analysis). Decisions should be made not on the basis of the extremes of the support but on the basis of the total probability distribution of potential rewards; the public sector should avoid being stampeded by incomplete evidence.
- [16] The latter is required since, as was pointed out to me by William Gates, the relative importance of the common pool problem versus nonappropriability changes as technology progresses through the R&D



process. Nonappropriability decreases in importance (as research results become more firm specific), and the common pool effect increases (as generic information becomes more available).

- [17] See below under "What Interventions Are Desirable to Correct Market Failures?"
- [18] Kamien and Tauman (1984) have models which explain this finding. The intuition is fairly straightforward. Each firm will pay more for the license than its own cost savings in order to prevent other competitors from getting their own cost savings. This does not, however, mean that the innovator can collect more than the social value.
- [19] This is another example in which the industry's interests and society's interests may be at odds. See also Note 3.
- [20] This is the standard, but false, assumption behind many cost-benefit studies.
- [21] See Reinganum (1986, pp.4-5 and Section 4) for a fuller analysis of these findings.
- [22] Of course the private sector can always claim that it will do no R&D (the pressures to gather instant profits are simply too great) and that the government better step in. It should be easy to see that this is a bargaining position and not a verifiable statement about the amount of R&D that would be done in the absence of government R&D efforts.
- [23] See Gallini (1984), where it is shown how a private firm may profitably encourage adoption of its own innovation to forestall other firms' efforts on further technical change.
- [24] Rose (1986) contains a fuller description and analysis of these and other examples of government efforts in R&D in aviation, nuclear power, and communications.
- [25] Below, under "The Economics of Public Sector R&D," we will see a completely different type of market failure for which government-funded R&D, and in particular demonstration projects, may be a sensible solution.
- [26] This section relies heavily on the provocative analysis by Dixit (1986).
- [27] This implies that the international industry must be imperfectly competitive so that there are profits to compete for. If the industry were perfectly competitive, then free entry would eliminate any potential profits, and interference in the market to promote industry would be self-defeating by leaving consumers in the United States worse off and producers no better off.

- [28] Of course consumers can be left worse off as a result of this strategic intervention.
- [29] If domestic R&D is a small part of world R&D then the strategies in Cells 3 and 4 would be reversed.
- [30] By "taxing our R&D" Dixit means following policies which will reduce U.S. industry expenditures on research and development. Such policies could include a reduction of tax credits, a slowing down of depreciation schedules, and a tax of, say, 10 percent of R&D expenditures.
- [31] In this situation expansion of our R&D effort expands foreign R&D also (because of the low common pool effect), but society gains because of the low appropriability. Even if our competitors win the R&D race, U.S. society can still reap many of the benefits.
- [32] Examples include provision for the national defense and the natural behavior of bureaucrats protecting their turf.
- [33] See Rose (1986, pp.46-47) for a fuller exposition of this view.
- [34] These estimates are apparently strengthened when the introduction of fiber-optics technology is also considered.
- [35] The heavier configurations lead to an inefficient overuse of the Space Transportation Systems (STS) as opposed to expendable launch vehicles (ELVs) and an overstated need for more heavy-lift vehicles. See Macauley (1986) p.16.
- [36] Macauley estimates that the marginal cost of that program is 8-14 times larger than her estimates of the marginal benefit of further spectrum saving.
- [37] The mobile satellite communications R&D program may be an example of this since, in rural areas, the public sector may be the major consumer and the potential profits from the private sector use may not be enough more than those profits generated by alternative technologies (such as cellular) to encourage private sector R&D.
- [38] There is an economics literature on this problem identified by Scitovsky (1954). The article by Heller and Starrett (1976, especially pp.16-19) contains a good discussion and includes the role of futures markets. For our example, the futures contract would be a commitment by the government to accept delivery from the private sector at some time in the future for a specific price to be paid (either now or then) no matter what contingencies and political events might have transpired. Of course the private sector also commits to fulfilling the terms of the contract.
- [39] This is a classic example of the mischief that can be caused by thinking of the economy as a zero-sum situation. If a dollar is transferred from the private sector, in the form of reduced profits,

to the public sector, in the form of a lower product price, by a well-meaning bureaucrat the net result is not necessarily zero but can create a loss for the economy. The first-order effect is zero but the second-order effects are negative and significant. Engineers and others sometimes forget that the distribution of the pie may affect its size.

- [40] See Baron and Besanko (1986) for a good discussion of this approach in a regulatory framework.
- [41] Another strategy which could cause private R&D effort to move in this direction is the correct pricing of STS and ELVs to reflect the true opportunity cost of using these scarce resources. [It is possible, if launches are to be available from Russian ELVs for only \$30 million, that I have exaggerated the extent to which weight savings are socially desirable. On the other hand, I do not think that \$30 million is the true opportunity cost of providing those launches.
- [42] At this point I draw on the material in Rose (1986).
- [43] In Ledyard (1986), I argue that there are fundamental differences between the organizational approaches taken by engineers to management, the organizational approaches proposed by economists, and those approaches that would be best. The traditional approach of engineers, based on project management techniques, is well-suited to programs with specific goals and flexible budgets. It is not well-suited to management if there is to be a market test. Most government R&D programs are managed by engineers.
- [44] Users will be around if this is a mature industry but then the case for government support is less obvious.
- [45] For a more complete exposition of the implications of the myopia of the political process for public sector R&D see Cohen and Noll (1987).
- [46] A classic application of this approach that led to a revision in the procedures by which airline landing slots are allocated can be found in Grether, Issac, and Plott (1981) and the various documents referenced there.
- [47] An example, and description, of this new discipline of mechanism design can be found in Banks, Ledyard, and Porter (1987).
- [48] Rent-seeking involves the (socially) nonproductive use of resources to attract a private benefit. An example is the use of corporate manpower to lobby for subsidies to an industry or for passage of a law preventing entry to an industry by foreign firms. A straight-forward economic calculation yields the observation that, if a subsidy may be available, then each firm will exert rent-seeking effort to acquire that subsidy up to the point at which the expected benefit of that subsidy is less than the costs of the effort. This

individual calculation can lead to a common pool problem with the totality of resources devoted to rent-seeking being greater than the net benefits being sought. From an economic point of view everyone would be better off if the temptation were removed. But that requires abstinence on the part of Congress which is composed of people who seek reelection and, therefore, who will rationally provide subsidies to constituents.

- [49] The most glaring recent example of this phenomenon is the Space Shuttle. The benefits promised relied on the attainment of a launch rate which never occurred. (Trying to attain that unrealistic rate probably contributed to the events surrounding the Challenger disaster.) Further, users' needs were neither contracted for nor integrated into the design stage. Users were forced to adapt to the designers' presumptions. Not only did the commercial sector, including the satellite communications industry, get less than it was promised, but NASA's own basic science research program was also harmed. (This is another example of the failure of politically-molded organizations to be sensitive to users' needs at the R&D stage.)
- [50] It is not necessary that the products or services from a new technology pass a market test to be considered socially desirable, but the burden of proof must be on those which don't. National defense is an example for which, because of the public good nature of the product (one's consumption of the good does not reduce the supply available to others), a market test is inappropriate.

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