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ECONOMIC ANALYSIS OF AERONAUTICAL RESEARCH AND TECHNOLOGY

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PREFACE

This study was conducted under NASA Project Number 10-29496 in the period May 1982 through August 1982. The principal investigator for the contract was Aaron J. Gellman. The principal authors of this study were Jerome T. Bentley, Frank J. Berardino, and Frederick G. Tiffany.

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I. EXECUTIVE SUMMARY

The purpose of this study is to examine the appropriateness of government intervention in the civilian market for aeronautics research and technology (R&T). The study concentrates on examining the economic rationale for government intervention; other public policy issues, perhaps of equal importance, are not fully addressed. The conclusion is that the institutional role played by NASA in civilian aeronautics R&T markets is economically justified. This conclusion is based upon five major findings:

(1) Firms in the aeronautics industry do not have sufficient incentives to conduct socially optimal levels of R&T--that is, private firms will tend to underinvest in these activities. Often it is the case that while industry returns (and consumer benefits) from particular projects may warrant investment from a social point of view, no single firm can capture returns sufficient to induce it to invest in one or more of these projects.

(2) Underinvestment by the private sector is most likely to occur for projects leading to neutral technologies--primarily discipline research, infratechnologies, and certain types of applied research-- because these are the farthest removed from commercial application, and because returns to these projects are least likely to be appropriable by a single firm.

(3) The government should intervene to ensure that those R&T projects are conducted which lead to neutral technologies that otherwise would not be developed because of the problem of underinvestment.

(4) It is particularly appropriate that the government intervene in the aeronautics R&T market because aeronautics output depends upon both high research intensity and a wide technology base. Like other high technology industries, aeronautics R&T represents a significant percentage of the value of final output. What distinguishes aeronautics is its dependence on inputs from so many other high technology industries. The high wide technology base of the aeronautics industry magnifies the possibility of underinvestment in relevant R&T. As a result, government intervention should include R&T efforts which cut across industry boundaries.

(5) In evaluating various policy options, the key consideration is whether the problem of appropriability in aeronautics R&T is addressed. Other factors for consideration include: scale economies in conducting aeronautics R&T, military spillovers, the structure of the aeronautics industry, and the problems of risk and the payback period. In addition to considering NASA's current institutional role, other policy options examined were: a free market, approach, a subsidy/tax credit approach, user charges, and a private R&T conglomerate. While each of these options holds some promise, the current NASA institutional role appears to be the best feasible solution.

The remainder of this report is organized into five sections. In Section II, a general economic model which demonstrates how firms tend to underinvest in R&T activities is developed. It is shown that this tendency toward private underinvestment is due, in part, to the nature of technology and how it is produced. In the third section, the model is applied to the aeronautics industry. The fourth section develops an analysis of the research intensity and the width of the technology bases of high-technology industries in the United States. Section V is a review of the various policy options in light of the research findings.

The final section of the report summarizes the findings and also examines the issue of whether (and in what ways) aeronautics, and appropriate public policies concerning aeronautics, are unique.

II. AN ECONOMIC MODEL OF THE MARKET FOR R&T

An economic model of the market for investments in R&T is developed in this section. It focuses on the incentives that private firms have to invest in R&T projects. The primary purpose of the model is to provide a framework within which imperfections in the R&T market can be detected and assessed.

This model shows that imperfections generally exist in R&T markets. As a result, individual private firms lack economic incentives to invest in some R&T projects that are in the best interests of society. Because both the model and the analysis are generally applicable, so is the conclusion. The applicability of the model and the analysis to the aeronautics industry in particular is described in the next section of this report.

The section begins with a general discussion of the nature of technology. This discussion provides a foundation for the economic analysis that follows. Next, some key technical concepts are described for the convenience of the reader. Immediately following this discussion, the formal economic model is developed. Potential impacts of market structure are then addressed. Finally, the conclusions are summarized.

The Nature of Technology

Prior to a formal discussion of the nature of the market for R&T in civil aeronautics, it is both convenient and appropriate to discuss the nature of technology. While several classifications of technology are possible, one that will facilitate the analysis that follows is selected. Specifically, the discussion focuses on differences in the ability of firms to capture or "appropriate" returns to investments in various types of R&T. The degree to which returns on investments in R&T can be appropriated by individual private firms is crucial to the economic analysis that follows. If private firms are unable to capture all benefits derived from R&T projects, the industry will, in general, underinvest in technology.[1]

Neutral vs. Proprietary Technology

The most general distinction regarding an industry's technology base is between "neutral" and "proprietary" technology. Neutral technology represents those elements of an industry's technology base that are neutral with respect to individual firms' proprietary interests. It is difficult, and sometimes impossible, for individual firms

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[1]For a detailed discussion of classifications of elements of industrial technology bases, see Gregory Tassey, "Infratechnologies and the Role of Government," Forthcoming in Technological Forecasting and Social Change. The discussion that follows is partially based on this work.

to earn private rates of return on these types of R&T activities sufficient to cover the opportunity cost of their investment. This problem occurs either because large investments in facilities are necessary to undertake such R&T activities or because the benefits of R&T flow to other concerns, either in the same industry or other industries--i.e., neutral technology serves as a common base for several different firms.

Elements of the technology base that may be considered proprietary include those activities for which individual firms are able to capture a return sufficient to justify investing in an R&T project. Those activities that are typically referred to as being developmental--e.g., the development of a specific aircraft for commercial use--could be regarded as proprietary in nature.

Even though this classification is convenient for economic analysis, it should be stressed that virtually no R&T (or R&D) activity can be classified as purely neutral or purely proprietary. Even research conducted at the most basic or generic level may hold the promise of some commercial value to a single firm. However, it is likely that the single innovating firm will capture only a fraction of the total derived benefits from discipline or generic research. On the other hand, some research activities directed toward the production of a specific commercial product contain neutral elements to the extent that other firms may capture some benefits through imitation. Nonetheless, this distinction is a convenient framework within which the economic anlaysis may be described.

A Further Classification of the Technology Base

The technology base of any industry is typically composed of several elements. A convenient categorization of these elements is as follows:

- o Infratechnology
- o Discipline research
- o Applied research
- o Development

Of these four elements, infratechnology and discipline research are the most neutral. Applied research may be characterized as being partially neutral and partially proprietary. Development is typically viewed as being proprietary, although, as noted previously, it may be partially neutral to the extent that it is borrowed by other firms.

Infratechnology includes both methods and basic data (e.g., test methods, computational procedures, and materials characteristics) for conducting or using other types of R&T. Perhaps the critical distinction between infratechnology and discipline research is that the former may have direct applications to several industries. This type of technology can serve as a common base for an entire industry (or several industries) and, therefore, complete appropriation by any single firm is difficult.[2]

Discipline research is conducted at the most basic or generic level of the discipline. Although this type of research represents a base from which proprietary applications are ultimately derived, it is not undertaken with any specific application in mind. As such, it too represents a common base for an entire industry and thus is difficult to appropriate. The results of discipline research may also be used by other industries, although such use is usually indirect.

Unlike discipline research, applied research is directed toward the solution of a specific problem (e.g., fuel efficiency). Nonetheless, applied research is not undertaken with a specific commercial product in mind (e.g., applied research may focus on fuel efficiency but not on an engine designed for a specific aircraft). This type of research may be partially appropriable in that it may be adopted eventually in the design and development

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[2]The term "infratechnology" should not be confused with more restrictive meanings--i.e., basic and applied knowledge for a specific industry. As used here, infratechnology includes elements which may serve several industries. See, Tassey, p. 5.

of a specific product. However, to the extent that discoveries in applied research may be learned by others or copied when applied to a specific product, the full benefits may not be capturable by the innovating firm.

Development represents the element of an industry's technology base that is closest to commercial exploitation. It is the activity of combining the component parts of a product and requires the three aforementioned elements of the technology base as inputs. As such, it is typically the most appropriable of the elements of the technology base, but, as previously mentioned, it may not be totally appropriable by any single firm.

Private Returns to R&T

Neutral technology provides a common base for all firms in an industry. These elements of R&T were referred to as neutral because it is difficult for private firms to realize rates of return sufficient to justify initial investment costs on an economic basis. There are several reasons for this:

- Knowledge is expensive to produce, but cheap to reproduce. A firm or institution that creates knowledge must incur sometimes substantial expenses, but others may reproduce, imitate, or learn the knowledge at relatively low cost.

- Use of the patent system to appropriate returns to R&T is difficult and costly in the aeronautical industry because technological advances often depend upon knowledge of specific processes--e.g., supersonic flow in aeronautics--instead of some mechanical or electronic device.
- While knowledge that flows from R&T efforts is a commodity in the sense that it embodies some value, it is unique because it may be reused, both by the innovating party and by those who learn it, without diminishing its value in production. This means that apart from the relatively minor expense and low risk of learning new knowledge, it is as valuable to the imitator as to the innovator, at least in terms of its value in production.[3]
- It is especially difficult for the firm conducting R&T to capture returns on infratechnology since it can be applied directly to other industries. Even if the research firm were the only firm in

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[3]Some R&T may lead to unique or highly desirable innovations that give a firm a substantial headstart in a new technology. In these cases, the demand for the firm's products may be enhanced and its production costs lowered. It should be stressed, however, that the headstart enables the innovating firm to appropriate only part of the benefits derived from its R&T efforts; once the knowledge is learned and adopted by imitators, some benefits flow to other firms.

its industry (a monopoly) some returns on the investment would spill over into other industries and may not be capturable. In deciding the appropriate level of internally financed R&T, a firm will consider only those returns that are appropriable. In short, the private return on investments in infratechnology generally will be less than the total social returns, resulting in an underinvestment in R&T. Of course, the same can be true for both discipline and applied research, which can be borrowed indirectly by other industries.[4]

o The existence of significant scale economies may also make it difficult for individual firms to realize sufficient private return on neutral R&T. It is often the case that R&T requires large capital-intensive facilities--e.g., wind tunnels, foundries, or facilities for analyzing metals and materials. The returns that a single private firm can capture are often not sufficient to justify extensive investments in these capital-intensive facilities.

[4]Conglomerates can sometimes appropriate more of the benefits of infratechnologies than can firms involved in a single industry.

With the exception of the last comment on scale economies, each of the points listed above has a common characteristic. They all describe the difficulties that confront individual firms in appropriating the full benefits derived from R&T efforts.

<u>Priorities of Private Firms for Investments in Technology</u>

From the foregoing discussions, those types of research-related activities that a private firm will tend to undertake can be listed in descending order of preference:

- o Development.
- o Applied Research.
- o Discipline Research.
- o Infratechnology.

Development-related activities are those for which the private firm is most likely to be able to capture the bulk of the resulting benefits, while discipline research and infratechnology are least appropriable by private firms. In other words, development activities are devoted to the production of proprietary technology; discipline research and infratechnology fall at the other end of the appropriability spectrum in that they are elements of a common technology base for several industries--i.e., neutral technology.

Key Economic Concepts

Several key economic concepts are important to the analysis that follows. These concepts are:

- Market imperfections,
- Consequences of underinvestment,
- Externalities,
- Technology and the production function.

Each of these is discussed below.

Market Imperfections

In general, a market imperfection exists when a firm fails to produce an extra unit of a good or service that would leave at least one member of society better-off and no member of society worse-off. This is best illustrated by example.

Suppose that a firm in the aeronautics industry identifies an R&T project that will produce consumer benefits of $10 million. Suppose further that the cost of the R&T effort is only $8 million.[5] If the market operates properly, this R&T project will be undertaken and the firm and consumers will split the $2 million net benefit. For

[5] The $10 million consumer benefit is determined by buyers' "willingness to pay" and, hence, reflects their valuation of alternative goods and services that could be purchased. Likewise, the $8 million cost reflects the seller's "willingness to sell" in that it includes, as a cost, a normal rate of return on resources employed--i.e., the cost includes the "opportunity cost" of not using resources for the next-best alternative activity.

example, if the firm is able to sell R&T results for $9 million, it will realize "economic" profits[6] of $1 million. The consumers also will be better-off by $1 million (i.e., the benefits of the project summed to $10 million while the total price was only $9 million). In this case, both the firm or, more properly, its owners, and consumers are better-off, and no member of society is worse-off.

If, however, a market imperfection exists, the R&T project may not be undertaken and society (both the producer and the consumers) would lose the $2 million net benefit. In general, market failures exist when sellers or firms are unable to capture a sufficient amount of the benefits derived from production to cover their costs. For example, if the firm in the example described above were able to capture only $7 million of the $10 million in benefits by selling their R&T results, they would incur a $1 million loss. There are several reasons why a firm may not be able to capture all (or enough) of the benefits

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[6]That is, profits above the "normal" rate of return on resources is employed.

derived from R&T projects, but the following explanation will suffice for present purposes.

Taking the example described above, suppose that the R&T results must be embodied in a consumer product in order to produce the $10 million benefit. Suppose further that the innovating firm produces the product but is able to capture only $6 million of the $10 million in benefits because the innovation is copied by a rival (i.e., the remaining $4 million in benefits go to the rival firm). In this case, the innovating firm will suffer an economic loss of $2 million ($6 million in captured benefits versus the $8 million R&T cost).

Of course, if the innovating firm anticipates imitation by its rival, the R&T project would never be undertaken in the first place. In this event, a market imperfection would occur; specifically, a project that would have produced $2 million in net benefits would not be undertaken.

Consequences of Underinvestment

The term "underinvestment" will be used on several occasions in the analysis that follows. If a firm (or industry) invests less than the amount that would have been invested in the absence of a market imperfection, then underinvestment occurs. In other words, underinvestment in R&T occurs anytime a project that would have produced total benefits greater than its cost is not undertaken.[7]

The cost of underinvestment is a reduction in the real value of goods and services produced with a given level of scarce resources. Using the example developed earlier, the failure of the firm (or industry) to undertake the $8 million R&T project that would have produced $10 million in benefits would result in a net economic loss of $2 million.

Externalities

An "externality" exists whenever a benefit is produced as a by-product of the consumption or production of a good or service that is not capturable by either the buyer or the seller.[8] Three general classes of externalities can occur:

- Benefits that are not capturable by the producing firm (e.g., the innovating firm) but are capturable by rival firms in the same industry.

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[7]More precisely, investment in R&T should be undertaken up to the point at which marginal total benefits are equal to the marginal opportunity costs of the project.

[8]Economists also recognize "negative" externalities. A negative externality consists of a cost spillover from the consumption or production of a good or service.

- o Benefits that spill over into other industries. These spillovers are not capturable by firms in the industry producing the initial innovation, but may be captured by firms adapting the innovation to serve a need in another industry.
- o Benefits that are not capturable by buyers or sellers in any industry.

An example of the first type of externality is the case where a rival imitates the innovating firm and captures some of the benefits of the R&T project. The automobile industry has used methods from the aeronautics industry to gather data on friction coefficients to develop tires for autos; this serves as an example of the second type of externality (i.e., a spillover to another industry). Finally, suppose an innovation in the aeronautics industry reduces the noise level of the aircraft. Residents living near an airport, who are not airline customers, will benefit.[9] This is an example of the third type of externality.

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[9] Externalities of this type can be "internalized" by noise pollution standards. This illustration still holds, however, if the innovation produces a noise level lower than the standard. The same principle holds if technology produces safety features that exceed the performance of safety regulations.

The important point about externalities for the present analysis is that external benefits are not appropriable by the producing (or innovating) firm. Therefore, the existence of externalities will tend to cause underinvestment by individual private firms.

Technology and the Production Function

The relationship between the quantities of various resources used in making a product (inputs) and the quantity of the product which those resources can produce (output) is referred to as a "production function." The idea behind this term is that for any combination of inputs, the maximum quantity of output which that combination can produce can be determined. A schedule relating combinations of inputs to the maximum level of output which they can produce is a production function.

It is important to stress that two or more different combinations of the inputs may be able to produce the same maximum output. For example, suppose that corn can be grown using land, labor, and shovels (tools are usually referred to as "capital"). It may be that ten bushels of corn is the most that can be grown using one acre of land, twenty man-hours of labor, and two shovels, or by using two acres of land, ten man-hours of labor, and one shovel. In addition, twenty bushels of corn might be the

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maximum amount that two acres of land, twenty man-hours of labor, and two shovels can produce. A schedule presenting this information for all possible combinations of land, labor, and shovels would be a production function for corn.

A standard simplification often made in economic models is to assume that only exhaustible resources (e.g., labor, capital, and land) are factors of production, and that these inputs can produce levels of output conditional on some given state of technology. The analysis in this paper, however, requires the direct inclusion of research and technology as an input. This input can be thought of as the quantity of resources devoted to improving the method of production or the final product itself. For example, if 5,000 man-hours of research time and 5 laboratories are combined with 30,000 man-hours of production labor and 2 airframe assembly lines, the best possible result may be the production of 50 aircraft, while if only 1,000 man-hours of research time are used, the techniques of production which they develop using their 5 laboratories may make it possible for 30,000 man-hours and 2 assembly lines to produce 30 aircraft. With regard to product quality, it may be that with only 1,000 man-hours of research, the 30,000 man-hours and 2 assembly lines can produce 50 aircraft, but that these aircraft are not as fuel-efficient as those which were the result of more research.

An Economic Model of the Market for R&T

A detailed economic model of the market for investment in R&T is described below. The model is developed in several phases. The first two models describe rather simple polar cases, distinguished, in each case, by the ability of firms to capture returns to R&T. While these models are somewhat unrealistic, they are easily understood and provide benchmarks from which a more realistic model may be developed. The third model is referred to as the "partial appropriability model," in which the rather stringent assumptions embedded in the first two models are relaxed. In each of these three models, the focus is on the varying ability of individual firms to appropriate benefits derived from R&T activities. Also, considered are two additional factors which further complicate the analysis: risk, and the duration of the pay-back period.

The Polar Cases

The issue of the appropriability of returns to R&T investment can be considered in terms of two polar cases. The analysis and the conclusions then follow in a relatively straightforward manner. The two polar cases are:

- o The "Common Technology Model"--none of the returns to privately conducted R&T are appropriable (i.e., all privately induced R&T immediately becomes part of the industry's common technology base).

- The "Perfect Secrecy Model"--the benefits of R&T efforts are completely appropriable; i.e., either perfect secrecy in the industry prevails or a perfect and free patent system exists.[10]

Conclusions derived from analysis of each polar case bear striking differences, but both result in market imperfections (underinvestment in R&T), even without considering the classic sources of market imperfections such as externalities and public goods.

In the case of the Common Technology Model--in which none of the benefits of R&T are appropriable--assume that the discoveries derived from R&T efforts are immediately known to all other firms in the industry and are assimilated or understood at zero cost. Under this scenario no single firm will have any incentive to conduct R&T. The firm that conducts the R&T and is responsible for the scientific discovery will bear the full cost of the R&T effort. However, given a competitive, or workably competitive, market structure, all other firms will adopt the new

[10]By a "free" patent system, we mean that patents are obtained instantaneously and at zero cost.

technology if it produces results of commercial value. By the theory of competitive markets, the price of a new or improved product will be driven down to a level just sufficient to cover opportunity costs in production but insufficient to cover the initial costs of producing the R&T.[11] Consequently, any firm that innovates will incur investment costs in producing R&T but none of these costs will be recouped. It is obvious, then, that no firm will have an incentive to conduct R&T activities.[12]

It is interesting to note that if only one firm exists in the industry, a monopoly, underinvestment in technology will not generally occur in the Common Technology Model (at least in terms of the appropriability problem). A monopolist enjoying substantial barriers to entry will not have its technology borrowed or imitated by rivals and thus, will be able to appropriate all capturable benefits flowing to the industry. In this case, however, the classic market imperfections generally attributable to the monopolist will occur (i.e., excessive price, restricted output and inefficiency in production).

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[11] So long as the costs of adopting the R&T can be recovered, all firms will adopt the new technology. The price of the product embodying the technology will not be sufficient to cover the cost of the R&T work because only one firm has experienced those costs. The cost of the initial R&T effort becomes a sunk cost which cannot be recovered, since competition will drive prices to a level equal to the costs of the imitating firms.

[12] This basic result has been derived for a more general and detailed model. See L. E. Ruff, "Research and Technological Progress in a Cournot Economy," Journal of Economic Theory, 1, December 1969, pp. 397-415.

In the second polar case--the Perfect Secrecy Model--it is assumed that innovating firms will be able to appropriate completely all of the benefits from their R&T efforts, by use of either perfect secrecy or the perfect patent system described above. Given the absence of traditional externalities, (i.e., the absence of benefits not capturable by any firm in the industry) standard economic theory does not justify a subsidy under this scenario because private and social returns to R&T will be equal. However, some waste or inefficiency may still result.

The possible outcomes under this scenario are as follows:

- o A monopoly (i.e., a single firm in the industry).
- o Inefficiencies associated with a heterogeneous product market.
- o Waste attributable to unwarranted duplication of R&T activities.

Each of these outcomes is described below in more detail.

One possible outcome of the Perfect Secrecy Model is that the industry will evolve to a monopoly market structure (i.e., only one firm in the industry). This would occur if a single firm produced an innovation so important that competitors in the industry could not survive. The consequences of such an outcome are predicted by economic theory. Monopolies have incentives to charge higher prices and produce lower outputs than those of competitive markets. In short, if the monopolist behaves in its own best interest, the classic market failures attributable to monopoly power will occur; however, the impact of the monopoly market structure on investment in R&T is less clear. [13]

A second possible outcome of the Perfect Secrecy scenario is a heterogeneous product market. Simply put, several firms may produce desirable innovations that are embodied in their products. Since, however, perfect secrecy prevails, the several firms do not incorporate rivals' innovations. The result is that each firm will produce a mediocre product with one or a few particularly desirable traits, but no firm will produce a superior product that would incorporate all innovations in the industry. Such an outcome would be particularly serious in aeronautics, given the high and diverse technological base of the industry.[14]

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[13] A considerable amount of empirical research has been directed towards the question of innovation rates for monopolies relative to more competitive market structures. These are reviewed later in this section.

[14] It would be possible, of course, for firms to cross-license innovations such that all firms would incorporate features developed in the industry-wide R&T pool. As a practical matter, however, this would violate the perfect appropriability assumption in this model because of difficulties in patenting disembodied inventions. This problem is discussed later in this section.

Finally, perfect secrecy is likely to lead to unwarranted and wasteful duplication of research activities.[15] This duplication would be a consequence of decentralized research activities, coupled with the absence of the flow of data within the industry caused by secrecy. Apart from the expense of conducting experiments, the duplication of large scale facilities would also be necessary.

The Partial Appropriability Model

In this section, the assumptions embedded in the two polar cases are relaxed and the more realistic situation is examined in which R&T is partially appropriable--i.e., each firm benefits, to some extent, from the R&T activities of other firms in the industry. It may also be assumed that the productivity of the firm's own R&T efforts is greater than the productivity of R&T borrowed from other firms. Consider, for example, two of many possible firms in an industry, firms A and B. Each one dollar of R&T conducted by Firm A may yield 10 units of productivity to Firm A but only 5 units to Firm B. The argument is symmetrical; that is, Firm B realizes 10 units of productivity from its own R&T projects (per dollar), while Firm A captures 5 units from B as a free rider.

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[15] Not all duplication of research activities should be considered wasteful. We have been told that one firm in the aeronautics industry sometimes assigned two research teams to study a common problem. The teams were given instructions not to communicate for a given period of time in order to promote independent generation of ideas. However, the two teams would eventually pool their resources in an effort to solve the common problem.

There are two additional assumptions:

- o Each firm behaves so as to maximize its own profits.
- o More than one firm exists in the market.

The conclusions that can be drawn from this more complex and more realistic model are much less straightforward than those derived from the polar models described above. It can be shown, however, that the following will result:[16]

- o All firms in the industry will tend to underinvest in R&T.
- o Each of these firms will produce an output that is less than optimum (i.e., less than what they would produce, absent market imperfections) and at costs that are higher than those consistent with maximum efficiency.

Both of these conclusions warrant further discussion.

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[16] The Partial Appropriability Model--and the consequent results--appears in the economic literature in various forms. A detailed exposition can be found in Williams D. Nordhaus, Invention, Growth, and Welfare: A Theoretical Treatment of Technological Change, the M.I.T. Press, Cambridge, MA, 1969, Chapter 3. See also, Karl Shell, "Towards a Theory of Innovative Activity and Capital Accumulation," The American Economic Review, 56, May 1966, pp. 62-68; L. E. Ruff, "Optimal Growth and Technological Progress in a Cournot Economy," Technical Report No. 11, Institute for Mathematical Studies in Social Sciences, Stanford University, 1968; and Zvi Griliches "Issues in Assessing the Contribution of Research and Development to Productivity Growth," The Bell Journal of Economics, 10, Spring 1979, pp. 92-116.

Each firm, following the maximum profit motive, invests in R&T only up to the point where its <u>own</u> profits are maximized. However, the productivity, and hence efficiency, of all other firms in the industry are influenced by this R&T decision. Using our earlier illustration, for example, each one dollar of R&T not undertaken by Firm A reduces Firm B's productivity (as well as the productivity of all other firms in the industry) by 5 units. Firm A, however, considers only its own return on R&T, and not the returns of others in the industry, in making R&T investment decisions. In short, Firm A will tend to underinvest in R&T because it cannot capture all the benefits derived from its own R&T projects.

If each firm recognized spillover benefits to industry rivals, and also had the altruistic motive of maximizing total benefits flowing from R&T instead of just those that are privately captured, all firms would increase the level of R&T output and thereby increase the total amount of benefits flowing from R&T efforts to the socially optimal level. Since firms typically do not have such altruistic motives, they are likely to underinvest in R&T.

The second conclusion has a related explanation. To the extent that firms underinvest in R&T, each firm's costs are higher than those that would be incurred under the socially optimal R&T level. Consequently, total industry costs are higher than those that would be realized under maximum efficiency and, in addition, a larger number of firms in the industry are required to produce a given level of output.

Appropriating R&T through the Patent System

The preceeding analysis has focused on the problem of the inappropriability of R&T as a cause of underinvestment. It should be emphasized, however, that the inappropriability of R&T investments is not inevitable. Specifically, the U.S. patent system was designed to permit private firms to capture the benefits of their inventions.

Despite the patent system, however, there is evidence that private firms find it difficult to appropriate the benefits of inventions, royalty payments notwithstanding. One study, for example, estimates that the average value of a patented invention is approximately thirty times the average value of royalties received.[17]

At least two explanations for the low royalties relative to the economic value of patents have been offered. The first suggests that development costs of the royalty-paying firm are large and comparable to imitation costs so

[17] Nordhaus, Op. Cit., pp. 40-41.

that there is little left over for the innovating firm to capture.[18]

The second explanation is possibly more persuasive and directly relevant to the aeronautics industry. This explanation is based on evidence that "disembodied" royalties are small relative to their economic value while royalties from inventions embodied in machinery are high. In short, the innovator will find it difficult to appropriate the benefits of an invention if it represents the discovery of a process and is not embodied in a machine from which royalties in the form of rentals can be received.[19]

Moreover, if disclosure is required under a patent, the unpatentable part of the invention will enter the market free to imitators. Laws of nature are not patentable, for example. Thus, the innovator often risks providing knowledge free to competitors in patenting inventions.[20]

The discussion above suggests that there exists a bias against patenting disembodied technology. If a firm believes that knowledge may be freely or cheaply transferred to competitors, it may forego the patent system and operate

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[18]Richard R. Nelson, ed., The Rate and Direction of Inventive Activity, Princeton University Press, Princeton, NJ, 1962, p. 354.

[19]Nordhaus, Op. Cit., p. 40.

[20]Ibid., 41.

under secrecy. Secrecy, however, will very rarely be complete since, once a product is offered on the market, rivals can appropriate some of the benefits through imitation. Nonetheless, the innovator can at least enjoy the advantages of leadtime through secrecy.[21]

Secrecy is not the only probable outcome resulting from the difficulties associated with patenting disembodied technology. The key issue here is appropriability. Even if secrecy is maintained, some of the benefits derived from the innovation will be captured by rival firms in the industry. As a result, there will be a tendency to underinvest in disembodied technology. This type of technology is most likely to result from discipline and applied research since, by definition, these types of research are not directed toward a specific commercial product. Underinvestment in infratechnology is likely to occur for the same reason. In short, the inability of the patent system to permit single firms to appropriate the full benefits of disembodied technology causes a bias against the private development of this type of technology.

[21]This discussion provides some insight as to why a patent-sharing agreement exists in the civil aeronautics industry. This is discussed in the next section of this report.

Externalities

The existence of externalities is central to the underinvestment problem. The three classes of externalities described previously are: benefits not capturable by the innovating firm, but appropriable by rivals within the industry; benefits capturable only by firms in other industries; and, benefits not capturable by any firms. The conclusions described above hold, even if only the first type of externalities are present. The level of underinvestment in R&T will be even more pronounced if the other two types of externalities are also present. This follows since the relative proportion of total benefits that are capturable by the single innovating firm will be even smaller.

Risk and the Pay-Back Period

Two other factors, risk and the payback period, should be considered in evaluating the tendency of private firms to invest in R&T projects even though neither can be considered a classic market imperfection. These two factors are especially significant with respect to R&T projects because such activities typically exhibit greater risk and longer payback periods than other types of investments.

Risk occurs when the outcome of a project or activity is uncertain, but the uncertainty is sufficiently mild so that the firm can estimate the likelihood of several possible outcomes. Given that the probability of each outcome can be estimated with some degree of confidence, firms can use standard (or subjective) decision techniques to determine an appropriate course of action (i.e., whether or not they should undertake an R&T project).

It should be noted that the risk problem is separate from the appropriability problem. That is, even if the expected pay-off of a particular R&T project is sufficient to cover the expected costs of the project, the firm may still decide to forego the project if the firm is averse to risk. The following example serves to illustrate this point.

Suppose that a firm is considering a potential R&T project and the cost of the project is known with certainty to be $8 million. For the sake of simplicity, further assume that only two outcomes are possible: 1) the R&T project will yield zero benefits, or 2) the R&T project will yield total benefits of $20 million. If the two outcomes are equally probable--i.e., they both will occur with a probability of one-half--then the expected pay-off from the R&T project will be $10 million. This expected pay-off is sufficiently large to cover the certain costs of the R&T project, and will produce an expected net benefit of $2 million. Nonetheless, the consequences of failure may be so disastrous that the firm will decide not to undertake the R&T project.

Standard portfolio-selection theory provides some useful insights into the types of incentives firms have to conduct risky R&T projects. If the probability distribution characterizing the range of possible outcomes flowing from an R&T project is "well-behaved," then firms can reduce risk by diversifying into a large number of relatively small projects. If, however, the nature of the industry is such that diversification into a large number of small projects is not feasible, then risk reduction through diversification will not be feasible. Consider, for the sake of illustration, two firms, A and B, each having a net worth of $10 million. Suppose further that firm A, because of the nature of the market within which it operates, can conduct 10 separate R&T projects, each costing $1 million. Firm B, on the other hand, has only one R&T option, a $10 million project. Even if the expected payoff from the R&T activities of each firm is the same, firm A, by diversifying into several smaller projects, will face considerably less risk than firm B. Thus, the scale at which an R&T project must be conducted affects a firm's willingness to undertake it.

In addition to the scale of R&T projects, the structure of the industry also plays a role in determining the willingness of firms to conduct R&T projects. Some industry structures (monopoly and oligopoly) are characterized by a few large firms, while others have many small firms. Large firms, with large research divisions engaged in several projects, face considerably less risk than small firms which are able to conduct only a few projects. As a final note, it should be apparent that if several small firms can pool their R&T projects at a centralized institution, the total amount of risk facing the group will be considerably less than that of each firm individually.[22]

The payback period can be defined as the interval between the time at which expenses in a particular project are first incurred and the time at which sufficient revenues are obtained to achieve a break-even point. From the perspective of the owners or stockholders in a particular firm, the payback period, in isolation, should not influence a firm's incentive to undertake investment projects. Standard economic theory states that, regardless of the timing of returns on a project, it should be undertaken so long as it increases the net present value of the firm. Moreover, should they require cash, the owners of a firm theoretically can sell their assets at any time for a market price which reflects the assets' discounted

[22]This, of course, is nothing more than an insurance principle; i.e., the industry "insures" individual members against risky R&T projects through the centralized R&T pool.

value. There are, however, two factors which complicate the payback-period issue. These are: management incentives to undertake projects with relatively short payback periods, and the relationship between the payback period and risk.

A significant amount of recent literature has presented arguments that the relationship between management incentive and the payback period is the cause of diminished R&T activities within the U.S. economy. The problem is that R&T projects typically have rather lengthy payback periods, while management has incentives to undertake projects with relatively short payback periods. At almost any level in the management hierarchy of a given firm, promotion opportunities for individuals depend on their short-term performance. That is to say, the profitability of recent projects determines, to a large extent, the rate at which project managers will be promoted. In addition, the management bonus structure is tied to short-term profit performance, usually the preceding year. The combined effect of these two factors provides strong incentives for management to undertake projects with relatively short payback periods.

The payback period also affects the type of R&T that firms choose to undertake, as well as the level of these activities. An overview of the typical product life cycle serves to verify this point. The cycle starts with discipline (or basic) research, which provides the scientific discovery of a new concept. Laboratory verification of the discovery is provided through applied research. Finally, demonstration of the application and the feasibility of product engineering are achieved through development activities. This means that discipline research, which is the farthest removed from commercial exploitation, is the least likely to be undertaken, given the management incentives which have been described above.

Exhibit II-1 provides a list of several important innovations and the corresponding length of time from the date of initial conception to the date of commercial introduction. The average duration for all innovations listed is 19.2 years, and the longest duration, that of the pacemaker, is 32 years. It should be noted that the figures reported in Exhibit II-1 understate the true payback period in that they only reflect the commercial introduction date. In some cases, several additional years were necessary to achieve the break-even point.

It has also been noted that the payback period and risk are related; that is, the longer the payback period for a particular project, the greater the risk or uncertainty embedded in the project. Suppose, for the sake of illustration,

Exhibit II-1

DURATION BETWEEN CONCEPTION AND COMMERCIAL INTRODUCTION FOR SELECTED INNOVATIONS

	Year of First Conception	Year of First Realization	Duration Time
Heart Pacemaker	1928	1960	32
Hybrid Corn	1908	1933	25
Hybrid Small Grains	1937	1955	19
Green Revolution Wheat	1950	1966	16
Electrophotography	1937	1959	22
Input-Output Economic Analysis	1936	1964	28
Organophosophorus Insecticides	1934	1947	13
Oral Contraceptive	1951	1960	9
Magnetic Ferrites	1933	1955	22
Video Tape Recorder	1950	1956	6
Average Duration			19.2

Source: Robert C. Dean, Jr., "The Temporal Mismatch - Innovation's Pace vs. Management's Time Horizon", Research Management, May, 1974, p. 4 (from Battelle Memorial Institute Study, 1973).

that it is known that a particular project will have a payback period of 20 years. Even if the firm is certain that this R&T project will yield significant benefits in terms of today's markets, it will face considerable uncertainty regarding the value of those benefits twenty years hence. Uncertainty regarding both market demand for the product, as well as market conditions for necessary productive inputs, may cause the firm to forego the investment opportunity.

The Impact of Market Structure on R&T Activities

Although the appropriability of benefits derived from R&T efforts should be regarded as the single most important factor affecting individual private firms' decisions to invest in R&T, market structure may also play a role.[23] The purpose of the general review presented immediately below is to investigate the possible mitigating

[23] Market structure describes the organization of both buyers and sellers in an industry. On the sellers' side, the market structure is characterized by the number and the distribution of firms by size, as well as the degree to which various stages of production are integrated into one or several producers. The number of buyers and the distribution of buyers by size characterize the market structure on the buyers' side.

effects of market structure on the propensity for private firms to conduct R&T projects.

Several specific facets of market structure (or market conduct) that may affect private firms' R&T decisions have been identified in the literature. A list of those relevant to the issues at hand is as follows:

- o firm size and seller concentration,
- o product diversity,
- o R&T rivalry.

Each of these is discussed below in turn.

Firm Size and Seller Concentration

Conventional economic thinking suggests that large firms may have certain advantages over smaller firms in terms of their willingness to conduct R&T projects. It should be stressed, however, that in the present context, firm size is distinctly different from seller concentration. For example, a relatively large firm may be a member of an industry in which several or a rather large number of firms exist. On the other hand, it is possible that a smaller firm may be a member of a market in which only a few, or sometimes a single firm participates.

Several characteristics of large firms have been suggested as providing advantages in conducting R&T. These include:

- The ability of large firms to secure financial resources necessary to conduct large-scale R&T projects.
- The fact that size, by itself, may enable relatively large firms to accept the risk inherent in research.
- The ability of large firms to take advantage of scale economies that may exi-t in research activities.
- The ability of large firms to spread the benefits derived from R&T activities over several products (this advantage applies mainly to large firms producing multiple products).

It should be recognized, however, that some take issue with at least some of these alleged advantages of large firms. It has been argued, for example, that a number of individual managers within a large firms must accept the risk of conducting R&T projects.[24] In large organizations, the decision to accept or reject a specific project often

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[24] F. M. Scherer, Industrial Market Structure and Economic Performance, Rand McNally, Chicago, 1980, p. 414.

must pass through a large portion of management hierarchy. This means that several individuals must simultaneously accept the risk inherent in research projects. A smaller firm, on the other hand, often has only one or a few individuals responsible for this type of decision. As a result, it may be that smaller firms are more likely to accept this type of risk, other things being the same, since it is more likely that a few rather than a large number of individuals are willing to accept risks.

The evidence in the economics literature regarding the effects of firm size on propensity to undertake research efforts is less than unambiguous. The strongest, or best, evidence suggests that the willingness to undertake research increases as firm size increases up to some threshold point, and then declines as firms grow still larger. The weakest evidence suggests that firm size has no impact on research efforts.[25]

There is little doubt that large firms do conduct a disproportionately large share of total R&D. For example, data from the National Science Foundation indicate that only about 10,000 of 263,000 U.S. manufacturing firms employing fewer than 1,000 workers maintained formal R&D

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[25]Unfortunately, all the empirical work reviewed below focuses on R&D rather than on R&T. To the extent that these two activities are correlated, these studies are, nonetheless, relevant.

programs in 1972. However, 481 of 540 firms with 5,000 or more employees maintained formal R&D programs.[26] Aggregate comparisons of this type, however, tend to mask the effects that other characteristics of the firm have on R&D efforts, including wide variations across industries.

While there have been numerous studies on the relationships between firm size and R&D,[27] one conducted by Scherer in 1965 significantly improved on the research designs of the preceding studies. It was found that R&D efforts did increase as firm size increased but only up to some threshold point. Once firm size exceeded that threshold point, further growth in firm size indicated a leveling off or even diminished level of R&D effort.[28] These results were confirmed in a later study by R. E. Schrieves.[29]

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[26] Scherer, Op. Cit., p. 419.

[27] See I. Horowitz, "Firm Size and Research Activity," Southern Economic Journal, 28, January 1962, pp. 298-301; and J. S. Worley, "Industrial Research and the New Competition," Journal of Political Economy, 69, April 1961, pp. 183-186.

[28] F. M. Scherer, "Size of Firm, Oligopoly, and Research: A Comment," Canadian Journal of Economics and Political Science, 31, May 1965, pp. 356-366.

[29] R. E. Schrieves, "Firm Size and Innovation: Further Evidence," Industrial Organization Review, 4, No. 1.

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Similar results were obtained in a separate study of the drug industry.[30]

Nonetheless, this basic relationship between firm size and R&D effort is less than fully robust. Several other studies found no significant relationship between firm size and R&D expenditures.[31] Most likely, several factors influence the level of a firm's R&D effort, and it is difficult to separate the impact of firm size from them.

In summary then, the best or strongest evidence suggests that moderately sized firms are most likely to engage in R&T activities. Smaller firms appear less likely to engage in R&T efforts, and very large firms are likely to conduct R&T at levels proportionately below, or at least not greater, than the medium or moderately sized firms.[32]. The discussion provided thus far in the economic

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[30] H. G. Grabowski, "The Determinants of Industrial Research and Development: A Study of the Drug, Chemical, and Petroleum Industries," Journal of Political Economy, 16, March-April 1968, pp. 292-306.

[31] See for example, E. Mansfield, Industrial Research and Technological Innovation--An Econometric Analysis, Norton for the Cowles Foundation for Research in Economics at Yale University, New York, 1968; D.C. Mueller, "The Quarterly Journal of Economics, 81, February 1967, pp. 58-87; and T. M. Kelly, The Influences of Firm Size and Market Structure on the Research Efforts of Large Multiple-Product Firms, Ph.D. Dissertation, Oklahoma State University, 1970.

[32] Scherer places the moderately sized firm at sales ranging between $240-400 million at 1978 price levels. See Scherer, Op. Cit.

literature has not totally resolved the issues regarding the relationship between firm size and R&T.

Earlier, it was suggested that another advantage that large firms may have over smaller firms is the ability to spread out the benefits of R&T activities over several products. This particular advantage, of course, would only apply to those firms producing several different products.[33] A second and somewhat related advantage here is the ability of multi-product firms to conduct several related projects and thus, through diversification, spread the inherent risk in R&T over several projects.

Evidence that this type of an advantage may exist is supported by several studies.[34] It is particularly interesting to note that one study discovered that the most pronounced effects of diversification appeared for firms whose multiple products were closely related--i.e., the products were sold in related markets. Firms producing multiple products in disparate or unrelated markets would appear to have a lesser advantage.[35] In brief, it seems that the ability of a firm to diversify through multiple

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[33] See Richard R. Nelson, "The Simple Economics of Basic Scientific Research," Journal of Political Economy, 67, June 1959, pp. 297-306.

[34] See, for example, Arabowski, Op. Cit.; and F.M. Scherer, "Firm Size, Market Structure, Opportunity, and the Output of Patented Inventions," American Economic Review, 55, December 1965, pp. 1097-1125.

[35] Kelly, Op. Cit. (1970)

products has a substantial impact on the likelihood or level of R&D effort, if the benefits of research can be spread over several somewhat related products.

Several studies have also focused on the potential impact that seller concentration has on R&D efforts. Seller concentration measures the extent to which the largest firms dominate sales in a market; it is often measured (at least in the studies reviewed below) as the market share held by the four largest firms in the industry.

The evidence suggests a weak but positive relationship between seller concentration and R&D effort, at least for U.S. industries. As was the case with firm size, it appears that this relationship disappears when the concentration level exceeds a threshold point.

Early studies found a weak positive relationship between seller concentration and R&D effort.[36] In a later study, Scherer found seller concentration to significantly affect R&T effort, but noted that the explanatory power of concentration fell when qualitative variables reflecting

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[36] See Horowitz, Op. Cit.; and D. Hamberg, R&D; Essays on the Economies of Research and Development, Random House, New York.

"opportunity class" (i.e., producer, consumer, durable or non-durable goods) were included in the model.[37] He also discovered that maximum predicted R&D effort (measured by technical employment) was predicted at concentration levels between 50 and 55 percent (i.e., percent of sales captured by the four largest firms in the industry). Both of these results were confirmed in a later study by Kelly.[38]

It has also been suggested that a second factor, somewhat related to seller concentration, may affect the tendency of private firms to conduct R&D. Specifically, it has been argued that the profitability or liquidity (i.e., cash flow) of a firm may enhance the ability of firms to finance internally risky R&D projects for which financing may be difficult to obtain. The evidence, however, does not strongly support this hypothesis.[39]

R&T Rivalry

Another issue regarding market structure is the potential impact of technological rivals on the level and

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[37]F. M. Scherer, "Market Structure and the Employment of Scientists and Engineers," American Economic Review, 57, pp. 524-531.

[38]Kelly, Op. Cit., (1970).

[39]For a survey of these studies, see Mortin I. Kamien and Nancy L. Schwartz, "Market Structure and Innovation: A Survey," Journal of Economic Literature, 13 March 1975, pp. 1-37.

timing of R&T efforts in an industry. The important question here is: Does the existence of rivalry produce an environment that promotes or reduces the level of R&T effort, and does it affect the speed of development? The answer to this question ultimately depends upon the firms' perceptions of the relative benefits and costs of innovation versus imitation as well as the firm's expectations regarding rival behavior.

In a setting where rivalry exists, the chief advantage of innovation is the benefit of a large temporary market share that is enjoyed by the leading innovator. The major disadvantage, of course, is that sometimes substantial costs are incurred through research, and then development, activities. Although the imitator may temporarily lose a favorable market position, it does usually incur a lower level of costs relative to the innovator.

Much of the work that has been done on the problem of technological rivalry has been of a theoretical nature that has not yet been empirically tested. Nonetheless, some conclusions can be offered. These include:

- Imitation is more desirable if it is quick and the expected market share through imitation is relatively large.[40]

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[40] F. M. Scherer, "Research and Development Resource Allocation under Rivalry," Quarterly Journal of Economics, 81, August 1967, pp. 359-394.

- Firms that expect to be a permanent leader in the industry (in terms of market share) will accelerate the pace of innovation if rivals do. Imitators, on the other hand, will reduce the pace when rivals accelerate technological development.[41]
- An intermediate degree of rivalry is likely to lead to the most rapid development rate; i.e., some structure between competition and monopoly is most conducive to promoting R&T.[42]
- Uncertainty regarding the introduction of an innovation by a rival will tend to slow the pace of R&D in early phases of a project, and increase it during later phases.[43]
- If innovational rivals exist, cash flow or liquidity problems will prolong the development period and reduce the acceptability of some projects.[44]

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[41] W. L. Baldwin and G. L. Childs, "The Fast Second and Rivalry in Research and Development," Southern Economic Journal, 36, July 1969, pp. 18-24.

[42] M. I. Kamien and N. L. Schwartz, "On the Degree of Rivalry for Maximum Innovative Activity," Discussion Paper No. 64, Center for Mathematical Studies in Economics and Management Sciences, February, 1974.

[43] M. I. Kamien and N. L. Schwartz, "Risky R&D with Rivalry," Annals of Economic and Social Measure, 3, January 1974, pp. 267-277.

[44] M. I. Kamien and N. L. Schwartz, "Self-Financing of an R&D Project," The American Economic Review, 68, June 1978, pp. 252-261.

As this list of conclusions suggests, the impact of rivalry on the level and pace of research activities depends upon perceptions and reactions of rivals. The implications for the civil aeronautics industry are best described within a historical context of the behavior of firms participating in this market. This analysis is provided in the next section of this report.

Summary

Briefly summarizing the results of the analysis in this section:

- If the technology base of a particular industry is purely common--i.e., firms are unable to appropriate any of the benefits derived from R&T activities--then no firm in the industry will have any incentive to invest in R&T. This, of course, represents the most extreme case of underinvestment in R&T.
- If firms are able to appropriate all the benefits derived from R&T efforts, strong incentives for investment will exist and market imperfections attributable to the nature of knowledge will not be present. However, several other imperfections may still exist. These are the problems associated with a monopoly

market structure, inefficiencies due to a heterogeneous product market, and unnecessary duplication of research efforts.

- Even if benefits are only partially appropriable, a market imperfection will exist to the extent that firms underinvest in R&T projects. That is, the level of investment will be less than the amount that would occur if all R&T benefits were appropriable by single innovating firms. Production costs for these firms would also be higher than those that would be incurred under maximum efficiency.
- Firms may also be discouraged from undertaking investment in R&T because of risk. The ability to diversify into several small R&T projects may mitigate the level of risk facing a single firm. However, if the nature of the industry is such that small R&T projects are infeasible, then risk becomes a more serious issue.
- Because of management incentives, as well as the relationship to risk, the lengthy payback period associated with R&T projects may even further discourage firms from such investments.

This is particularly true for discipline or basic research; in other words, the payback period promotes preference for investment in development activities.

- Regarding market structure, both firm size and seller concentration may affect the propensity for private firms to conduct R&T projects. Evidence suggests that R&T intensity is weakly but positively related to both; however, these effects diminish at some threshold point. In addition, the ability of firms to diversify in product markets and technological rivalry may increase R&T intensity.

Some final comments on the issue of appropriability and the nature of knowledge are worthwhile. The fact that knowledge can be learned relatively cheaply and may be reused without diminishing its value makes it particularly difficult for any single firm to appropriate benefits. It is somewhat paradoxical that market imperfections due to the inappropriability of knowledge disappear, or at least are diminished if a single firm prevails in the market. A monopolist will be able to appropriate all benefits flowing from R&T within the industry. However, those market imperfections that are predicted by economic theory as being attributable to a monopoly market structure will then be present.

Even apart from the monopoly problem, a paradox remains. If the benefits derived from R&T activities are not appropriable, other firms in the industry serve as imitators and promote the rapid diffusion of new technology. The problem is that the rate of diffusion and incentives for individual firms to conduct R&T are inversely related; that is, the more rapid the diffusion process among firms in an industry, the less the incentive for any single firm to conduct R&T. On the other hand, if benefits derived from R&T are appropriable by individual firms within an industry, the rate of diffusion will slow down and the problem of a heterogeneous product market arises. This discussion suggests that the very nature of technological knowledge, by itself, creates market imperfections.

III. AN APPLICATION OF THE ECONOMIC MODEL TO THE CIVIL AERONAUTICS R&T MARKET

The economic model developed and described in the previous section is applied below to the civil aeronautics R&T market. The discussion begins with a description of the sources of R&T in the market. Next, the applicability of the Partial Appropriability Model to the civil aeronautics R&T market is assessed, with the conclusion that it is an appropriate characterization of the aeronautics R&T market. Extensions to the basic economic model are then offered; these describe the nature of technological rivalry, buyer concentration, and the role of the military in the industry. Following this, an analysis of risk faced by firms in the industry is provided.

The key findings of this section are:

- o Aeronautics firms in general have a tendency to underinvest in R&T because of the difficulty they have in capturing a sufficient portion of the benefits from these activities.
- o The effects of large risks encountered in developing new aircraft are parallel to and reinforce those due to the appropriability problem: firm resources are most likely to be devoted to those activities closest to commercialization.

- History suggests that dominant firms in the airframe industry will be reluctant to make technological leaps forward because they do not wish to compete with their existing and successful product lines and their incentives to undertake the considerable risks involved are less than those of companies with less of a stake in the existing market for aircraft.

Elements of the Civil Aeronautics Industry Technology Base: An Example

Recall that the four basic elements of an industry's technology base are: infratechnology, discipline research, applied research, and development. These four elements may play a role in the development of a specific aircraft as follows:

- Discipline Research--a study of laminar flow provides information regarding the properties of the flow of particles about a foil (laminar flow deals with the nonturbulent flow of fluid in layers near a boundry).
- Infratechnology--sophisticated computational or numerical methods are necessary to conduct the laminar flow study.

- o <u>Applied Research</u>--the results of the above-described discipline research are used to study desirable properties of aircraft-wing shapes. This research is applied because it is not yet concerned with developing a wing for a specific aircraft (note also that infratechnology still plays a role here since sophisticated computational methods facilitate the analysis of wing design).
- o <u>Development</u>--the results of the applied research are used to develop or design a wing for a specific aircraft.

Based on the previous discussion, the examples of infratechnology and discipline research represent basically neutral elements of the industry's technology base. The applied research on wing design may be partially neutral and partially proprietary. Finally, the development phase is largely proprietary (although benefits may not be totally appropriable by the innovating firm.)

To facilitate the discussion which follows, it is appropriate to cross-classify the description of the basic elements of the aeronautics industry technology base with the program titles utilized by NASA and DOD. Such a classification scheme is shown in Exhibit III-1. While the fit especially between the NASA and DOD categories is not exact, this presentation is meant only as a guide to the reader.

Exhibit III-1

DEFINITIONS OF TYPES OF R&D ACTIVITIES

PHASE	PRIMARY OUTPUT	DOD CATEGORY	NASA CATEGORY	BASIC ELEMENTS OF TECHNOLOGY BASE	
Technology Development	Understanding Physical Phenomena	6.1 Basic Research	R&T Base	Discipline (or Basic) Research*	Infra-technologies*
	Creation of New Concepts				
		6.2 Exploratory Development	R&T Base	Applied Research*	
	Design Data and Procedures	6.3A Advanced Development (Non-Systems)	Systems Technology		
Technology Demonstration	Demonstrated System/ Sub-System Performance	6.3A Advanced Development (Non-Systems)	Systems Technology		
System Development	Operational Systems	6.3B Advanced Development (Systems)	----------	Development	
		6.4 Engineering Development			

*Neutral Technology

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Sources and Types of R&T in the Aeronautics Industry

The discussion in Section II of the incentives to produce R&T can be brought more clearly into focus by considering the sources of R&T in the aeronautics industry and the types of technology which each can provide. With this foundation, the issue of appropriability can be discussed specifically in terms of the aeronautics industry.

There are four sources from which the aeronautics industry draws its R&T:

- Military Research--the military is a significant source of aeronautical R&T, which it provides to the industry in a number of ways. A major portion of this R&T is performed directly by firms within the industry under specific military contracts, including contracts in which two or more firms are funded to develop competitive prototypes (e.g., the C-5A transport and F-16 fighter). In addition, the military authorizes IR&D at major military contractors and makes available (for a fee) military facilities for experiments and occasionally for production. Many civilian applications can be drawn from the knowledge acquired through these activities, some examples of which will be given below.

- <u>NASA/NACA</u>--NASA, and its predecessor, the NACA, has served as a conduit for government-sponsored R&T to the aeronautics industry. It conducts its own aeronautical research, the results of which are publicly available unless given a security classification because of military relevance. NASA also funds R&T performed by individual firms and universities. Finally, the agency maintains advanced research facilities which are available not only for NASA-sponsored projects, but for research activities initiated and funded entirely by the private sector. Through the above activities, NASA provides discipline research, applied research, and infratechnology.

- <u>The Academic Community</u>--a major contribution of the nation's universities is to train the scientists and engineers who perform the R&T described above. Universities also perform some R&T in the areas of infratechnology and discipline research although they are restricted by a lack of the expensive, large scale, advanced facilities such as those operated by NASA and the military.

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- Privately Initiated R&T--in addition to military and NASA-sponsored projects, firms in the aeronautics industry also perform their own R&T. Such privately financed projects typically involve development or applied research.

Appropriability of R&T Sources

With an understanding of which organizations provide which types of R&T, the question of appropriation by firms engaged in development of commercial aircraft can be addressed. R&T derived from military sources is often appropriable by a private firm in the sense that technologies are "copied" for civilian aircraft (some examples are provided in Exhibit III-2).[1] It should be stressed, however, that the total spillover benefits from military R&T to civilian aircraft are not generally appropriable by a single private firm. The B-707, for example, was developed contemporaneously with the KC-135. The wing placement was then copied two years later by Douglas and Convair. (See Exhibit III-3).

R&T provided by NASA, or the academic community, is clearly neutral. The results of these R&T are disseminated publicly, thus, they are equally accessible to all firms

[1]One study identifies twenty-two "significant" technological advances that were transferred from the military to civil aeronautics during the 1925-1972 period. See R&D Contributions to Aviation Progress, (RADCAP), U.S. Department of Commerce, Vol. I, Section III.

Exhibit III-2

EXAMPLES OF CIVILIAN AIRCRAFT AND TECHNOLOGIES APPROPRIATED FROM MILITARY DEVELOPMENT PROGRAMS

Engines: The turbofan engine introduced on the B-707 was originally designed by Rolls Royce for the Vickers V1000 military aircraft, which was never built. In addition, the J-57 (Pratt & Whitney), Avon and Conway (Rolls Royce), and J-79 (General Electric) engines were all originally developed for military use.

B-707: The Boeing 707 was developed jointly with the KC-135 military tanker.

Wide-Body Aircraft: The DC-10, L-1011, and B-747 were all developed based on technological research into wide-body aircraft made by Douglas, Lockheed, and Boeing while competing for what became the C-5A military transport contract.

DC-8: Initial engine was the J-57, originally developed for military use. In addition, the wing geometry was based on designs from the B-47, B-52, and B-66.

Exhibit III-3

EXAMPLES OF APPROPRIATION BY ONE CIVILIAN FIRM OF TECHNOLOGY FIRST USED BY ANOTHER FIRM (WITHIN THE AERONAUTICS INDUSTRY)

DC-3/B-247: In the early 1930's, TWA and United Airlines were in fierce competition for the transcontinental mail and passenger market. Both had extensive experience in metal twin-engined aircraft through competition for military contracts. Boeing introduced its 247 first (1933) and Douglas, following the basic layout of the B-247, improved upon it with its DC-2 (1934) and DC-3 (1936).

Tricycle Landing Gear: Originally, these landing gear were incorporated into aircraft because they made take-off and landing easier, and reduced the runway length required. The DC-4E (1938) was the first airliner to incorporate the concept once it was proven on several earlier aircraft.

KC-135/707 Design: Based on their experience with the B-47, B-52, and KC-135 military programs, Boeing was emboldened to change military designs to civilian designs. This basic external design was adopted by Douglas and Convair two years later because they wanted to avoid the risk of failing to find an alternative design that was better.

(as well as potential entrants to the industry). A more interesting policy issue is the degree to which NASA-type R&T would be appropriable if these projects were conducted in the private sector. The character of R&T currently conducted is basically neutral, however. As was already mentioned, NASA supports discipline and applied research in addition to making contributions to the industries' infratechnology. As the discussion in the preceding section of this report indicated, these elements of the technology base are neutral. Moreover, it is difficult to patent discoveries of these types, given their disembodied nature.

Even privately sponsored R&T is not, in general, totally appropriable by single firms. Exhibit III-3 provides some examples of cases in which basic designs of commercial aircraft were copied by industry rivals. The privately sponsored R&T is generally only appropriable by the innovating firm to the extent that the benefits of a lead time over rivals are realized. In some cases, however, this lead time is relatively short (for example, the basic design of the B-707).

An additional issue in the realm of the appropriation (or perhaps, more properly, transfer) of R&T is the application of aeronautical technology to other industries. For example, advances in the technology of turbine engines have led to wider use of turbines in the generation of electrical power for peak periods and for use on a standby basis. Turbines have also been adapted to pipeline technology, and are now being used in chemical processing (see Exhibit III-4). In these cases, the benefits of technologies transferred to other industries cannot be appropriated by a single firm in the aeronautical industry.

Indeed, technology from the U.S. aeronautical industry is sometimes first transferred to foreign-based industries. Describing a visit to a Japanese steel plant, Robert Dean writes:

> Let me give an example. When I visited Mitsui in Japan, I was proudly shown a new and very large, 50,000 kilowatt, blast furnace blower. I examined it closely and discovered an enormous example of a modern aircraft engine's axial compressor with every stator row adjustable for peak performance and flexibility. It was obvious, on inspection and upon querying the Japanese engineers, that they had been dedicated students of U.S. aircraft engine technology. And Mitsui had spent several years and a large amount of money developing this highly commendable machine which I predict we will soon see penetrating the U.S. market.[2]

In general, technology transfers flow in both directions; that is, technologies developed in other industries may be borrowed by firms in the aeronautics industry. In

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[2]Robert D. Dean, Jr. "The Temporal Mismatch--Innovation's Pace vs Management's Time Horizon," <u>Research Management</u>, May, 1974, pp. 14-15.

Exhibit III-4

EXAMPLES OF TECHNOLOGIES WHICH CAN BE USED IN THE CIVILIAN AERONAUTICAL INDUSTRY AND OTHER INDUSTRIES

Microelectronics: Development of semiconductors for missile guidance systems and the advent of small computers have been applied to commercial aviation in such areas as communications, radar, and on-board computers providing improved navigation and maneuvering.

Metallurgy: Metallurgic science has been essential to the development of alloys for use in monocque airframe and high-temperature turboprop and jet engines.

High Octane Fuel: Improvements by oil companies in the octane ratings of aviation fuel have spurred improvements in gasoline for use in automobiles.

Computer Software: The NASA Structural Analysis (NASTRAN) software package, developed by the Goddard Space Flight Center to analyze the static and dynamic behavior of elastic structures, has been applied in the civil aviation industry as well as automobile production, bridge construction, and plant modelling.

Exhibit III-4, (Cont'd)

Turbine Engines: Advances in the technology of turbine engines led to wider use of turbines in the generation of electric power and in chemical processing.

other cases, technology may be borrowed partially from other sources and partially developed by the aeronautics industry itself. For example, the aeronautics industry clearly borrows technology in materials characteristics (e.g., metallurgy) and still makes contribution of its own (e.g., the NASA materials programs at Langley). In short, many industries may share a common technological base, each drawing upon a common pool of information, and each making its own contributions to the pool (see Exhibit III-4). In these cases, no single firm in any one industry is able to capture or appropriate the total benefits derived from its own R&T projects. Further documentation of the wide or diverse technology base in the aeronautics industry is provided later in this report. The implications of such a technology base are also discussed.

<u>An Application of the Partial Appropriability Model to the Civil Aeronautics R&T Market</u>

The general economic model for the market for private R&T that was described earlier focuses on two characteristics of the market. These are:

- o The appropriability of private R&T,
- o The profit maximizing behavior of private firms.

The discussion that follows describes the civil aeronautics industry in terms of these characteristics.

Appropriability of Private R&D

The various sources of R&T for the civil aeronautics industry have been identified and described earlier in this report. The relative appropriability of each of the various sources was also discussed. Here, the discussion focuses on privately financed R&T.

Appropriation Through Patents

There are indications that private R&T in the industry is only partially appropriable. First, a patent-sharing arrangement--administered by the Manufacturers' Aircraft Association (MAA)--currently exists in the aircraft manufacturing industry. Under this arrangement, no member may have a monopoly on any patent, regardless of whether a member was responsible for the invention or the patent was obtained through a licensing agreement with a non-member. Most patents pooled under the MAA can be obtained by any member free of royalty payments. Approximately one in twenty is judged to hold exceptional incentive merit--by a panel of arbitrators--and token royalties are paid for these.[3] Obviously then, benefits of inventions cannot be appropriated by single firms under this institutional arrangement.

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[3] For a more detailed description of the MAA agreement, see Ronald Miller and David Sawers, The Technological Development of Modern Aviation, Routledge and Kegan Paul, London, 1968, pp. 255-257.

What is even more interesting, however, is the mere existence of the patent-pooling arrangement. At a minimum, it indicates a lack of faith in the patent system as vehicle through which the benefits of R&T may be appropriated. This, of course, is not surprising. First, much of the technology base of the industry is, by nature, disembodied; earlier comments have described the difficulty of appropriating this type of technology through the patent system. Second, and perhaps more importantly, the development of an aircraft requires the synthesis of a wide range of interdependent technologies. A proliferation of patents could produce the heterogeneous product market that was described earlier in this report (i.e., the production of several mediocre, but no superior aircraft). This would clearly be to the detriment of the entire industry. Finally, the MAA agreement eliminates the need for expensive patent litigation among industry members.

It is clear that the industry patent-sharing agreement creates incentives for secrecy in the industry. The only advantage here, however, is leadtime. Secrecy cannot be maintained indefinitely when final products are open for dissection by rivals once they are exposed in the market. In fact, a long history of rivalry through imitation exists in the industry. Several examples of technological imitation are provided in Exhibit III-5.

Exhibit III-5

EXAMPLES OF IMITATION BY INDUSTRY RIVALS: MAJOR INVENTIONS

Invention		Inventors	First Successful Commercial Application	Succeeding Applications
Aerodynamic knowledge permitting designs of well-streamlined airplanes	1906-08	Lanchester, working privately. Prandtl, at University of Gottingen, and others mostly at universities. Gilder designers, working privately, Northrop while working for Lockheed	Lockheed Vega (1927)	DC-3
Cantilever monoplane	1910-15	Junkers, at Aachen Technische Hochschule, Levavasseur of Antoinette	Junkers F-19 (1919)	Fokker Monoplanes
Slotted Wing	1917-19	Lachmann, working privately, Handley Page Ltd.	Albatross C-72 (1926)	Junkers JU-52
Slotted flap	1920	Handley Page Ltd., O. Mader of Junkers	Albatross C-72 (1926)	Northrup Gamma Lockheed Orion
Cowls for radial engines	1921-28	V. Clark of Dayton-Wright, Townend of the National Physical Laboratory, Weick of NACA	Lockheed Vega (1927)	Northrup Alpha Boeing Monomail
Variable-pitch propeller	1923-29	Hele-Shaw and Beacham, working privately, but with some government funds. Turnbull, again working privately but receiving government funds. Caldwell working for the Army, then privately, then for Hamilton-Standard	Boeing 247 (1933)	DC- 3
Stressed-skin metal construction	1914-29	Junkers, at Aachen, then forms company. Dornier, working for Zeppelin company. Rohrbach also working for Zeppelin. Wagner, working for Rohrbach's company. Northrop, head of his own company	Northrop Alpha Boeing Monomail (1930)	DC-3
Jet engine	1929-36	Whittle, working privately, von Ohain, working privately. Wagner and Mueller, at Junkers	Boeing 707 (1958)	DC-8
Swept-back wing for transonic and supersonic flight	1935-39	Busemann and Betz at University of Göttingen	Boeing 707 (1958)	DC-8
Variable sweepback for supersonic airplanes	1941-58	Lippisch at Messerchmitt, Stack et al. at NACA, Wallis et al. at Vickers	-	-

Source: R. Miller and D. Savers, The Technical Development of Modern Aviation, Rutledge and Kegan Paul, London (1968)

The upshot is that the assumption of the partial appropriability of private R&T that was embedded in the earlier economic model is relevant to the civil aeronautics market. Recall that it was assumed that the R&T of each firm affected the productivity of every other firm in the industry, but each firm's own R&T had a greater impact on its own productivity than on the productivity of competitors. Specifically, in terms of the civil aeronautics industry, a firm conducting R&T and adopting the benefits of its own research through innovation has the advantage of lead time over its competitors. Each individual firm, however, cannot capture the full benefits of many of its own R&T activities since innovations can be copied by its competitors.

Profit-Maximizing Behavior

A conventional assumption embedded in standard economic anlaysis is that firms behave in a manner consistent with profit maximization. There is no apparent reason to believe that firms in the civil aeronautics industry behave otherwise. It should be recognized that it is sufficient that firms attempt to maximize profits--i.e., the conclusions hold, even if firms are sometimes unsuccessful in maximizing profits, as long as the profit motive dictates their decisionmaking behavior. At any rate, the assumption of profit-maximizing behavior appears to be both reasonable and appropriate.[4]

Overview of Applicability of the Economic Model to the Civil Aeronautics Industry

The foregoing discussion suggests that the assumptions embedded in the economic model are appropriate in terms of describing the conduct and structure of the civil aeronautics industry. This holds for both of the key assumptions--appropriability of R&T and profit-maximizing behavior.

It follows, then, that the general conclusions regarding imperfections in the market for privately funded R&T will hold specifically for the civil aeronautics industry. Most importantly, the civil aeronautics industry will tend to underallocate resources to private R&T. Firms in the industry will conduct less private R&T than the socially optimal level (i.e., less than the level that would occur absent market imperfections).

Market Structure

Appropriation difficulties will cause an underinvestment in R&T by private firms in the civil aeronautics industry. Below, the potential impacts of market structure on the level of R&T efforts are reviewed.

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[4]More precisely, it is required that firms attempt to maximize long-run profits (i.e., maximize the net present value of the firm).

A Description of the Civil Aeronautics Industry: Market Structure

The structure of the civil aeronautics industry can be characterized as having a relatively high degree of horizontal concentration, but a lack of vertical integration. Horizontal concentration describes the number of firms participating in the market at any one stage of production (e.g., airframes or engines). Vertical integration refers to the extent to which single firms participate in the market at several stages of production (e.g., a firm producing both airframes and engines is vertically integrated).

Firm Size and Market Share

In Section II of this report, tentative evidence that both firm size and seller concentration affect R&T efforts was described. Specifically, the evidence suggests that increases in firm size resulted in proportionately greater levels of R&T effort; beyond the threshold point (about $400 million in sales in 1978 dollars), however, further increases in firm sales caused diminished levels of R&D.

Similarly, increases in market concentration tend to cause proportionately greater R&D to be undertaken. Again, however this effect diminishes at some threshold point--namely, the point at which 50 to 60 percent of the market was controlled by the four largest firms in the industry. However, the evidence is relatively weak on both accounts. Accordingly, the conclusions offered below should be viewed with this in mind.

The civil aeronautics industry exceeds, by large magnitudes, the threshold points for both firm size and market concentration. The three largest airframe manufacturers, Boeing, McDonnell-Douglas, and Lockheed, for example, had 1981 total sales revenues of $9,788, $7,385, and $5,176 million, respectively.[5] Similarly, the marketshare of just the largest commercial airframe manufacturer, Boeing, exceeds 60 percent of the market for large aircraft. Thus, by both standards, the industry is far past the optimal thresholo points condusive to R&T activities. Because of this, and in view of the inconclusive evidence regarding the general effects of firm size and marketshare, these aspects of marketshare are not likely to mitigate the appropriability problems facing the industry.

Product Diversity

It was also mentioned in Section II that firms producing products in closely related markets may have added incentives to conduct R&D because the benefits can be spread over several products. The existence of a large military market aids the industry in spreading the costs of the common military/civilian R&T base. But, the key question here is: whether the existence of the military market causes firms to undertake civilian-oriented R&T, speculating that the results can be applied in the military sector? While this effect may exist,

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[5] Annual Reports for Boeing, McDonnell-Douglas, and Lockheed.

it is likely to be small. Military and civilian hardware tend to be quite different in performance characteristics with military applications usually preceding civilian use. Disembodied technologies--new concepts or knowledge--may be applicable in either sector, but the production of such R&T will be subject to the appropriability problem, regardless of its eventual use.

Other Sources of R&T

The discussion provided immediately above has intentionally focused on privately funded R&T. Considered here are incentives private firms in the industry would have to fund R&T that is currently derived from other sources. In general, the types of R&T provided by other sources are, by their very nature, less appropriable than privately conducted R&T which is dominated by applied research and development activities. Consequently, private firms will have, in general, even less incentive to conduct R&T currently derived from other sources.

R&T currently conducted by NASA is, of course, the present issue. The critical question is: to what extent will private firmshave incentives to conduct R&T currently performed or sponsored by NASA? As an R&T source, NASA makes contributions to the industry's technology base in terms of infratechnology, and discipline and applied research. Relatively little private expenditure is devoted to these elements of the technology base. The reasons for this phenomenon are twofold:

- o Private firms have less incentive to conduct discipline and applied R&T because of the problems of appropriability (as well as the risk and payback period problems).
- o Neutral technology can be obtained from other sources.

The latter point, of course is the central policy issue. Given the previous discussion on the appropriability of neutral technology and the results obtained from the economic model of the market for R&T, it appears that the private market will not respond well to the burden of undertaking R&T activities currently conducted by NASA.

A second issue is whether NASA sponsored R&T conducted by private firms is a complement or a substitute for privately financed R&T. The concern here is that NASA (or government) sponsored R&T "crowds out" R&T that would otherwise be financed and conducted privately. *A priori* expectations lead one to believe that the crowding out effect is not substantial: NASA typically sponsors projects that exhibit scientific potential rather than short-term commercial potential. In addition, there is empirical evidence that the crowding out effect is minimal. One study, which focused specifically on the transport industry, estimated that each dollar cf government sponsored "mission-oriented" research reduced privately sponsored research by only eight cents.[6]

NASA Sponsored R&T: Risk and the Payback Period

Appropriability is not the only factor considered in a firm's decision to invest in R&T. Specifically, both the level of risk associated with a project and the duration of the payback period influence the investment decision, even when appropriability is not an issue. Development activities are least risky and have, in general, the shortest payback period, while investments in discipline (or basic) research and infratechnology are generally most risky and have the longest payback periods.

Regarding the risk and payback period problems, the important issue here is: does the type of R&T conducted by NASA complement R&T (or R&D) that private firms tend to conduct, or are NASA R&T activities substitutes. Many

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[6] J. Charmicheal, "The Effects of Mission-Oriented Public R&D Spending on Private Industry," Journal of Finance, 36 June 1981, pp. 617-627.

of NASA's resources are devoted to basic research and the development of infratechnology. These activities complement the efforts of the private sector since they are both risky and tend to have one long payback period.

NASA also sponsors and conducts applied research. Although this type of R&T investment is generally less of a problem in terms of risk and the payback period, it is less desirable to private firms than development activities. Moreover, applied research in aeronautics, particularly the type that NASA conducts, often requires the extensive use of large scale facilities. If the burden of conducting these projects were placed on the private sector, substantial duplication of both large scale facilities and expensive experiments may result.

Dynamic Extensions of the Model: A Historical View of Technological Rivalry and Other Observations

There are three refinements of the model that are necessary to characterize more fully the aeronautics industry. The refinements address the following issues:

- The monopsony buying power which is sometimes invested in airlines as a result of direct competition between aircraft manufacturers.

- The role of the dominant firm and its effects on competition and technological change.
- The significant intervention in the marketplace by the military.

Each of these facets of the aeronautics industry is considered below.

Monopsony Power of Airlines

Because aircraft manufacturing requires high development costs, the industry is often compared to other industries with high development costs--e.g., automobiles. The key distinction is that aircraft are built in small numbers and, in fact, are custom-built to airline specifications. Stability in the marketplace depends upon the ability of firms to differentiate their products and, more specifically, to build different size aircraft with different capabilities which will be attractive to specific niches in the marketplace. When firms build aircraft of the same size with similar capabilities, they find that the market is too small to yield satisfactory returns on their investments. Competition becomes so vigorous for limited sales opportunities that airlines acquire a form of monopsony power--the ability to dictate the terms of the sale to the seller. This situation can have debilitating effects upon the competitors, and can reinforce the already existing tendency for one firm to emerge as the dominant competitor during any given era.

The Effects of a Dominant Firm

Firms have become dominant in the industry when they have been successful in making significant technological leaps forward. Boeing's dominance over the past twenty-five years can be directly traced to its introduction of the 707 which, although it was not the first turbojet introduced, was the first to combine both speed and cost savings for its operators. Similarly, the DC-1-2-3 series dominated airline fleets worldwide in the 1930's. The DC-3 combined advantages in speed, size, range, and cost.

What is most significant about these two success stories is that both Douglas in the 1930's and Boeing in the 1950's were minor competitors in the civil aeronautics business when they undertook their projects. In fact, the DC-1-2-3 series was the first air transport Douglas ever built. History suggests that dominant firms in the airframe industry will be reluctant to make technological leaps forward because they do not wish to compete with their existing and successful product lines and their incentives to undertake the considerable risks involved are less than those of companies with less of a stake in the existing market for aircraft.

In other words, dominant firms become dominant by successfully making significant technological breakthroughs first. They remain dominant by winning any direct competition with other major manufacturers--e.g., the 707 vs. DC-8 and the DC-3 vs. the B-247--and by successfully differentiating products--e.g., the 727 and the 747. But they can lose their dominance by under-investing in technological advances and the R&T necessary to support them.

It should be stressed that incorporating a major technological advantage is no guarantee of success. The de Haviland Comet, the Vickers V-1000, and the Concorde are examples of failed attempts by relatively minor competitors to make technological breakthroughs.

In reviewing these histories of major technological breakthroughs, it is important to recognize the role played by externally generated technology. The DC-3 incorporated a number of innovations first developed elsewhere: the NACA cowling; all metal, stress monoplane structures; and variable pitch propellers (invented in 1871). The inability of the original investors to appropriate all of the benefits of the technologies made the DC-3 possible. Likewise, the KC-135/B-707 was based upon Boeing experience with the B-47 and B-52, both military aircraft.

The findings concerning the incentives of dominant firms to under-invest in major technological advances and the R&T necessary to support them is consistent with the economic literature. A brief summary of that literature would indicate that:

1. Some concentration in an industry may be conducive to invention and innovation because the firms will have sufficient financial capabilities to undertake these activities and because they have an incentive to differentiate their product and thereby earn some monopoly profits; but,
2. High concentration (the case of the dominant firm) can retard progress by restricting the number of independent initiatives and by dampening the incentives of other firms to compete;
3. The key to preserving effective competition in less-than-perfectly-competitive industries is to keep entry barriers sufficiently low so that newcomers can enter or threaten to enter.

4. Access to radical new technologies (and the complementary technologies to support them) is a key to preserving low entry barriers and competition especially in high technology industries.

The Role of Military Intervention

One of the keys to preserving the role of the "newcomer" (the firm seeking to make significant technological breakthroughs) in the aeronautics industry in the United States is that all firms participate in military procurement as either prime or subcontractors. Military R&D expenditures as a percent of total federal aeronautics R&D swamp those of civilian agencies, accounting for over 70 percent of the total.[7] The importance of these military procurements in the development of jet aircraft--e.g., 707, L-1011, DC-10, 747--should not be underestimated. However, even military procurements of a specific type tend to become concentrated, especially as the cost of developing new weapon systems continues to accelerate. This can have carry over effects into the commercial sector. For example, in the early 1950's Boeing had significant technological and cost advanteages over Douglas and the British firms because of their previous work in the B-47 and B-52.

In sum, military procurement can effectively subsidize commercial ventures just as any large customer's purchases

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[7] Aerospace Facts and Figures 1981/1982, Aerospace Industries Association of America, Inc. (August 1981).

can affect the viability of a firm. Such carryover effects can influence competition in the commercial market, and can have distributional consequences in the commercial sector that are independent of public policy. Seen in this light, military procurement can simultaneously preserve the role of the newcomer and help to create or maintain the position of a dominant firm.

Risk in the Civil Aeronautics Industry

A significant policy change whereby the private civil aeronautics industry would be required to bear the burden of conducting R&T currently conducted or sponsored by NASA would add considerable risk in the private sector. One way to evaluate the potential impacts of this additional risk is to assess the level of risk that currently faces the industry.

Certainly the financial difficulties that surfaced with Douglas in 1967 and Lockheed in 1971 atest to the already risky nature of the business. As J. R. Woody puts it:

> The development and production of highly technical new aircraft requires immense financial investments, high production costs, and uncertain delayed returns due to lengthy development and production lead times. The very nature of the product then, has inherent business risks. Whenever airframe producers utilize borrowed funds, these business risks evolve into financial risks as well... Defense airframe demand surges during periods of war but shrivels afterwards, and the cyclical nature of commercial aircraft demand further amplifies these fluctuations.

> Highly variable sales, magnified by financial leverage, heightens fluctuations in profits and intensifies financial risk.
>
> The aerospace industry must also contend with rapidly advancing technology and costs... There are innate risks associated with developing and producing airframes which incorporate new and often untried technology. The emphasis on research and development in the airframe industry is a two edged sword with respect to financial risk, it is costly, and the returns from R&D are highly uncertain.[8]

Earlier, in Section II of this report it was shown that risk could be mitigated if a firm could diversify its activities into several relatively small projects, even if the total level of R&D is relatively high. On the other hand, if the nature of the industry is such that R&D diversification is infeasible, then the risk problem becomes more significant.

The nature of the civil aeronautics industry is, of course, such that very large single R&D projects must be undertaken. Development costs for the 747, for example, have been estimated at $1.2 billion dollars spanning roughly a 3 year period between December 1965 to January 1970.[9] At the time the development of the aircraft commenced, in late 1965, total shareholder's equity was only about $372

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[8] J. R. Woody, Evaluating the Financial Risk of Major Airframe Manufacturers, Ph. D. Dissertation, The Colgate Darden School of Business Administration, University of Virginia, December 1980, pp. 151-152.

[9] RADCAP, Op. Cit., Appendix 9, p. 21.

million.[10] The ratio of development costs to equity was approximately 3.23; that is, the development cost of the 747 alone was more than 3 times the value of stockholders' investments. In short, Boeing was required--literally--to "bet" the company on the success of the 747.

McDonnell-Douglas incurred similar risks in developing the DC-10. Development costs for this aircraft have been estimated at $1.1 billion.[11] The value of shareholders equity was only about $364 million in 1967, the year in which development commenced.[12] The ratio of development costs to equity was about 3.02. McDonnell-Douglas then, was also required to risk the fate of the firm in developing the DC-10.

As the above discussion demonstrates, it is not possible for large aircraft manufacturers to mitigate risk by accepting numerous relatively small R&D projects. The development of large aircraft requires these firms to commit to large R&D programs in excess of the value of the firm. This is in contrast to the drug industry, for example, where average development costs have been estimated at approximately $10 million per chemical entity--less

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[10] Boeing Annual Report.

[11] RADCAP, Op. Cit., Appendix 9, p. 21.

[12] McDonnell-Douglas Annual Report.

than one percent of unit development costs for large aircraft--during the late 1960's.[13]

The degree of risk facing manufacturers of large aircraft is best put in perspective through a comparison with other industries. One appropriate measure is development costs as a percent of average annual sales. These figures are 8.5 and 5.4 percent, respectively, for the 747 and the DC-10.[14] These figures can then be compared with similar data for other industries.

Business Week's 1981 annual survey of R&D expenditures indicates that average R&D as a percent of sales for all manufacturing industries was only 2 percent;[15] it should be stressed that this figure includes <u>all</u> projects undertaken by firms included in the survey. Thus, the <u>single</u> projects undertaken by Boeing and McDonnell-Douglas were several multiples of the average for <u>all</u> projects for these industries in terms of R&D expenditures as a percent

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[13] Scherer, <u>Op. Cit.</u>, <u>Industrial Market Structure and Economic Performance</u>, p. 421.

[14] These figures were computed by first dividing development costs by the development period--assumed to be seven years in both cases which allows inclusion of development costs after commercial introduction--and then dividing average annual development costs by annual sales at the date of development commencement (1965 and 1967 for the 747 and DC-10). Sales figures were obtained from annual reports.

[15] "Annual Scoreboard of R&D Spending," <u>Business Week</u>, July 5, 1982, p. 74.

of sales. In fact, the highest ranked industry--semiconductors--averaged R&D expenditures of only 7.1 percent.[16] Again, this comparison includes only single aircraft projects, versus all projects for the comparison group.

Firms that are required to face substantial risks are typically compensated by higher profits; in other words, in order to accept a risky project, the expected net return on the project must be higher than those for less risky projects. Such has not been the historical trend for firms in the aeronautics industry, however. J. R. Woody writes:

> ... aerospace profits have been less than those for manufacturing corporations in general, despite the relatively higher risks of producing aerospace products. With returns not commensurate with their risks, airframe producers have more difficulty obtaining the necessary external financing to operate.[17]

The profitability trend for aerospace firms--measured as after-tax returns as a ratio of both equity and sales--is illustrated in Exhibit III-7 for the period spanning the 1960's and 1970's. By these measures, aerospace firms lag behind all other manufacturing firms.

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[16] Ibid., p. 73

[17] J. R. Woody, Op. Cit., p. 153.

Another measure of the relative financial risk confronting the aeronautics industry is a comparison of long-term debt/equity ratios with other manufacturing firms. This comparison is illustrated in Exhibit III-8. Briefly, this figure indicates that this ratio has been about 50 percent higher for aerospace firms over the two-decade period spanning the 1960's and 1970's. These figures suggest the aeronautics firms are already financially risky, and may have difficulty in obtaining capital to finance additional risky R&T projects.

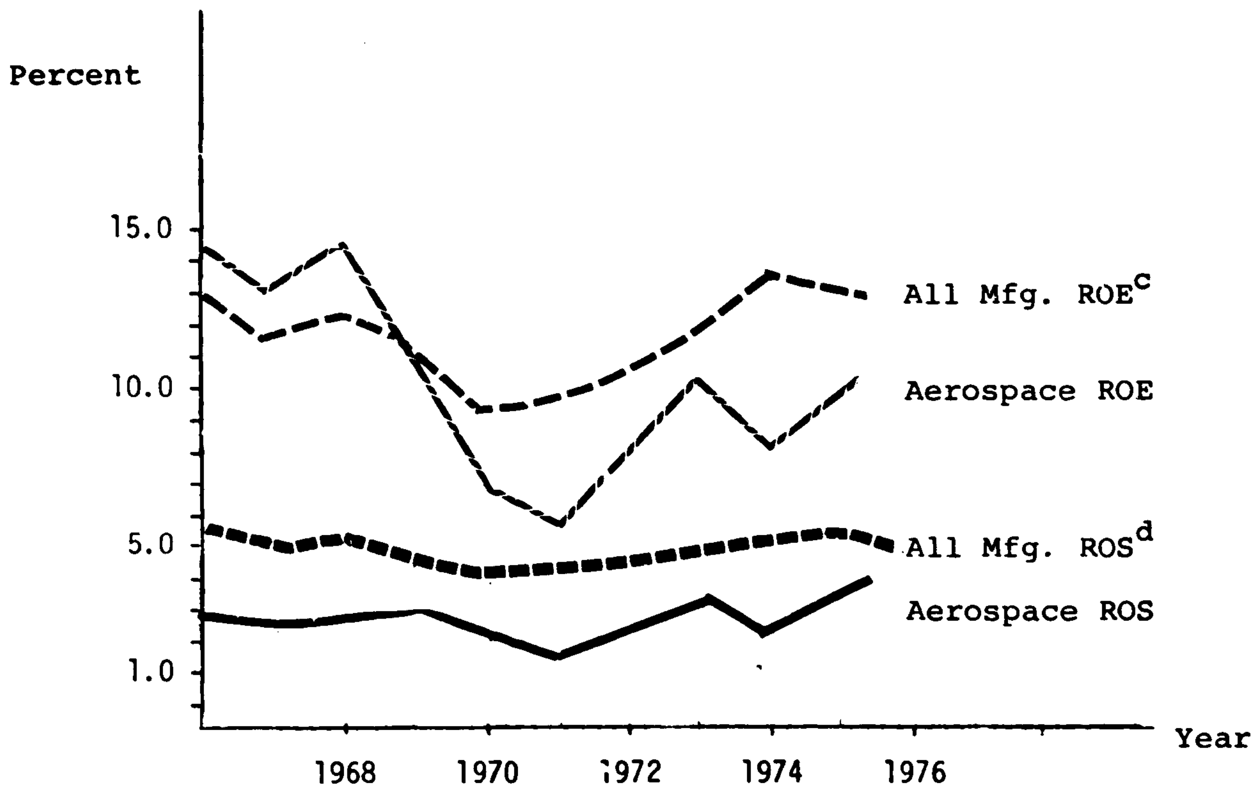
Briefly summarizing, there is strong evidence that firms in the aeronautics industry already face relatively large risks. Given this fact, they are not likely to be able to respond well to the task of bearing additional burdens, especially for relatively risky projects that have been sponsored and conducted by NASA. The effects of risk are therefore parallel to and reinforce those due to the appropriability problem: firm resources are most likely to be devoted to these activities closest to commercialization.

Summary

Access to non-appropriable technologies from other sources--e.g., NASA--appears to be critical to the maintenance of efficient production of civilian transports for the following reasons:

Exhibit III-7

RATES OF RETURN AFTER TAX
AEROSPACE AND ALL MANUFACTURING
1969-1975[a,b]



[a] Aerospace Industries Association of American, Inc. Financial Profile of the U.S. Aerospace Industry, 1960-1973 (Washington, D.C. December 1974) p. 28, citing FTC Quarterly Financial Report for All Manufacturing Corporations, fourth quarter data.

[b] 1974-1975 data from FTC, Quarterly Financial Report for All Manufacturing Corporations, fourth quarter data.

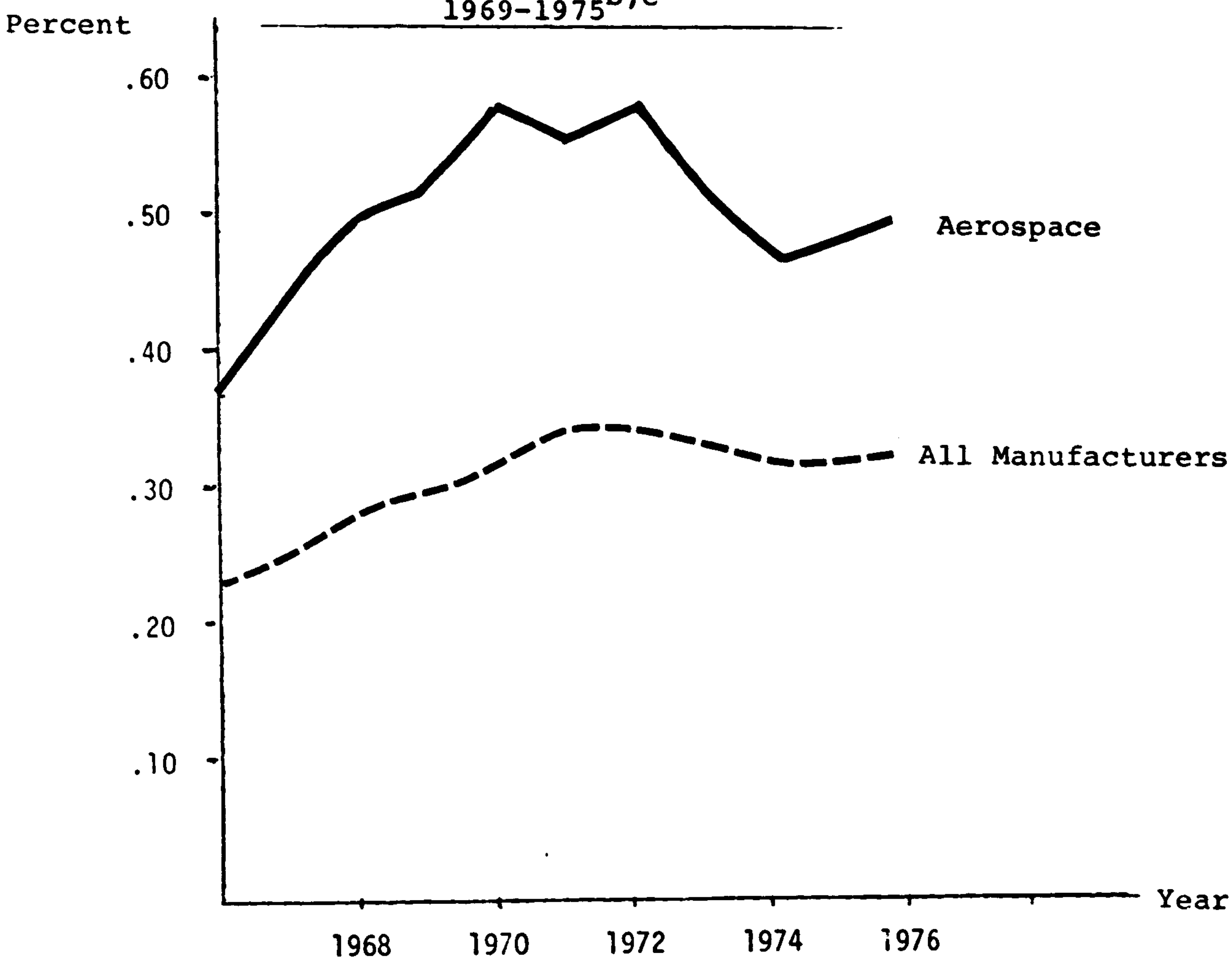
[c] Return on Equity (ROE) is defined as $\frac{\text{Net Income.}}{\text{Stockholder's Equity}}$

[d] Return on Sales (ROS) is defined as $\frac{\text{Net Income}}{\text{Sales}}$

SOURCE: J. R. Woody, op. cit., p. 45.

Exhibit III-8

LONG TERM DEBT/EQUITY RATIOS[a]
AEROSPACE AND ALL MANUFACTURING
1969-1975[b,c]



[a]Long Term Debt/Equity Ratio is defined as $\frac{\text{Long Term Debt.}}{\text{Stockholder's Equity}}$

[b]Aerospace Industries Association of America, Inc., Financial Profile of the U.S. Aerospace Industry, 1960-1973 (Washington, D.C., December 1974) p. A-10, citing FTC Quarterly Financial Report for All Manufacturing Corporations, fourth quarter data.

[c]1974-1975 data from FTC, Quarterly Financial Report for All Manufacturing Corporations, fourth quarter data.

SOURCE: J. R. Woody, op. cit., p. 46

- Firms in general have a tendency to underinvest in R&T, for all the reasons cited previously.
- The existence of dominant firms tends to impede technological progress and competition.
- The financial capacity of aeronautics manufacturers is sometimes debilitated by the monopsony power of airlines.
- The intervention of the military through its procurement and R&T programs can have significant carryover effects in the commercial sector, and in fact can give one firm a competitive advantage--e.g., Boeing in the case of the 707.
- Aeronautics firms already face substantial risks relative to other manufacturers. The industry is not likely to be able to respond well to the burden of accepting additional risky R&T projects.

IV. HIGH TECHNOLOGY AND WIDE TECHNOLOGY BASE: THE CASE OF AERONAUTICS

The key conclusion to be drawn from the partial appropriability model is that market imperfections can cause private firms to underinvest in R&T activities. As a result, output will be more costly to produce and/or the quality of output will be lower than would otherwise be feasible. From a public policy standpoint, underinvestment in R&T may be a particularly serious problem in high-technology industries because:

- These industries tend to grow faster than typical industries in the United States, and, moreover, often provide key inputs used by other industries to increase productivity.
- Many of the high-technology industries also depend heavily on a wide range of inputs from other high-technology industries. (We will refer to such industries as having a "wide high-technology base.") As a result, underinvestment in R&T in one high-technology industry can slow productivity increases in others.

In this section, some of the special characteristics of high-technology industries are outlined. In particular, indicators of research intensity and measures of the width of an industry's high-technology base are developed. This review leads to a discussion of how high-technology firms are exposed to the risk of underinvestment, both in their own R&T activities and in the R&T activities of input industries. Finally, the special nature of aeronautics is examined. Because it depends on so many high-technology inputs, both from its own industry and other industries, the chances are high that, in the absence of government intervention, aeronautics firms will produce less than socially optimal products because of underinvestment in R&T somewhere in the economy. The key implication of this finding is that government intervention in aeronautics R&T markets should cut across industry boundaries to include research in other industries which are likely to underinvest in R&T areas that are relevant to aeronautics.

The Importance of High-Technology Industries in the U.S. Economy

In a recent study prepared for the Cabinet Council on Commerce and Trade,[1] several distinguishing characteristics of high-technology industries were discussed. Of particular

[1] Cabinet Council on Commerce and Trade; "An Assesement of U.S. Competitiveness in High-Technology Industries," Final Draft Report (May 19, 1982).

importance to the present study is the fact that the high-technology industries in the United States in the period 1970-1980 exhibited a growth in real output of 7 percent in contrast with the 3 percent growth rate exhibited by total U.S. business. Complementary figures concerning the rate of inflation, trade balance, and employment growth all indicate that high-technology industries have out-performed the rest of the U.S. economy. These facts by themselves tend to indicate that high-technology industries are special, but their implications for the present study should be reviewed in some detail.

By significantly out-performing the rest of the U.S. economy in terms of growth of output, high-technology industries have made a disproportionately large contribution to what economists term "social welfare." Specifically, the high rates of technological innovation in these industries have led to decreased costs, increased quality of products, increased corporate profits, and increased consumer satisfaction.

One way to examine how the benefits from technological innovation are distributed to both consumers and producers is to compare the social rate of return on innovations with the private rate realized by the innovator. At least two studies in this vein have been completed. The social and private rates of return for industrial innovations from both studies are shown in Exhibit IV-1. A quick perusal of this exhibit will show that, in general, the social rate of return exceeds the private rate of return on innovation by a wide margin. In fact, the median social rate of return is 71 percent while the median private rate of return on innovation is 24.5 percent. There are, of course, exceptions to this trend, but in general one can conclude that society benefits more from innovation than is indicated by the returns to the innovating firm.

It is instructive to review what is included in the private and social rates of return. The private rate of return to the innovating firm includes:

- the net cash flow attributable to the innovation, minus
- profit lost from displaced products, minus
- a proportional share of R&D that never makes a commercial contribution, ("uncommercialized R&D").

The private rate of return, therefore, is net of the profits that otherwise would have been earned if the R&D that led to the innovation had not been undertaken, and also assigns an R&D overhead to the innovation in the form of a proportionate share of the costs of uncommercialized R&D.

Exhibit

SOCIAL AND PRIVATE RATES OF RETURN FROM

INVESTMENT IN 30 INNOVATIONS

Innovations	Rate of return in percent		Innovation	Rate of return in Percent	
	Social	Private		Social	Private
Primary metals innovation	17%	18%	Industrial product A	62%	31%
Machine tool innovation	83	35	Industrial product B	negative	negative
Component for control system	29	7	Industrial Product C	116	55
Construction material	96	9	Industrial product D	23	0
Drilling material	54	16	Industrial product E	37	9
Drafting innovation	92	47	Industrial product F	161	40
Paper innovation	82	42	Industrial product G	123	24
Thread innovation	307	27	Industrial product H	104	negative
Door-control innovation	27	37	Industrial product I	113	12
New electronic device	negative	negative	Industrial product J	95	40
Chemical product	71	9	Industrial product K	472	127
Chemical process A	32	25	Industrial product L	negative	13
Chemical process B	13	4	Industrial process R	103	55
Major Chemical process	56	31	Industrial process S	29	25
			Industrial process T	198	69
			Industrial process U	20	20

	Social	Private
Median rates of return	71.0%	24.5%

Sources: Column (1): Mansfield (et al) "Social and Private Rates of Return from Industrial Innovations" QJE March 1977
Column (2): Tewksbury (et al) "Measuring the Societal Benefits of Innovation" Science 8/8/80

Note: Both articles used identical estimations and data collection techniques.

The social rate of return includes the following:

- o the private rate of return, <u>plus</u>
- o net profits of firms which imitate the innovation, <u>plus</u>
- o savings to consumers that result from the innovation, <u>plus or minus</u>
- o any other benefits or costs attributable to externalities--e.g., effects on the environment, health, safety, etc., <u>minus</u>
- o profits lost on displaced products of firms other than the original innovator, <u>minus</u>
- o a proportionate share of uncommercialized R&D overhead of firms other than the innovator.

The social benefits therefore include the net benefits (or losses) to all producers and to all consumers in the economy.

While the sample of social rates of return to innovation is limited and not directly linked to high-technology industries, it does illustrate how the benefits of technological innovation are distributed to both consumers and producers. Because high-technology industries tend to grow much faster than do other industries, it follows that their contribution to "social welfare" through innovation has also been disproportionately significant relative to the contribution of all other industries.

Having established their importance to the U.S. economy, what remains to be explained is how high-technology industries can be affected by market imperfections which reduce the incentives of firms to conduct R&T activities. This discussion depends upon developing measures of high-technology embodied in the output of industries and upon measures of the width of the technology base of these industries.

Measures of High Technology

The study conducted by the Cabinet Council on Commerce and Trade[2] developed a series of measures of high-technology based upon research intensity. The most direct measure of research intensity of an industry used in that study was the ratio of applied R&D funds to shipments of the industry. However, this measure takes into account only the research efforts of firms and governmental entities involved in applied research and development in a particular industry; it ignores the research and development efforts made by other industries which supply inputs to the high-technology industries.

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[2] Op. Cit., Cabinet Council on Commerce and Trade.

This omission in measuring research intensity is corrected in Exhibit IV-2. Here, research intensity includes the cost of R&D (both private and public) embodied in the inputs used by a particular industry. These estimates were developed utilizing the Department of Commerce Input/Output Model of the U.S. economy. Using the input/output tables, it is possible to determine the value of inputs per dollar of final output for a particular industry. Embodied in each of the inputs is R&D expense. The R&D expense of the inputs to a particular industry as a percent of the value of output is defined as the total research intensity of the industry.

The results of the analysis in Exhibit IV-2 show that the aeronautics industry (aircraft and parts) is one of the top-rated industries in terms of total research intensity. Only guided missles and spacecraft (which sells the majority of its output to the government) and communications equipment and electronic components (a key aeronautics industry supplier) are ranked higher.

The results of the analysis in Exhibit IV-2 indicate that high-technology industries are dependent upon their own R&T activities and the R&T activities of other industries to produce innovations which lead to increases in output and impro ments in the quality of products. To the

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OF POOR QUALITY

Exhibit IV-2

U.S. MANUFACTURERS RANKED BY TOTAL EMBODIED R&D,[1]
THE DOC3 DEFINITION OF HIGH-TECHNOLOGY PRODUCTS[2]

SIC CLASS	DESCRIPTION	TOTAL INTENSITY[3] (PERCENT)
376	Guided Missiles and spacecraft	63.86
365, 366, 367	Communications equipment and electronic components	16.04
372,[4]	Aircraft and parts	15.40
357	Office, computing, and accounting machines	13.65
348	Ordnance and accessories	13.64
283	Drugs and Medicines	8.37
281	Industrial inorganic chemicals	8.23
38 (excluding) 3825	Professional and scientific instruments	5.70
351	Engines, turbines and parts	5.49
282	Plastic and synthetic materials	5.42
	Weighted average all manufacturers	3.30

[1] The total of direct and indirect R&D expenditures.

[2] High-technology products are defined as those having significantly higher R&D embodied in them. Plastic and synthetic materials have 30 percent more R&D embodied in them than agricultural chemicals (the next group of products in the ranking).

[3] Total R&D expenditures, both direct and indirect, as a percentage of product shipments.

[4] Aircraft and parts includes aircraft engines.

SOURCE: Davis, L.A. "Technology Intensity of U.S. Output and Trade," Office of Trade and Investment Analysis, U.S. Department of Commerce, February 1982.

extent that these industries or their suppliers are characterized by market imperfections which can lead to underinvestment in R&T, their performance, measured in terms of output and quality changes, is at risk. Some of the elements of that risk can be further elucidated by examining the width of the technology base of these high-technology industries.

Measures of the Width of Technology Bases

The risk that underinvestment in R&T will hurt an industry depends not only upon the incentives to conduct R&T in that industry, but also on incentives which exist in other industries. The wider the technology base of an industry, the more it is "exposed" to the risk of underinvestment.

To examine how important the number of supplying industries is to the research intensity of high-technology industries, an analysis has been developed based upon the 1972 Input/Output Tables for the United States.[3] Shown in Exhibit IV-3 is the input/output structure of the high-technology sectors of the U.S. economy. The numbers in the columns of this table are the value of inputs from high-technology industries per dollar of final output of

[3]U.S. Department of Commerce: "The Detailed Input-Output Structure of the U.S. Economy, 1972" (Volume 1) (1979).

Exhibit IV-3

Value of Inputs From High Technology Industries Per Dollar of Total Output of High Technology Industries (1)

SIC Codes	I/O Industry Number	Guided Missles & Space Vehicles	Ordnance & Accessories	Industrial Chemicals	Plastics & Synthetic Materials	Drugs & Medicines	Engines, Turbines & Parts	Office, Computing, Accounting Machines	Communications & Electronics	Aircraft & Parts	Professional & Scientific Instruments
		13.01	13.02-13.07	27.01	28	29.01	43	51	56-57	60	62-63
376	13.01	.01362	---	---	---	---	---	---	---	.00011	---
348	13.02-13.07	.00065	.08089	.00002	.00001	.00003	---	---	.00002	.00008	---
281	27.01	.00002	.00001	.19229	.28952	.02604	.00005	.00018	.00482	.00082	.00444
282	28	.00110	.00029	.00332	.02075	---	---	.00146	.01015	.00239	.00696
283	29.01	---	---	---	---	.06151	---	---	---	---	---
351	43	---	.00290	---	---	---	.10745	---	---	.00076	---
357	51	---	---	---	---	---	---	.06476	.00039	.00205	---
365-7	56-57	.05447	.00888	.00007	.00004	.00020	.00004	.05815	.18528	.05789	.01930
372	60	.09302	.00497	.00002	.00001	---	---	.00001	.00001	.15955	.00001
38 exc 3285	62-63	.00746	.00021	.00152	.00159	.00207	.00042	.00326	.00129	.00943	.05482
	High Technology Inputs Excluding Own-Industry Inputs	.15672	.01726	.00495	.29117	.03834	.00051	.06306	.01668	.07353	.03090
	Number of Supplying Industries	6	6	6	5	4	3	5	6	3	5
	Ranking (Based on No. of Supplying Industries)	(2)	(2)	(2)	(3)	(4)	(5)	(3)	(2)	(1)	(3)

(1) Inputs for an industry are read down the column. All numbers are in dollar per dollar of final output.
Source: "The Detailed Input-Output Structure of the U.S. Economy: 1972" (Volume 1) (1979)

(2) Aircraft and part includes aircraft engine.

the high-technology industry shown in the column heading. For example, the first entry at the top of the column furthest to the left of the page indicates that 1.3¢ of the final output of guided missiles and space vehicles is attributable to purchases from that same industry. The entry just below indicates that .065¢ of inputs from the ordinance and accessories industry is purchased per dollar of output of the guided missiles and space vehicles industries.

But the numbers in this table, are less important than the patterns of high technology inputs for different industries. The aircraft and parts industry (aeronautics) purchases inputs from all other high-technology industries with the exception of drugs and medicine. No other high technology industry exhibits as much width in its high-technology base. In contrast, for example, the engines and turbines industry (which excludes aircraft engines) is dependent upon only three other high-technology industries for its high-technology inputs.

Another indication of the width of the high technology base of the aeronautics industry is shown in Exhibit IV-4. Here, the OSTP Aeronautics Policy Study Working Group devised a classification of basic discoveries and innovations in aeronautics and other industries which remain to be exploited by the aeronautics industry. This exhibit

Exhibit IV-4

Classification of New Technologies to be Exploited in the Aeronautics Industry

Microelectronics

Active Control: Stability, Structural
  Response, Variable Camber
Propulsion Control
Microprocessors, Displays
Weapons, Voice Actuation
Robotics
RPV's

Materials

Composites, Metal Matrix
Structural Concepts, Stealth
Processing Techniques
High Temperature: Ceramics, Coatings
Aeroplasticity
Weight, Durability, Fatigue

Aerodynamics Ideas

Vortex Lift
Laminar Flow Control
Circulation Control
Turboprops
Tip Shapes, Winglets
Configurations

Large Computers

Numerical Techniques
Computational Fluid Dynamics
Integrated Design, CAD/CAM
Material Structural Analysis
Aerolastics and Acoustics

Lasers

Experimental Techniques
Navigation
Weapons

Fiberoptics

Controls, Displays

Fluidics

Hydraulics, Actuators

Source: OSTP Aeronautics Policy Study, Working Group emphasizes the large and growing role that electronic devices (classified under microelectronics, large computers, lasers and fiber optics) are likely to play in the advance of aeronautics technology in the next 10 to 15 years. This high dependence on electronic components is a relatively new phenomenon and has resulted from fundamental advances in the microelectronics, computing, and communications and electronics components industries. This suggests that the relative importance of supply industries in the high technology base of the aeronautics industry tends to change over time as the pace of technological change in other industries accelerates or decelerates. This finding suggests government R&T policy in the aeronautics industry should be sensitive to changes in the industry's technology base. In supply industries where underinvestment is likely to occur, government intervention may be appropriate.

The aeronautics industry not only exhibits high research intensity, but also is highly dependent on other high technology industries for inputs. The chance is greater that market imperfections in other high technology industries will have a detrimental affect on the aeronautics industry than is the case for other high technology industries. This finding is particularly important when one considers the interdependence of inputs in the construction of aircraft. The unavailability or low quality of inputs from certain key industries--e.g., electronic components--can affect the design and performance of many other aeronautics systems. Seen in this way, market imperfections in other industries can have an effect on the quality and cost of aeronautics products which are disproportionately large relative to the cost of the other-industry inputs.

Implications

A review of measures of research intensity and width of the technology base for various industries has demonstrated that the aeronautics industry is characterized by high research intensity and a wide technology base. That is, aeronautics depends upon R&T performed within the aeronautics industry and on R&T performed by virtually every other high technology industry. The implications of these findings depend directly upon the appropriability of R&T in the high-technology industries and on the appropriability of R&T in the industries that supply them. In particular, to the extent that there are market imperfections in either the aeronautics industry or its high technology supply industries, the performance of the aeronautics industry--measured in terms of growth of output and quality of products--will be hampered.

The dimensions of "exposure" to market imperfections depends upon whether firms are able to appropriate the benefits of R&T. Exhibit IV-1 summarized findings that showed that the median social rate of return on innovation exceeds the private return to the innovation by a wide margin. Admittedly, the social rate of return figures include benefits to consumers which are seldom capturable by the innovator. But, the social rate of return also includes the positive profits of imitating firms; the presence of these other-firm profits tends to reduce the private marginal incentives to innovate. As a result, firms will quite generally tend to underinvest in R&T.

The effects of underinvestment in R&T are magnified in high-technology industries where research intensity and a wide and changing technology base play a major role in the production process. The exposure to this problem appears to be particularly acute in the aeronautics industry. The key implication of this finding is that government intervention in the aeronautics R&T market should cut across industry boundaries to include research in other areas which are likely to exhibit private underinvestment. For example, many of the advances in materials science that have been applied to aeronautics have been funded by the government. Such funding is justified in cases where metals firms are unable to capture a significant portion of the benefits derived from a technological advance. This will often be the case because the demand for the material is small relative to the benefits derived by aeronautics firms and their customers.

V. POLICY IMPLICATIONS

For the most part, the analysis has focused on the problem firms in general, and aeronautics firms in particular, have in appropriating the benefits from their activities. To the extent that there are imperfections in the market for aeronautics R&T or for R&T embodied in inputs used by aeronautics, there is a rationale for market intervention by the government. The question addressed in this chapter is: what type or types of market intervention (if any) should the government use to correct the market imperfections.

Based on a review of several policy options, the "as is" scenario is preferred. The "as is" scenario contemplates the retention of the current institutional relationship between NASA and the civil aeronautics industry. This recommendation does not address the scale issue--that is, the specific level at which NASA should be operated. Rather, the conclusion is that the potential consequences of any major change in the institutional relationship between NASA and the industry are undesirable. There is one area of concern: changes in the current arrangement regarding user charges at NASA facilities may improve efficiency. A more complete discussion of this issue is provided later in this chapter.

Obviously, any public policy recommendation must take into account the issue of appropriability and the consequences of underinvestment in the civil aeronautics industry. But, there are four other factors which should be considered in making market intervention decisions:

- o Scale economies in conducting aeronautics R&T,
- o Military spillovers,
- o Industry structure,
- o Risk and the payback period.

The first three of these are defined briefly below.

The term "scale economies in conducting R&T" refers to a situation in which certain R&T activities can be conducted in a more cost-effective manner in large and sophisticated facilities. For example, the NTF facility has a greater capacity to analyze Cord Reynolds numbers than do other existing wind tunnels. In this case, a larger-scale facility leads to both cost reductions and better research.

In judging the appropriateness of various public policies, however, the real issue is whether there is a need for more than one or, at most, a few aeronautics research facilities. At least in the case of the NTF, it is apparent that given its expense and the likely utilization of the facility, the nation--both the public and private sectors--currently requires only one such facility. To the extent that this is true of other aeronautics facilities, we should consider whether the various policy scenarios are likely to lead to the continued provision of them in the future.

Military spillovers can take on several dimensions. For example, technology transfers often occur (in both directions) between the military and the civilian sectors of the aeronautics industry. Additional spillovers occur to the extent that the military gains surge capacity in production from the civilian sector during time of war. Again, we should evaluate the way in which the policy scenarios address these military spillovers.

The policy scenarios considered also can affect the structure of the aeronautics industry. It is appropriate to consider not only whether the policy scenario would tend to lead to increased monopolization, but also what the strategic behavior of firms would be vis-à-vis their competitors under different policy regimes.

Each of the criteria listed above were selected based on economic efficiency considerations. Appropriability is an issue because the inability of private firms to capture benefits will lead to underinvestment in R&T in the industry. Underinvestment will reduce economic efficiency in the sense that a greater amount of scarce resources will be otherwise required to produce a given level of goods and services. Scale economies is clearly an efficiency consideration: the failure to take advantage of scale economies will require unecessary duplication of expensive facilities and manpower. Military spillover effects result in the provision of civil transport services and national defense at lower costs than would otherwise be incurred. Industry or market structure is likewise an efficiency criterion: if a public policy results in diminished competition in the industry, the standard inefficiencies attributable to market imperfections associated with greater monopoly power will occur (i.e., higher prices, restricted levels of output, and inefficiency in production). Finally, substantial risk and long payback periods--like inappropriability--are likely to cause underinvestment in R&T.

Policy Scenarios

There are five scenarios which describe the range of options available with respect to government intervention in the aeronautics R&T market. These scenarios, listed in the order in which they will be considered, are:

- The free market/invisible hand scenario,
- The free market/subsidy--tax credit scenario,
- The user charge scenario,
- The free market/monopoly R&T conglomerate scenario,
- The "as is" scenario.

<u>The Free Market/Invisible Hand Scenario</u>

This scenario represents a situation in which some or all NASA programs are eliminated and the burden of conducting research and technology is placed on the private sector.

<u>Appropriability</u>

As it relies solely on the private sector to conduct R&T, this scenario is appropriate only if no serious market failures due to the partial appropriability of aeronautics R&T can be detected. The analysis indicates that appropriability is generally a problem in R&T markets. The exposure of aeronautics to underinvestment in R&T is particularly acute because of the high research content and wide technology base which characterizes aeronautics production. In short, one would expect to see substantial underinvestment in those R&T activities most difficult to appropriate--basic research, and some applied research and infratechnology--under this scenario.

Scale Economies in Conducting R&T

While it may be feasible for the government to sell off some of its large-scale facilities, such as the NTF, the building of new facilities could be threatened under this scenario. Moreover, there would be a propensity to conduct development work at some of these facilities at the expense of discipline research. In addition, the economic viability of facilities designed to conduct mostly discipline research would be threatened as the demand for this type of work declines. Finally, and perhaps most importantly, all work conducted would be owned exclusively by the firm conducting research, thus eliminating the dissemination of data and reducing the rate of technology transfer within the industry. A likely result would be the duplication of expensive experiments, which would remove one of the primary benefits attributable to the scale factor.

Industry Structure

Under this scenario, it is likely that firms with well-established positions in certain product lines would have an advantage over their competitors in conducting certain types of R&T. For example, a firm with several civil transport projects under way simultaneously could spread its R&T activities over a larger revenue base than could a smaller competitor. Because the results of these R&T activities would not be transferred, as they are through NASA, it is likely that the industry would become more concentrated.[1] Furthermore, the market imperfections typically attributable to monopolies--higher prices and lower output--would be more likely to be present in the industry than they are today.

Military Spillovers

A more concentrated industry structure would affect the military in two ways. First, fewer firms would be involved in both military and civilian markets, and, as a result, competitors disadvantaged in civilian markets would be less able to provide the surge capacity that may be necessary in the event of war. Second, the tendency toward increased concentration in the civilian market could spillover into military markets and adversely affect the cost-effectiveness of DOD procurements.

Risk and Payback Period

Neither the risk nor the payback period problems would be mitigated under the free market/invisible hand scenario. Rather, the burden of conducting risky projects having relatively long payback periods would be placed on the private sector.

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[1]We recognize, of course, that by some measures, the industry is already highly concentrated. Nonetheless, potential competitors or entrants into the industry do exist, thus mitigating the concentration of actual producers. For a fuller discussion of this topic, see Section III on technological rivalry.

Conclusions

The free market/invisible hand scenario does not lead to a set of attractive results in terms of the criteria for public policies outlined above.

The Free Market/Subsidy scenario

In this situation, some or all NASA programs are eliminated and R&T responsibilities are given to the private sector, but the government subsidizes private R&T efforts. Subsidies could be designed to encourage certain types of R&T, either the most desirable or those types where problems of appropriability are present. The subsidies could take the form of direct payments, additional IR&D allowances or tax credits; the implications are the same for any form of subsidy.

Appropriability

Theoretically, at least, it is possible to subsidize firms to conduct less attractive R&T activities than they would in the absence of subsidies--e.g., discipline, infrastructure, and certain types of applied research. The ideal subsidy would compensate the firm for R&T benefits that could not otherwise be appropriated.

Several rather difficult management problems emerge, however. These include:

- Designing and administering a subsidy scheme that would overcome private firms' natural propensity to conduct proprietary R&T, while, at the same time, avoiding overcompensation.
- Developing a workable forum in which government subsidized R&T is publically disseminated. (Otherwise, the rate of technology diffusion--both within the aeronautics industry and to other industries--will decline substantially. The diffusion of technology should be encouraged so that the spillover to other aeronautics firms and other industries can be realized.)
- Avoiding the unwarranted duplication of R&T efforts.

Although the subsidization of privately conducted R&T may be a conceptually attractive option for eliminating or reducing underinvestment in neutral technology, as a practical matter, the management of such a program would be difficult.

Scale Economies in Conducting R&T

To the extent that the subsidized R&T would be conducted in facilities that are smaller than necessary for maximum efficiency, the cost of the research and the size of the subsidies would be greater than would have been the case had the research been done in larger, more efficient NASA facilities. To remedy this situation, the government could subsidize firms to acquire certain types of R&T facilities. In that case, the government could find itself subsidizing duplicate installations, thereby increasing the overall cost to the nation of aeronautics R&T. Because of these problems, it would be necessary to continue the operation of NASA facilities in order to take advantage of scale economies.

Industry Structure

The effects of this scenario on industry structure are unclear. On the one hand, the government could elect to provide subsidies more or less on an equal basis to all firms in order to maintain the current number of competitors in a given product line. On the other hand, the government could be more selective in its subsidy decisions with the possible effect of providing one or only a few firms with significant advantages over competitors. In the latter case, the industry would tend to become more concentrated and the market imperfections attendant to monopoly would become more likely. In the case where all firms were subsidized equally, the cost of aeronautical R&T could be much higher than it is today. In addition, it is likely that the free market/subsidy scenario would discourage the potential entry of new firms into the industry. Even if subsidized R&T were publicly disseminated, existing firms would have a greater advantage over potential entrants than they do under the current arrangement.

Military Spillovers

If all civilian-oriented firms were subsidized on an equal basis, then the cost of joint military/civilian programs would increase. Selective subsidization of certain private civilian aeronautics programs and the resulting increased concentration in civilian markets would (1) reduce surge capacity in time of war and (2) potentially reduce competition for military procurements. In addition, selective subsidization of civilian programs could adversely affect military contractors currently working on large scale military procurements.

Risk and the Payback Period

The subsidy scenario would reduce only slightly the problem of the payback period and would have no impact on risk. The problem of the payback period would be slightly mitigated because private firms would receive some funding as they conduct R&T activities, thus reducing the net cost of projects. It is unlikely, however, that this would significantly reduce the duration of time necessary to achieve the break-even point, since the subsidy would only be large enough to compensate the firm for otherwise inappropriable benefits.

Although the subsidy would reduce the net cost to the firm of conducting neutral R&T, it would not otherwise affect the probability of a successful commercial outcome. Thus, the subsidy would not reduce risk.

Conclusion

The free market/subsidy scenario would reduce under-investment due to market imperfections and have a small positive impact on the payback problem. Difficult administrative problems would emerge, however. In addition, this scenario would not resolve scale or risk problems and may, in the long-run, produce an undesirable market structure.

The User-Charge Scenario

An alternative policy would have NASA retain all of its current joint activities with industry and the military, but these users would be charged fees sufficient to cover NASA costs. This alternative contemplates that NASA would conduct no R&T on its own, but would merely serve the military and private sectors as a contractor.

Appropriability

Under this scenario, NASA would conduct none of its current research activities that are unrelated to either private-sector or military development programs. These are precisley the types of R&T activities which the private sector is least likely to replace--i.e., discipline research, infratechnologies, and certain types of applied research. As a result, civilian aircraft could in the long run be more expensive and of lower quality than is feasible for a given level of resource expenditure. Inevitably, military aircraft would be affected in the same way because there could be reduced technology spillovers from the civilian sector and because the military might be less willing (than NASA) to conduct R&T activities which are far removed from current military development programs.

Scale Economies in Conducting R&T

Because the NASA facilities would remain intact and would remain available for industry and military use, this scenario would have no direct impact on the benefits attributable to scale economies in conducting R&T.

Industry Structure

The effect of this scenario on industry structure is unclear. Firms with large market shares in a particular product line might be better able to protect their competitive position *vis à vis* smaller rivals as technological change slowed in the industry. A reduction in competition could occur for two reasons. First, potential entrants would be discouraged somewhat because of the slowdown in the diffusion of technology. Second, the technology base of the industry in general would tend to mature which could lead to a stabilization of market shares. Two examples of this latter effect would be the steel and auto industries in the post-war era. Like the auto and steel industries, a reduction in technological rivalry would make the domestic aeronautic industry more suseptible to a major shakeout caused by the entry of well-financed foreign rivals. However, it is difficult to forecast whether the effects of a reduction in technological change would be as strong in the aeronautics industry as it has been in the steel and auto industries.

Military Spillovers

One of the main results of this scenario would be a slow-down in civil R&T activities related to discipline research, infratechnology, and certain types of applied research. This could have an effect on the quality of some military aircraft, especially to the extent that NASA represents a critical mass of research talent which would be lost or reduced in size. Although the military might be able to provide some of the R&T activities which are particularly relevant in military applications, the rate of technical progress in the civilian sector would be slowed which would adversely affect spillovers to the military sector. The suseptibility of the domestic industry to foreign competition could also adversely affect military programs.

Risk and the Payback Period

To the extent that a significant reduction in investment in neutral R&T occurred, both the risk and payback problems would become moot issues.

Conclusion

The user-charge scenario is unsatisfactory for two reasons. First, as with the free market scenario, a substantial reduction in nonproprietary R&T would occur; this scenario would not resolve the problem of market imperfections in R&T. Second, the military would no longer enjoy the benefits of sharing current NASA R&T complementary to its own needs. Unlike the free market scenario, however, the benefits from scale economies in conducting R&T would be realized.

The Free Market/Monopoly R&T Conglomerate Scenario

The objective of this scenario is to allow private firms to assume R&T responsibilities, giving them the opportunity to form an R&T conglomerate to take advantage of scale factors and facilitate the transfer of technologies among participating firms.

Appropriability

In theory, by participating in an R&T conglomerate, each firm could capture the benefits of joint research. Furthermore, this conglomerate would have incentives to conduct the types of R&T that single firms might not conduct because of market imperfections.

Scale Economies in Conducting R&T

Presumably by forming a conglomerate, the industry could spread the cost of large-scale facilities over all of their product lines. As a result, in theory, the cost of conducting R&T would be at least as low as is currently the case through the use of NASA facilities.

Industry Structure

Obviously, this scenario holds a certain attraction at least with respect to appropriability and scale economy issues. The question is whether firms would have sufficient inventive to join and to operate efficiently such an R&T conglomerate. First, one must question whether firms currently holding strong positions in certain product lines--e.g., commercial transports--would have incentives to join a conglomerate and whether their participation could pass antitrust tests. Clearly, market leaders would be of two minds when considering the research conglomerate. On the one hand, they would want to join to insure that they have available to them any significant research results that might be forthcoming. On the other hand, if they did not join, and the research conglomerate were not productive, the market leaders might be able to exploit their current market positions for a longer period of time.

In reality, the decision may rest with the Antitrust Division of the Justice Department. In a recently completed policy statement entitled "Antitrust Guide Concerning Joint Research Ventures"[2] the Justice Department lays down a series of general guidelines concerning research conglomerates. One of the key characteristics of these guidelines is that the Department will choose to study very carefully any R&T conglomerate which would include firms having more than 25 percent of market share in any particular product line. Clearly, this would represent a problem for market leaders in several aeronautical product lines, including commercial transports, large-scale engines, and perhaps helicopters.

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[2]U.S. Department of Justice, Antitrust Division, (November 1980).

Whether these antitrust problems could be overcome cannot be answered here, but it is likely that any research conglomerate excluding the market leaders in aeronautics would not be able to generate sufficient capital to be effective. Yet, participation of those firms in a conglomerate would be subject to antitrust problems.

Military Spillovers

The effects on the military depend directly on whether the R&T conglomerate is successful. A productive conglomerate would be a good substitute for NASA programs. However, it seems unlikely that either the administrative or antitrust problems that would surface in an aeronautic R&T conglomerate could be overcome. An ineffective R&T conglomerate would: (1) reduce competition in the civilian industry, which could adversely affect competition in the military sector, and (2) reduce the rate of technological innovation in the civil sector which could adversely affect both the cost and quality of military aircraft.

Risk and Payback period

By combining R&T resources in a conglomerate, aeronautics firms would be able to diversify their R&T risk. The conglomerate structure would have no effect on the payback period.

Conclusion

In theory, a R&T conglomerate would reduce the private appropriability problem and capture scale economies in research. However, there are likely to be significant administrative problems in organizing and maintaining such an organization because of the strategic behavior that is likely to arise. In addition, there may be antitrust problems in organizing the conglomerate.

The "As Is" Scenario

This final policy contemplates no changes in the institutional role currently played by NASA in the civil aeronautics industry. Certain aspects of the funding of NASA R&T activities, however, might be altered. These will be discussed presently.

Appropriability

In general, NASA R&T activities concentrate on discipline research, infratechnology, and certain types of applied research. These are precisely the R&T activities which private sector firms have least incentive to conduct because of the imperfections in the R&T market.

One weakness of this policy scenario, however, is the difficulty of determining the appropriate scale of NASA activities. Having demonstrated market failures in the R&T market--i.e., that private markets will tend to underallocate resources to R&T--does not address the issue of "how much" and exactly what type of R&T NASA should conduct. Theoretically, of course, NASA should expand (or contract) each R&T project so that the incremental social benefits are equated with incremental program opportunity costs. The absence of price signals from the market, however, makes it difficult to assess potential social benefits. As a result, both the scale and type of R&T must be based on scientific judgement of the likely social benefits.

<u>Scale Economies in Conducting R&T</u>

NASA currently operates several large-scale facilities which may exhibit significant scale economies. In some cases, there may be no need for more than one of these facilities--e.g., the NTF. In making these facilities available to the private sector and the military, NASA reduces the cost of aeronautics R&T.

<u>Industry Structure</u>

The institutional structure of NASA is designed to make available to the industry virtually all of the research results that are forthcoming. In this way, NASA not only promotes rapid technological advances, but also ensures that spillovers from neutral technologies are captured by aeronautics firms and other industries. By providing a common technology base for the aeronautics industry, NASA also keeps all aeronautics firms up-to-date on technological advances and thereby enhances actual and potential competition in the industry. Finally, because NASA's activities are far removed from commercial applications, its near-term effects on industry structure should be neutral.

Military Spillovers

By disseminating the results of its R&T activities, NASA keeps aeronautics firms technologically current which enhances the capabilities of these firms to provide surge capacity for military production in time of war. The common technology base provided by NASA also has spillover effects in the military sector which reduces the cost and increases the quality of military aircraft.

Risk and Payback Period

NASA conducts R&T which is most risky and characterized by the longest payback period. These are precisely the activities that private firms are likely to underinvest in; NASA R&T activities therefore complement private R&T.

However, the fact that a specific risky R&T project is conducted by NASA instead of a private firm will not necessarily change the likelihood of a success. This, however, is not the sense in which risk will be reduced.

rather as a centralized government institution, NASA can pool the risk of several projects together, thus mitigating risk through diversification, in other words, the risk facing individual members of society, whom NASA represents, is collectively less than the risk that any one single firm would face. Moreover, given the already high level of risk facing firms in the private sector, there is a substantial likelihood that they will be unwilling or unable to accept additional risk.

It should also be recognized that NASA, like private firms, may have a bias toward projects that have the potential for more immediate success. At NASA, however, the criterion for success is scientific discovery rather than commercial payoff. Since scientific discovery preceeds commercial development in the typical product cycle, the "as is" scenario, with NASA conducting and sponsoring basic and applied research, does remedy, at least partially, the problem of the payback period.

Conclusions

The current institutional arrangement between NASA and the private civil aeronautics industry is appropriate. NASA R&T activities tend to correct for private underinvestment in R&T, promote efficiency in the production of R&T, and facilitate military apillover. Moreover, they are at leat neutral with respect to industry structure.

Final Comments Concerning NASA User Charges

The major conclusion of this study is that the institutional role played by NASA in the civil aeronautics industry is appropriate from an economic standpoint. However, the allocation of resources within NASA facilities remains problematical, even while recognizing that imposing a fee system for all uses may have the undesirable effect of biasing the allocation of resources away from neutral technologies.

This problem is discussed in some detail below. First, a solution is offered that considers only the economic efficiency aspects of the problem. Following this, a discussion of practical and administrative problems is provided.

Currently the demand for some NASA facilities exceeds their capacity. The root cause of the queues, or excess demand, is that many users place a greater value on use of the facilities than the fee charged for them. In short, the price is too low.

Before describing a solution to this problem, it is appropriate to explain why excess demand poses an economic efficiency problem. Anytime excess demand exists in a market, an economic "shortage" is created. When a shortage exists, there is no guarantee that those who benefit most from the scarce service--i.e., use of the facilities--will gain access to the service. The expected benefits from users are best measured by the price they are willing and able to pay. If the queue is eliminated by charging a price sufficiently high to eliminate excess demand, those users placing the highest value on the service will receive the service. This follows since any potential user could gain access to the facilities by bidding-up user charges. This, in fact, is the method by which the market system allocates goods and services among many consumers.

It is also important to note that the true economic cost of the use of such facilities <u>cannot</u> be measured by the variable or marginal cost of operating the facility. Rather, the true cost must be measured as the benefit foregone by the <u>best</u> project that does <u>not</u> gain access to the facility. This cost, in a very real sense, is an opportunity cost.

The central question is: What price should be set for use of facilities with excess demand and who should pay this price? The answer, based on strict economic efficiency criterion, is straightforward. User charges should be set such that the queues are eliminated[3] and all users, including NASA and the military, should pay this price.

One problem, of course, is that both NASA and military budgets are funded institutionally. As a result, there is a concern that basic or discipline research will be squeezed out in favor of commercial users. Theoretically, this need not be the case. The budgets of both NASA and the military could be adjusted upward so that they could compete with private users, or with each other. The net effect on the federal treasury would be zero since fees paid by NASA and the military would ultimately be returned.

What is important, from an efficiency standpoint, is that all users consider the true opportunity cost of using the facilities. Again, this can be measured as the benefits foregone by the best user excluded from the facilities. Setting prices that eliminate excess demand will guarantee that these costs are recognized. The fact that private users exist affords the convenience of having signals from the private market that serve as indicators of true user costs.

[3]The elimination of the queue need not be interpreted literally. Some waiting lines are normal in typical business operations. So long as individuals in the queue are not willing to pay for the privilege of earlier use, waiting lines pose no problem.

As a practical matter, of course, there are several administrative problems that surface with the prescribed economic solution. These include:

- Practical problems of administrating user charges that eliminate the queue but are not so unstable as to create uncertainty problems.
- The administration of recycled funds paid by NASA and the military.
- The difficulty facing administrators in estimating budgets in the face of changing user charges.
- The impacts on the private sector of uncertainty regarding future user charges.
- The fact that many existing R&T projects, both privately and publicly funded, were based on expectations of relatively low user charges.

As a policy matter then, final resolution of this problem must weigh the potential gains in economic efficiency with the resulting administrative burdens.

For practical purposes, it may be desirable only to adjust the current technical merit selection process to increase the information available to the administrator of the facility and to charge certain groups for use of the facility when such charges are unlikely to have undesirable effects. For example, by charging the military the marginal cost of NASA facilities, military planners would be induced to consider the effects of their research in their own budgets instead of depending upon implicit subsidy from NASA. Such a charging system is unlikely to affect significantly the ultimate allocation of military resources or spillovers from military R&T, but it would aid planners in assigning priorities to new projects.

Likewise, it may be appropriate for NASA to evaluate the current fees it charges to private firms conducting proprietary research in its facilities. Any reallocation of private resources would be unlikely to have an undesirable effect on spillovers to other aeronautics firms or other industries because the research involved is proprietary.

In summary, the allocation of scarce NASA resources should continue to be governed by the likely future benefits of the R&T projects. The current technical selection mechanism may be the only feasible means of approximating these likely future benefits. However, keeping track of the costs of these activities and charging for military research and proprietary private research may improve the technical merit selection process.

As a final note, higher user charges may <u>not</u> be the best solution, even in terms of strict economic efficiency criteria. Specifically, the demand for some facilities could be sufficient to justify the construction of new facilities or the expansion of existing facilities. This would be the case if the total expected benefits of expanded capacity exceeded the long run opportunity cost of construction and operation. In that case, raising user charges to levels that would eliminate the queue would be inefficient.

VI: SUMMARY AND FINAL COMMENTS

The major conclusion of the present study is that the current institutional arrangement of NASA with respect to the civil aeronautics industry should continue, including the maintenance of R&T programs which cut across industry boundaries. The current role of NASA is to address the problem of underinvestment in aeronautics R&T which arises for the following major reasons:

- Firms in all industries will quite generally tend to underinvest in R&T when they are unable to capture sufficient benefits from innovations to justify investment in these activities.
- This problem appears to be particularly acute in the aeronautics industry because: (1) so much of the technology is disembodied as opposed to being a physical entity which can be easily patented;[1] (2) firms find it difficult to diversify the risk inherent in the many large-scale R&T activities in aeronautics; (3) aeronautics production is characterized by high research

[1]Recall that "disembodied" technology represents knowledge that need not be imbedded in a physical entity.

intensity and a wide high technology base which increases the likelihood of aeronautics products being more costly or of lower quality as a result of underinvestment either in the aeronautics industry or in other high technology industries.

The study has addressed a full range of possible policies to address the problem of underinvestment in R&T and aeronautics, the main conclusion is that the current institutional role played by NASA should be preserved because:

- NASA's current activities focus upon those R&T areas which are most likely to be subject to underinvestment--basic research, the production of infratechnology, and applied research.
- The spillovers between the civil aeronautics industry and the military sector are more easily taken advantage of within an institution whose mission includes the transfer of technology.
- The spillovers between the civil aeronautics industry and other industries within the economy are best facilitated in an institution which addresses directly R&T activities which cut across industry lines.

- Competition between aeronautics firms--in both the civil and military sectors--is more likely to be preserved with NASA involvement than without NASA involvement in aeronautics R&T.
- The cost of aeronautics R&T is likely to be lower through government intervention in those cases where large-scale facilities are required.
- By centralizing R&T resources, it becomes possible to diversify the risk of large-scale R&T projects.
- Because NASA, as a government institution, operates under a different set of incentives than do private firms, it will be more patient in awaiting the payoffs from R&T activities--especially those furtherest removed from commercialization.

Final Comments

One final question remains: whether aeronautics is in some way unique or special? Answering this question would require a broad-based comparative study of the market for R&T activities in many other industries--especially high technology industries. Such an undertaking is beyond the scope of the present project. Nonetheless, the finding that NASA's present institutional role is the most efficient means of overcoming the problem of underinvestment in R&T may mean that civil aeronautics is special (or unique) but it is also probably true that new (but perhaps different) policies may be required in other high technology industries to address similar problems. For example, currently the Congress is deliberating whether or not it would be appropriate to extend the duration of the life of patents for those industries such as the drug industry which are subject to significant delays in product introductions because of time-consuming and costly safety regulations. Such a policy may adequately address the problems of underinvestment in research in the drug industry because, aside from the problem of regulatory lag, patents do provide adequate means for innovating drug firms to capture the benefits of their new product introductions. In contrast, lengthening the duration of the life of patents would have little or no effect on the incentives of firms to invest in R&T in the aeronautics industry where so much of the technology is disembodied as opposed to being embodied in physical devices or chemical compounds.

What this suggests is that the problem of underinvestment in research and in the development of technology is a general problem which affects the private sector and especially high technology industries where research makes up a significant portion of the firm's production processes. The aeronautics industry may be special in that while significant portion of its output is sold in the private sector, it is still economically efficient for the government to play an active role in R&T activities. Government participation in the production of R&T is also appropriate in cases where the government is the sole buyer of high technology products--missiles and spacecraft, and ordnance. But this form of government intervention may not be appropriate in other high technology industries where the problems of underinvestment may arise for quite different reasons.