ENERGY LABORATORY

MASSACHUSETTS INSTITUTE
OF TECHNOLOGY

PERSPECTIVES ON THE GOVERNMENT ROLE IN NEW TECHNOLOGY DEVELOPMENT AND DIFFUSION

Drew Bottaro*
Paul R. Carpenter**

MIT Energy Laboratory Report No. MIT-EL 81-041

November 1981
revised December 1981

"Your planet is very beautiful," he said. "Has it any oceans?"

"I couldn't tell you," said the geographer.

"Ah!" The little prince was disappointed. "Has it any mountains?"

"I couldn't tell you," said the geographer.

"And towns, and rivers, and deserts?"

I couldn't tell you that, either."

"But you are a geographer!"

"Exactly," the geographer said. "But I am not an explorer. I haven't a single explorer on my planet. It is not the geographer who goes out to count the towns, the rivers, the mountains, the seas, the oceans, and the deserts. The geographer is much too important to go loafing about."

- Saint Exupéry
<u>Little Prince</u>

I. INTRODUCTION

The last two decades have seen a considerable expansion in the level of direct governmental involvement in technology develoment, particularly in energy related technologies. The last year has seen a dramatic retreat from this policy. Is there any sense that we can say that the particular program activities which constituted this expansion and now the retreat were based on sound economic criteria? Why does the discussion of federal involvement in technology development and diffusion (also known as "commercialization") seem so mind-numbing? Are economists part of the problem of lack of focus in this debate or are we part of the solution? Four years of direct involvement by the authors in one of these technology development programs (solar photovoltaic conversion) has led us to reexamine these questions.

Economists have been fond of using the concept of market failures or externalities to justify government involvement in technology development. But coincidentally, we have also been fond of arguing that none of these failures prescribe government involvement on a technology-specific basis. As George Eads observed a decade ago, we have left policy makers and program managers with little to guide them in the decision to fund or to design and manage these programs:

> This gap is caused in part by the fact that the theory of externalities and the conditions under which its simplest prediction is a proper guide to policy have not been clearly understood by those formulating U.S. government science and technology policy. This misunderstanding has been abetted by the failure of economists to present the theory of externalities in an operational form. We economists have given policy makers a theory that possesses a great deal of political attractiveness, but we have failed to develop the tools that would allow us either to show those government officials charged with implementing science policy how the theory should be applied in specific cases or to demonstrate to them and to the public that the theory is being misapplied.[1]

While we do not propose to provide all of these tools in this brief paper, we do propose to present a framework around which the theory can be made relevant to the program manager.

---

[1]George Eads, "US Government Support for Civilian Technology: Economic Theory Versus Political Practice," Research Policy, Vol. 3, 1974, p. 2-16. (Emphasis added).

The remainder of this paper is divided into two major sections which correspond to the questions whether (is there a government role?) and how (if the government is involved, how should these programs be designed and managed?). In the first section we will characterize the traditional economic literature on this subject and present the market failure concept as we believe it relates to technology-specific activities. In the "how" section a framework for program design will be presented and the example of solar photovoltaic technology will be used to illustrate its use. This section and the paper will close with some comments on the problems inherent in government-managed programs with some suggestions for improvements as well as a discussion of industry market structure and its implications for program management.

II. IS THERE AN APPROPRIATE GOVERNMENT ROLE?

A. Current Theories

Like the Little Prince's geographer, the economists who have contributed to this field have largely been concerned with the "whether" question and not the "how". While it is not immediately obvious that the literature falls into a convenient classification scheme, we detect a spectrum of approaches that range from a direct frontal assault from a theory perspective to a case study approach that evaluates past program successes and failures. The work which best represents the theory perspective and the only paper that to our knowledge treats the question of whether government support should be given on a technology-specific basis is Schmalensee (1979).[2,3] This work contributes three valuable conclusions with regard to the government role question:

- There is no efficiency basis for treating energy technologies as a special case even under domestic energy price controls. (The "why not textiles?" argument).

[2] Richard Schmalensee, Appropriate Government Policy Toward Commercialization of New Energy Supply Technologies, MIT Energy Lab. Working Paper 79-052WP, October 1979.

[3] Other work here includes Eads, op. cit.; Nelson, Richard, The Moon and the Ghetto, New York: Norton, 1977; Joskow, Paul and Robert Pindyck, Should the Government Subsidize Non-conventional Energy Supplies?, MIT-EL 79-003WP, MIT Energy Laboratory, 1979.

- When domestic energy prices are less than world prices and in a world of certainty, general output subsidies are usually superior to selective input-subsidies.

- With decontrolled domestic prices and in an uncertain world, selective governmental intervention may be warranted if there are market failures associated with buyer information, or institutional problems in the appropriation of benefits. (Schmalensee finds this case unpersuasive and warns that governments, like markets, are also imperfect.)

This third conclusion is only briefly developed in Schmalensee, but unfortunately it is the only one of immediate relevance to our concerns here.[4]

The other end of the literature spectrum is represented by the Rand Corporation's study of the factors which led to the success or failure of 24 government-supported commercial demonstration projects.[5] The important conclusions of this study have to do with when demonstration projects (one of may potential activities, as will be discussed later) are likely to be successful. Rand argued on the basis of the cases studied that the technolgoy must be "well-in-hand" to show significant diffusion after the demonstration. This work does not and was not intended to address the more general question of the government role beyond demonstration projects nor does it discuss how demonstration

---

[4]Our analysis should not be construed as being limited to energy technologies, and for all intents and purposes domestic energy prices have been, or will be, decontrolled. Finally, we live in an uncertain world where it is not generally possible to write perfect contingent claims contracts.

[5]Baer, W., et. al, "Analysis of Federally Funded Demonstration Projects," The Rand Corporation, R-1925-DOC, April 1976.

projects fit into the entire "commercialization process."

The concept of a "commercialization process" from basic research through diffusion is not new in any sense, having been developed at some length in the R&D management literature. It was connected with the concept of market failures in an energy market context by the MIT Energy Laboratory Policy Study Group work[6] in 1976. This final piece of the literature is a start at drawing the linkage between the motivation for government support and program design and management. Unfortunately, the MIT report does not distinguish between market failures which justify technology-specific activities and those that do not. Rather, it breaks down the technology development process by stages and analyzes the appropriateness of the governmental role as a function of the technology's developmental stage.

In the remainder of this section we examine briefly the market failures which are inherent in the development of new technologies. Some, we believe, justify technology-specific involvement by the government; our reasons are spelled out. Finally, we examine briefly but do not attempt to resolve the issue of evaluating the severity of these market failures.

---

[6]MIT Energy Lab Policy Study Group, "Government Support for the Commercialization of New Energy Technologies," MIT-EL 76-009, November 1976.

B. Traditional Justifications for Governmental Involvement in New Technology Development

Several market failures are commonly used to justify governmental intervention in the development of new technologies. They range from price problems to various market uncertainties to market structure concerns; a brief review of them will set the subsequent discussion.

Perhaps the most commonly discussed market failure in the energy field is incorrect prices. Typically, price distortions in oil and gas markets are raised, although coal, nuclear, and electricity are also portrayed as victims of this market failure. Its sources are usually ascribed to non-competitive market structures (e.g. OPEC), price regulation (price controls or rate regulation), and subsidies (e.g. the oil depletion allowance). These price distortions can lead to underinvestment in new energy technologies which, it is often argued, make governmental intervention into development of those technologies desirable.

Imperfect information flow between producers and consumers is also raised as a source of market failure. The inability of consumers to convey to producers exactly what their needs are results in some uncertainties in the profits producers will realize from investments in new technology production equipment; hence they tend to underinvest in such equipment. Similarly, the inability of producers to describe exactly the characteristics of their products results in some consumer uncertainty regarding the product and hence some underconsumption which results in underinvestment.

A similar market failure involves the coordination necessary between developers of the new technology and developers of the production equipment for the new technology, as they are often not the same. This market failure is obviously more applicable to technologies which will be produced in quantity such as ultra-sound scanners or heat pumps.

If the benefits which flow from the development of a new technology cannot entirely be captured by the innovator, a diminished incentive to invest in the development of new technologies results. This inappropriability of the innovation's benefits should be alleviated by the availability of patents; there are those who would argue about the efficacy of our patent system.

Finally, the existence of a non-competitive market structure has been alleged to inhibit the development of new technologies. The Schumpeterian hypothesis argues the contrary, however, and the evidence is not entirely persuasive on either side.

C. Justifications for Technology-Specific Governmental Involvement in New Technology Development

In general, the above market failures may provide justification for governmental involvement in new technology development, depending upon their significance. Whether action should be taken on a broad basis which is technology-neutral or whether it should occur on a technology-specific basis is another matter. Technology-neutral actions do not select particular technologies such as "semiconductors" or "oil shale" as targets for government funding, whereas technology-specific actions do so select, often in the form of "programs" for particular technologies.

While in theory technology-neutral governmental action is optimal, it is not clear how to design programs which are even-handed across all technologies. For example, how does one develop a tax credit based upon the degree of information imperfection existing in a market? And who receives the tax credit? Obviously some classification of potential recipients according to the particular technologies is essential or else the IRS cannot determine how much credit to allow to whom.

1. Output versus input subsidies

Previous analysis of the question of technology-neutral versus technology-specific governmental involvement has taken the form of a discussion of the relative merits of input subsidies as compared to output subsidies. Input subsidies are awarded to various inputs to the technology development process; some examples include grants for prototype testing and for research on various aspects of the technology's design or operation. Output subsidies are awarded on the basis of the technology's energy output. Output subsidies, it is argued, are technology-neutral; any technology which produces the desired output receives the subsidy. Input subsidies, on the other hand, can do no better than output subsidies because at best they will duplicate the results of the technology-neutral output subsidies and at worst they will subsidize unfruitful technologies at the expense of ones which, *ad hoc*, would have been successful.

But are output subsidies really feasible? Perhaps they make some sense for synthetic fuels and other new energy supply technologies, but they make little sense in other instances. Indeed, some of the problems make them seem more clumsy than input subsidies; one serious practical problem, apparent with the solar tax credits, is the inability to predict budgetary impacts with any reasonable accuracy.

One large problem arises in applying them to energy conversion technologies, which include heat pumps as well as conventional heating systems; both convert energy in the form of electric or chemical potential into kinetic energy in the form of heat. Clearly the "output" from such technologies depends upon the capital and energy inputs. An output subsidy would give a greater subsidy to a large, energy-inefficient conversion device than to a small, efficient one, even if capital costs per unit output were identical! The problem here is that it is not obvious what the output measure should be: BTU-equivalents, barrels of oil displaced, or some other measure.

The existence of output subsidies, while useful in some contexts, is not in itself sufficient for denying or minimizing the need for technology-specific governmental assistance for development of new energy technologies. It is now appropriate to examine reasons why a need does exist for technology-specific action in certain instances.

2. Market failures which justify technology-specific governmental involvement

Of the five market failures listed in section II.B above, we argue that some of them justify technology-specific action by government while others do not. We begin by dismissing those which do not seem to warrant technology-specific governmental involvement.

First, the problem of mispriced energy supplies is addressable better through changes in price controls or, should that prove politically or institutionally infeasible, price subsidies to alternative fuel supply technologies. The effects of incorrect energy prices are widespread and the adjustments which must be made in response to them pertain to many technologies. Ideally these subsidies can be made technology-neutral, though there may be some problems even with that, as the preceding discussion indicates. In any event, we do not think that incorrect energy prices are a sufficient justification for technology-specific programs in most instances.

Also, the problems of non-competitive market structures and their implications for new technology development do not constitute a sufficient basis for technology-specific intervention into the marketplace. In our opinion, the evidence to date on the consequences of market concentration upon innovation is not persuasive enough to rest governmental involvement solely on this market failure. Indeed, the Schumpeterian hypothesis argues to the contrary. Should this thorny issue become better resolved within the economics profession, perhaps undue market concentration could become a satisfactory basis for action; that time has not yet arrived.

We do think that the other identified market failures are sufficient in themselves for technology-specific governmental involvement, assuming they are sufficient in magnitude. The inappropriability of the benefits of new technology development is likely to vary from technology to technology; some technologies exhibit highly localized learning effects while others do not. The differences in the localizability of benefits have little or nothing to do with the potential value of the different technologies but are artifacts of the particular technologies involved and the extent of relevant technological progress that has occurred to date. Furthermore, determining the appropriate level of governmental involvement to alleviate this market failure requires a fair knowledge about the technological opportunities facing society; the governmental action, in whatever form it ultimately takes, is likely to take into account the specifics of the technologies examined rather than attempt to devise a generally applicable formula for lending support.

The other two market failures (imperfect information flow and lack of coordination between producers and technology developers) both pertain to information asymmetries among actors in the marketplace. How significant these asymmetries are will vary from technology to technology, again without regard to the potential value to society of the various technologies. Some of the miscoordinations may even be due to institutional barriers created by the government. In any event, any governmental involvement in these problems is likely to come through technology-specific actions rather than attempts at broad-scale structural changes within society.

These arguments hold, we believe, in a first-best world where no impediments to reaching equilibrium exist. We believe they are made stronger in a second-best world in which the market failures we have identified have been technology-specific and, in effect, have favored existing technologies.

> What is readily apparent is that the appropriate degree of compensation for any tendency to underinvest will vary widely by industry. This suggests that industry-specific programs are more likely to produce appropriate results than are programs applicable to all industries.[6a]

We are somewhat comforted in our views by a comparison to recent views on the behavior of the Japanese government in relation to its industry. Far from the popularized view of "Japan, Inc.", this government seems to be involved in its industry in two ways.

First, it insures the availability of one key resource -- trained professionals -- to industry. In addition, it finances cooperative applied research and experimental development in technology-specific areas of significance (e.g. shipbuilding). The actual commercial development of the resulting products or processes is left to industry. In this fashion Japan deals directly with the inappropriability market failure.

Second, it provides export market assistance in the form of an organized export trading ministry. In this manner Japan helps to alleviate the information and coordination problems associated with emerging technologies.

[6a]Eads, op. cit. p. 7.

D. Evaluating the Significance of Failures in Markets for Developing Technologies

We have identified two types of market failures which justify technology-specific intervention in the marketplace. However, as all market failures are present to some degree or another in all markets, the question ultimately becomes one of evaluating their significance.

Measuring the significance of failures in particular markets would help immensely in determining whether technology-specific action is warranted. Unfortunately, econometric measurement techniques are not precise enough to give solid quantitative answers to these questions.[7] Hence, the judgments of many on the significance of particular market failures all too often seems to be subjective. The need for more detached analysis is strong and would go far in improving the quality of policy analyses concerning government involvement in new technology development and the strength of the resulting recommendations.

We do not pretend to address this issue beyond merely pointing out its importance. Its significance for the present discussion, however, is that if we do not have precise knowledge of the extent of these market failures, then <u>of necessity</u> we are operating in a situation in which bounded rationality reigns. Alternatives must be compared by policymakers on the basis of scant knowledge, and decisions will be made.

---

[7]For an attempt to quantify learning effects in the case of nuclear power, see Zimmerman, Martin, "Learning Effects and the Commercialization of New Energy Technologies: The Case of Nuclear Power," prepublication draft, MIT Sloan School of Management, June 1981.

What is the role of the economist giving policy recommendations in this case? The decisions to be faced are often political. Without hard numbers the economist's role is largely advisory. Nevertheless, the economist can establish broad principles for future decisions which are as far removed from subjectivity as possible. We have presented our views for discussion on what those principles should be when the question is whether to embark upon a technology-specific governmental program. The economist's role need not end here, however. As there are times when technology-specific programs are warranted, the questions of how to manage such programs and, perhaps more importantly, when to stop them, will benefit from discussion by economists. The following section presents our framework for approaching these issues.

III. DESIGNING AND EVALUATING COMMERCIALIZATION PROGRAMS

Once the decision has been made about the need for developing a particular technology through the use of a technology-specific governmental program, the questions of designing that program and evaluating its continued usefulness must be explored. This section provides a framework for approaching two basic questions concerning program design and evaluation. First, what are the activities which the technology-specific program should include in its design? Second, at what point should the governmental involvement stop?

The example of photovoltaics is presented to provide a context for the framework's subsequent discussion. In essence, the framework presents methods for characterizing, in relatively simple terms, the products which a technology-specific governmental program should produce as they relate to the stages of development of each aspect of the technology. These two dimensions of the process are combined into a matrix which is then used to determine which technological products at which stages of development are to be the objects of technology-specific governmental attention, and for how long.

A. Basic Photovoltaic Technology

The Department of Energy has pursued a program for developing photovoltaics over the past several years. The program's content has changed somewhat from year to year as funding levels has risen and fallen. The salient characteristics of the technology are presented below.

Photovoltaics convert sunlight and other solar radiation into direct current electricity through the use of thin semiconductors, usually in wafer form, which produce their power when exposed to the sun. At current prices photovoltaics systems are upwards of ten times the prices they would have to be to compete effectively with centrally-generated electric power. The governmental efforts to date have focused upon ways to lower present prices by addressing several aspects of photovoltaics technology.

Materials: Most photovoltaics semiconductors are made from crystalline silicon, which is expensive and accounts for much of the high cost of photovoltaics. Efforts to reduce the costs here have examined materials other than silicon and ways to produce crystalline silicon from its raw material (sand or quartzite) more cheaply.

Production: Currently most photovoltaics modules are made by slicing crystalline silicon ingots into wafers, turning the wafers into semiconductors, connecting them by soldering, and encapsulating them.

Automating many of these procedures would result in economies of scale in production and would reduce the cost greatly.

Module: Photovoltaics are currently made into modules with metal substrates and glass covers of dimension 1' x 4'. Increasing the size may reduce costs. Also, innovative concepts which abandon the notion of a module include rooftop photovoltaics shingles which would theoretically save installation costs.

Photovoltaics system: Photovoltaics modules produce direct current. In order to meet most electrical needs of today, this must be inverted into alternating current at 60 hz. Furthermore, the waveform of the resulting alternating current must be close to a particular shape; this is achieved through power conditioning devices. The complete system must also be installed safely and economically.

Efforts here have tried to reduce the power conditioning device and installation costs, in some cases by trying to combine the inverter and the power conditioning equipment into a single device.

B. Delineating an Appropriate Governmental Role

What follows is a suggested framework for delineating the proper governmental involvement in a particular technology's development. It begins with the nature of the technology in question, proceeds to a discussion of the different roles possible (grouping them according to their relationship to stages of technological and commercial development), and describes how the framework can be used to design or evaluate technology-specific governmental programs. The case of photovoltaics is used to demonstrate the use of the framework.

1. Technology Products of Governmental Involvement

Initially one must determine what technological progress has to occur before a new technology becomes successfully integrated into the marketplace. While this may seem rather obvious, it provides one way of describing the content of a technology-specific governmental program. It indicates what research and engineering obstacles must be overcome before the technology can be called a market success. The definition of success is, of course, relative to the market as that determines whether the ultimate product will achieve widespread diffusion.

The technological progress needed to get from the existing state of technology to the desired one can be represented as a series of "technology products". A technology product is an engineering advance which either increases capabilities or reduces costs. The series of technology products summarizes the technological roadmap for getting from here to there and is useful in assessing alternative technological strategies.

One way to characterize the technology products is according to their upstream-downstream sequence in production. For example, in the photovoltaics case described above, the "technology" is described from the point of crystal manufacture to the installation of a complete system. The key features of the technology which were described were those for which some innovation was possible which would help reduce costs to an acceptable level. The potential innovations were grouped into four broad categories: materials, production processes, photovoltaic device, and photovoltaics system. More generally, these could be described as raw materials, production processes, device, and final product.

These four categories of technology products can be used to describe most technology development situations. Not every new energy technology will have technology products in each category; however, this does not diminish the usefulness of the categories. For example, oil shale technology products would not include anything in the device or final product categories as the oil shale production process results in (somewhat tautologically) shale oil; shale oil is almost exactly analogous to petroleum-based oil (hence no need for "device" technology products as the device is already in the market) and it does not need additional equipment to make it marketable (hence no need for "final product" technology products). Using these categories focuses attention on the first two for the oil shale case. On the other hand, for a technology such as photovoltaics, technology products are required in all four categories, and their use ensures that any program will not omit key technology products such as installation procedures and power conditioning equipment.

2. Problem-solving Roles Which Government May Play

The roles which government may play in developing a particular technology product vary with the distance from the existing state of the technology to the desired one. This distance is typically measured by phases of technological development. While there are many different paradigms for phases of the innovation process, they are all fairly similar, and we use one in which an innovation moves from basic research through technology, engineering, and market development. These phases are described in some detail below.

As a technology undergoes change, it passes through the four phases on its way to becoming commercial, each phase being characterized by different types of information development and transmission. The strict sequence of the phases should not be given sacramental importance, as it is only an approximation of the actual timing. The point to emphasize here is that because of the differences in information developed and transmitted in each phase, the governmental problem-solving role changes also. This point will be discussed further in subsection B.3 below.

<u>Basic Research:</u> Basic research involves scientific investigation aimed toward understanding the scientific principles underlying the behavior of things. It does not necessarily aim toward a specific solution but rather toward the development of basic information which may spur innovation. In the context of a technology-specific governmental program, this basic information is helpful in selecting the overall

strategy for achieving the desired technological progress. For example, in photovoltaics the research into basic properties of different semiconductor materials helps in selecting among crystalline silicon and the other options for reducing the cost of the materials.

Technology development: As the technology develops, the eventual product begins to take on a more definite shape, and information about the processes for producing it is developed. This information is gathered by testing of prototype devices and the building and operation of pilot production facilities, among other activities. In photovoltaics, technology development activities could include both of the above, although actual efforts to date have stopped short of pilot facilities.

Engineering development: Once the device's form and characteristics are fairly well established, the device and its related system components must be proved in actual operating environments. This is often done initially with test facilities, with engineering field tests following. Photovoltaics systems were initially tested on laboratory rooftops before being tested on actual residences.

Market development: In this phase comes the first "live market" tests of the products. Possible roles for government are dwindling at this stage. Primary possibilities for governmental roles at this point could include actual market testing and broad-scale information dissemination to both potential users and affected regulatory institutions. Talk of these has occurred in the photovoltaics efforts to date. The development of information appropriate for digestion by regulatory institutions is an interesting role which one branch of government might play in trying to achieve technological change despite the actions of other branches.

This classification of potential problem-solving roles which the government may take helps in analyzing different proposals for program design or modification. As described below, it should be used in conjunction with the technology products categorization to help match governmental roles with the technology products needed.

3. Using the program design and evaluation matrix

The technology products categories and the problem-solving roles classifications can each be represented as separate axes on a matrix, as shown on the following figure. This analytical tool will help its users ask more detailed questions about the appropriateness of a selected technology-specific governmental program. In essence it decomposes the simple question of whether technology-specific involvement is warranted into a series of questions, one for each cell in the matrix. The questions become more refined, thus making the resulting analysis more satisfactory to economists and non-economists alike.

To use the matrix for designing a technology-specific program, one must simply ask whether either of the two types of market failures discussed in section II is present to a sufficient degree to warrant

Problem-solving "Roles"

Technology "Products"

	Basic Research	Technology Development	Engineering Development	Market Development
Raw Materials	A	A,B		
Production Process	A	A,B		
Device			B	b
Final Product				b

A = Inappropriability

B = Coordination

governmental action. If so, then the roles indicated in the horizontal axis are appropriate to include in the program for the technology products indicated on the vertical axis.

For example, we have taken the liberty to fill in the matrix for photovoltaics based on our own subjective judgment about the relative seriousness of various problems in the development of photovoltaics technology versus other possible uses of public funds. We do so in full light of the difficulties of measuring the significance mentioned in section II.D above solely for the sake of argument and not to propose that we have the "right" photovoltaics program in our grasp. We have indicated with capital letters where we think the more serious market failures are in the matrix, with lower case letters where they are less serious, and with blank areas where we do not perceive significant market failures.

Our strawman program indicates that there is an appropriate governmental role in basic research into semiconductor materials and photovoltaics production processes. As these are somewhat intertwined with some of the more radical design concepts (e.g., continuous process crystal growth and module manufacture), both technology products need coordinated research activities. The inappropriability market failure is strongly operative here.

Both kinds of market failures are operative in the technology development phase of materials and process development. Coordinaton of module designers, production process equipment suppliers, and materials suppliers (often different firms) are essential if the requisite cost reductions are to obtain. The device itself could appropriately be the object of engineering development activities as a market failure exists in the coordination between photovoltaics module manufacturers and installers.

Whether the coordination market failure is serious enough in the market development phase to warrant involvement is an open question; hence our entry of lower case letters for the device and final product. There are many institutional problems which might impede diffusion of photovoltaics technology; problems in hooking up with the local utility, problems with codes, and possibly insurance problems are a few examples. While theoretically sufficient, these problems might not be that much worse for photovoltaics than for other technologies which currently are bought and sold in the marketplace. There may be some inappropriability problems with being the first firm to resolve these institutional issues; again, the seriousness cannot be accurately estimated.

Once a program has been established, the same matrix approach can be used to evaluate how well the program is running or the desirability of modifying the program. (These days "modifying" means "cutting".) The same basic approach applies: Are the market failures which gave rise to the need for the program still serious enough to warrant continuation of each activity currently in operation or proposed for addition or deletion? Used as such, the matrix provides a convenient device to ensure that the right question gets asked.

C. Management Issues

As we indicated earlier in our brief characterization of the literature, Schmalense (1979) argues that in many cases "imperfections" in government management may be as serious as the market imperfections these programs are designed to correct. Our experience indicates that this concern is not to be taken lightly. In this section we will examine some of the conditions required for successful management of these programs, drawing further on the photovoltaics example. Where improvements in the current process are warranted, we will suggest them. In this connection five areas will be discussed: program flexibility, program uncertainty, political constraints, and recommendations for management organization structure.

1. Program Flexibility

One of the central themes of the framework discusson earlier was that the proper timing of certain governmental activities depends strongly on the occurrence of specific events, notably the achievement of certain technological milestones (expressed in economic terms) and the relative economics of different market segments. Since no one can perfectly forecast these events, multi-year program design must be based on an educated expectation of and variance around their occurrence contingent, of course, on budget levels.[8] By necessity, then, the

---

[8]The best way to make these determinators (eliciting expert judgement) is an important area of research. The record with respect to cost estiamtion has historically been bleak; c.f. Merrow, Edward, et al., A Review of Cost Estimation in New Technologies: Implications for Energy Process Plants, R-2481-DOE, Santa Monica, California: The Rand Corporation, 1979.

program must be flexible enough to be modified (even terminated) should expectations or conditions change. For example, should world energy prices rise faster than expected or should the costs of nuclear energy or coal-fired power plants become more prohibitive than expected, technology development objectives may be better served by a greater emphasis on flat-plate silicon photovoltaic technology serving central station utility needs than waiting to make central station engineering development decisions based primarily on the availability of photovoltaics made from exotic materials (e.g. amorphous silicon). Conversely, should (for whatever reason) the expectation of the availability of low-cost flat-plate silicon photovoltaics shift from 1982 to 1984, then engineering development activities relying on flat-plate silicon technology and its expected cost should probably also be delayed.

These program flexibility concerns underscore the need for analysis and evaluation capability in the management organization. Of particular importance are costing capabilities which allow the detailed examination of the effects of scale, materials, and process modifications[9] on product cost, and market analysis tools which estimate market potential based on product performance, price and the cost of alternatives. Technology and engineering development activities should include the use of field experiments and controlled market research to calibrate and verify the results of these analysis tools.[10]

---

[9]See for example, R.G. Chamberlain, A Normative Price for a Manufactured Product: The SAMICS Methodology, DOE/JPL-1012-79/5, Jet Propulsion Laboratory, Pasadena, January 15, 1979.

[10]G.L. Lilien, The Diffusion of Photovoltaics: Background, Modeling, Calibration and Implications for Government Policy, MIT-EL-78-019, MIT Energy Laboratory, Cambridge, Massachusetts, May 1978.

2. Program Uncertainty

Since one Congress cannot bind the next, future U.S. legislation affecting energy market must be treated as in part random. Similarly, the future actions of state and Federal regulatory authorities are in part unpredictable and thus a souce of risk. Risk that derives from the unavoidable unpredictability of U.S. governments' actions can be central here.[11]

While flexibiliy to respond to changes in the market and technology is a necessary feature of successful program management, flexibility to the point of uncertainty can be its undoing. Due to the nature of the Congressional authorization-appropriation process, budget level uncertainty can never be completely eliminated. Recent budget cutting fervor in Washington is an all too painful reminder of this uncertainty. Another source of uncertainty is year-to-year changes in internal program budget allocation. In particular, the urge to throw money at individual firms or ideas which promise miraculous results without subjecting them to the same technical scrutiny or competition as the other alternative approaches should be strongly resisted. The process argued for in this paper is one of predictability, with the option to accelerate or decelerate as events dictate. Once a fundamental philosophy and approach is determined, however, it should be followed. This is the essence of multi-year planning.

Should program uncertainty be so rampant as to adversely affect private investment decisions,[12] then it can easily be argued that

---

[11]Richard Schmalensee, Appropriate Government Policy Toward Commercialization of New Energy Supply Technologies, MIT Energy Lab. Working Paper 79-052WP, October 1979, pp. 44.

[12]Arguably, this was the situation faced by solar heating and

program imperfections have merely substituted for market imperfections with possibly negative results.

3. Political Constraints

One of the characteristics of U.S. governmental activities is that they consist of some mix of administrative and legislative actions, and technology development is certainly no exception to this. In particular, as program activities become publicly visible, either in the technology or engineering development phases, Congressional influence tends to turn from general program budget concerns to specific project design concerns. Often this concern for program content stems from what is considered to be inaction or lack of aggressiveness on the part of the administrative authority.[13] This multiple-authority management can be disastrous due to the often inappropriate timing of program activities and internal misallocation of program resources. Numerous examples also abound in nearly every technology class of premature pork-barrel demonstration projects, the failures of which either lead to costly overruns or damanged technological credibility or both. Most program

---

[12](continued from previous page)
cooling products with the uncertainty surrounding federal tax credits over the last several years. Of course, whether the solar tax credits were an appropriate commercialization tool to be employed at this time is another matter.

[13]This is most certainly the situation in the creation of FPUP (Federal Photovoltaic Utilization Program) where what was considered a void in DOE photovoltaic commercialization plans was filled by a program of congressional origin. Most analysts of photovoltaic commercialization viewed this program as poorly timed and of questionable design.

managers seem to view these projects as an unfortunate but necessary evil to maintain public (i.e., Congressional) visibility.[14] Perhaps pork-barrel projects are unavoidable, but certain actions may help to minimize their frequency and impact. First, the elimination of perceived gaps in the program approach should serve to minimze the projects proposed to fill the gaps. We think our framework helps accomplish this. The everpresent political tendency to over-accelerate or eliminate technology development programs must be tempered with sound technical judgment, which does not always mean catering to "industry" wishes. Second, the explicit set-aside of a small amount of program resources for the purpose of funding unsolicited proposals or "innovative concepts" may serve as a tool to channel political pork-barrel proposals so that they may be evaluated against each other and the program in terms of timing and technical content, and thus, limited in size.

Other institutional factors may place contraints on program design and management as well. One manifestation of this constraint could be termed "inertia for technology losers." One of the major questions above

---

[14]In a totally serious discussion in Chapter V, "Implications for Congress" of the report by the Office of Technology Assessment, The Role of Demonstrations in Federal R&D Policy, 1978, p. 45, we find:

> "In contrast to their limited usefulness in the R&D framework, demonstrations are considered by many be to politically attractive. Demonstrations permit modestly priced responses to emerging political problems; they are, in a sense, a means of symbolic action. Demonstration projects can show constituents that Washington is doing something for them. Demonstration may be a means of delaying policy decisions while additional information -- both technical and political -- is accumulated. Demonstrations are a convenient point of compromise between those who would do much and those who would do little."

concerned the decision to drop losing options. Complicating this decision is the tendency of program players to fight to retain support for their losing options. Political pressure can often be effectively applied even if all technical and economic judgement indicates that the organization's pet project is a clear loser. This applies to non-profit research organizations as well as private industry.[15] Solutions to this problem are not easy, but it clearly calls for regular and credible program assessment.

4. Organization Structure and Goal-Oriented Management

Several implications for program organization structure should be obvious from the previous discussions. First, the requirements of the suggested approach imply that the management of technology development cannot be separated from the management of engineering or market development activities.[16] Second, it is probably more desirable to structure the organization along the lines of our matrix elements, where clear tasks and roles vis a vis private industry can be assigned than to attmept to mimic a corporate organization structure.

A frequent criticism of commerialization programs is that they are either too "goal-oriented" or that they have no stated objectives

---

[15]This problem is, of course, not unique to government sponsored R&D, but may be more prevalent there.

[16]This condition existed within DOE for many years when separate Assistant Secretaries were responsible for Energy Technology and Conservation and Solar Applications. This structure has recently been modified.

("technology sandboxes"). Certainly, effective management of technological change requires some kind of quantitative objectives or goals to guide decisions, but which kinds of goals are appropriate and which are not?

Numerical goals are fundamentally management tools. They function as yardsticks to measure technological progress and to continuously compare technology options.[17] To be useful in this respect, they must be easily communicated and flexible (recall that we have a moving target). Consider two examples of commonly used program goals: price and quantity.

Since we have argued that these programs should be directed at technology development to achieve cost reduction, price goals ($/kW, $/kWh, $/Btu, etc.) become the management mechanisms for the measurement of technological change. Quantity goals (BBls, quads, GW, etc.) are primarily the measures of successful diffusion into society. It was argued above that the program manager has a much more direct involvement in the process during the development phases than during market development activities by their very nature. Thus, from an internal management point of view price goals seem to be more direct measures of program success. Of course, price goal achievement also requires private sector capital investment and thus market volume, but to assess and compare technology options with respect to the price goals merely

---

[17]See U.S. Department of Energy, Federal Policies to Promote the Widespread Utilization of Photovoltaic Systems, Vol. II, Chapter 4 (prepared by the Jet Propulsion Laboratory, March 24, 1980) for a more complete discussion.

requires the tools to make consistent cost/price projections. Quantity goals, on the other hand, are much more subject to non-controllable actions in the market development phase, making their use from a management control point of view very clumsy.

The price goals structure employed in the development of the U.S photovoltaics program is considered by most observers to be the chief factor which contributed to this program's success prior to 1980. Unfortunately, the recent budget cutbacks were accompanied by the elimination of price goals as a program management tool for photovoltaics.

D. Market Structure Concerns

Since the concept we are presenting here relies on the government as a manager of activities which fundamentally are carried out in the private sector, it is important to consider the supply-side market structure. We have alluded above to vertical integration possibilities. The purpose of the following section is to draw some conclusions about the relevance of market structure concerns in program design and management.

Concern for market structure and supply-industry competition stems from basically two factors. The first is the impact of market structure on continued, further technological change in the industry. The second involves the ability to incorporate and realize the benefits of current technological change.

1. Market Structure and Technological Change

A very significant literature has been developed on the relationship between competition in industries and the rate of technological change. We do not review this literature here other than to say that the results are quite inconclusive. Research shows a correlation between R&D intensity and high industry concentration, but is in unclear as to the direction of the cause and effect.[19]

While we cannot conclude that a competitive market structure is beneficial for future technolgical change, we may be able to conclude that due to the effects of market stucture on pricing, competitive structures may be vital to the realization of the benefits of technological change through price reduction.

Finally, economics aside, there is a substantial political sentiment which requires actions that ultimately promote the maintenance of highly competitive industries. This sentiment probably cannot be successfully dismissed.

Given the need to promote (or at least not inhibit) competition, the lack of a body of theory which adequately describes the relationship between government policy and market structure (especially in the context of technological change) makes it difficult to prescribe appropriate government actions during the process of technology development to

---

[18]See Kaimien and Schwartz, "Market Structure and Innovation: A Survey," Journal of Economic Literature, March 1975.

[19]See Scherer, F.M., Industrial Market Structure and Economic Performance, Rand McNally, Chicago, 1980, pp. 371-376.

promote competition.

In the remainder of this part we look at some of the factors involved in anti-competitive market structures and some of the traditional tools used by the government to deal with them.

2. Anti-Competitive Factors

For the purposes of a brief discussion we separate the factors which traditionally are considered to be contributors to anti-competitive market structures into four areas: concentration, vertical integration, barriers to entry, and government policy.

Concentration. It is generally believed that the higher the concentration of a particular industry, as measured by one of many indices and ratios, the greater the degree of monopoly power which can be exercised by any particular firm. This may make some sense in theory, but is very difficult to discern in practice. The greatest problem may simply be the definition of the industry. The photovoltaics industry, for example, is composed of players from the oil industry, the semi-conductor industry, and the electrical service industry, to name a few. How does one measure concentration when the industry members cut across classifiable lines? Furthermore, concentration in a static, mature industry is fundamentally different from concentration in an emerging one. We certaintly have to be worried about the number and types of firms involved in developing and incorporating the new technology, but how many should there be and of what type?

Vertical Integration. Vertical integration involves the degree to which intermediate production materials and products are produced within a given corporate entity or "firm." A highly integrated photovoltaics firm, for example, would refine silicon, produce modules, fabricate systems and install them on roofs.

While vertical integration may be desirable in terms of reducing transaction costs and preventing monopoly price stalemates for the integrating firm, it may harm non-integrated firms by restricting sources of supply or markets. This problem could exist, for example, if the firms producing low-cost raw material silicon chose to dedicate their production to internal module manufacturing.

Barriers to Entry. Other factors contributing to anti-competitive market structure include such things as patents or secrecy; the need to commit large amounts of capital on entry; strong consumer preference favoring established products, etc. One not mentioned which is relevant to new technologies is the possible barrier associated with economies of scale in production. Scale economies may be quite beneficial in terms of realizing cost reduction through technology development, but the scale may be so large relative to market size that only a few very large firms can generate the captial and sustain (sell) the volume required. As an empirical matter, however, scale economies may not be all that important.

Government Policy. So as not to give the wrong impression, government regulation independent of program actions may serve as a significant contributor to non-competitive market structure. It will also become obvious that there are certain program actions which if poorly timed could have a serious anti-competitive effect (e.g., product standards).

3. Techniques Traditionally Available to Promote Competition

Despite the lack of an adequate theory, the techniques traditionally available to the government commercialization programs to promote competition are four-fold: competitive contracting; small business set-asides; multiple contract awards; and product standards.

Competitive contracting helps to insure complete consideration and comparison of all potential bidders' concepts, technologies and products, but is insufficient to insure that the industry is composed of many competing winners.

Small business set-asides insure that large established entities do not overwhelm small, potential entrants, but do not substantially mitigate many barriers to entry. Furthermore, if some scale economies are fundamental to cost-reduction and technological change, it is not inconceivable that the technological process is simply not feasible for small ventures and hence small business set-asides may prove detrimental to accelerated technological change.

Multiple contract awards serve to increase the number of players involved which must be a positive influence on competition, but they also increase program costs substantially. How many awards are appropriate for any given contract? Two, three, four?

Interchangeability brought about by product standards may serve to ease entry barriers. But if inappropriately timed such standards may inhibit innovation, resulting in a more severe deterrent to entry.

The prospects here look pretty bleak. The theory does not provide sufficient background to determine whether these actions are potentially good or bad. Compound this uncertainty with the dynamic characteristics of emerging industries, and the prospects for definitive answers to the market structure concerns in commercialization programs seem remote. About all that we can do here is to call for more research into these factors.

IV. CONCLUSION

While the Little Prince's geographer did not wish to go mucking about in the details of his planet's characteristics, we have argued that the economist needs to make an effort to operationalize his concept of market failures in the context of new technology development. Toward that end, we have examined the question of the appropriate governmental role and found it to contain two questions: whether the government should be involved in a technology-specific way, and if it should, how should it design its program for involvement. While most analysis to date has focused solely upon the first question, we offer some perspective on the second. Further, we have developed some concepts for decomposing a technology development activity into subsidiary activities and developed a method for questioning the appropriateness of governmental involvement for each of the subsidiary activities. We have demonstrated the use of these concepts with a matrix and shown how it could be used with an example technology (photovoltaics). Finally, while we raise the issue of measuring the significance of market failures, we do not answer it, but merely point out its importance.