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Policies in Support of High Technology Industries

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Section I: Rationale

An important part of the current discussion about industrial policies is concerned with "high technology" industries, defined as those characterized by large R&D expenditures and rapid technological progress. It has been proposed that, in high income countries at least, a central goal of government policy ought to be to help to establish them, and to facilitate their progress and competitiveness. The stakes are seen as largely economic, although there may be important political values as well.[1]

Many arguments, some of them complex and subtle, have been put forth in support of this position. However, not much injustice is done if I paraphrase them in terms of two related, but distinguishable, propositions. One is that high technology industries often are "leading," in that they tend to drive and mold economic progress across a broad front. The second is that high technology or leading industries are "strategic", in that national economic progress and competitiveness is dependent upon national strength in these industries, and governmental help is warranted to assure this strength.

The leading industry idea has a long tradition, among scholars, as well as sophisticated lay observers. The sharpest articulation probably is Schumpeter's. In his *Business Cycles* some time. Countries trying to modernize and catch up with a perceived leader -- as Germany Britain in the mid 19th century -- often have given special treatment to certain high technology industries of the day - then steel and machine making -- seeing these as source and symbol of the leaders strength. The last decade or two has been marked by increasingly sharp articulation of the idea, and the adoption in many countries of extensive policies explicitly based on it.

However, one can accept the leading industry hypothesis, and at the same time be skeptical about whether any major strategic advantages accrue to the countries where these industries are largely based. If international economics were as depicted in standard neo-classical trade theory, it is hard to see any general national advantage stemming from a strong position in high technology, or leading, industries. Rather, that theory would reverse the discussion. The orienting question would be -- what kinds of factor endowments and other conditions give a country a comparative advantage in high technology industries. The presumption would be that, given those conditions, it is advantageous to exploit that comparative advantage, otherwise not. To the extent that a comparative advantage can be built through various forms of investment, the wisdom of such investments should be assessed in terms of the standard rate of return criterion. According to this point of view, there certainly is nothing special about high technology industries. Market mechanisms work as well, or poorly, on them as on other industries.

industries can reap externalities, if they can exploit the new opportunities before their competitors do. The key is good information connections. If communication proceeds, or can be made to proceed, more effectively within national boundaries, than across them, then a nation's high technology industries indeed may lend strategic advantage to the nation's downstream industries. It may make sense, then, to subsidize, or protect, national firms in the key industries in order to get hold of these inter-industry externalities. Of course this argument, while different, is not incompatible with the product-cycle, general R&D externalities, argument.

While these arguments are plausible, they have not been well documented empirically. At the least their quantitative importance is unclear. The question of whether high technology or leading industries are strategic should be regarded as open.

But assume that they are strategic. Assume that there are strong arguments for a national effort to encourage and support them. The policy implications are not immediately obvious. Most of the current policy discussion is focussed on policies explicitly "targeted" to aid them. However, it can and has been argued that the key to strength in high technology industry resides in more broadly based factors. Thus, David Landis', in his discussion (1970) of why Britain led the continent in the industries that sparked the early industrial revolution, stresses the general flexibility of British economic institutions compared to those on the continent at that time. His analysis of why Germany overtook Britain in steel and chemicals, and elsewhere, from the latter arena to the former, and away from protection and towards more positive forms of support. However, in the United States the basic high technology industries are, by now, quite traditional. Representatives of those industries, as older ones, rail about unfair foreign competition and call for offsets of various sorts, if not blatant protection. Proposals for positive support are less well articulated.

It seems recognized that staying in the forefront of a rapidly advancing field is not the same thing as closing a gap with the industrial leader. However the policies of foreign governments, particularly Japan, often held forth as possible models for the U.S., have usually been of the "catch up" sort, and may not be well suited to preserving or enhancing technological leadership. The objectives of technological leadership in fast moving fields raises some tough questions about what policy instruments are, and are not, appropriate.

To recapitulate, there are several basic questions about policies in support of high techology or leading industries, in the expectation of significant national economic advantage. One relates to the gains a country reaps from being strong in the leading industries of the day. Are there special economic advantages that accrue to a country because it is strong in high technology industries? If so, what are they? The second relates to the direction of causation. To what extent does strength in these industries flow from general economic strength rather than the other way around? A third is about the efficacy of more narrowly focused instruments. What kinds of industry specific

Section II: Characteristics of Technological Advance in Leading Industries

In this section, I highlight certain features of technological advance in leading industries that need to be understood when one thinks about government policies to help these industries. The account draws on a variety of different studies of technological advance in aviation, nuclear power, computers, semi-conductors, and several other industries. While there are important differences in patterns of technological advance in these industries, there also are certain fundamental similarities.

These are, first, that the precise path taken by technological advance is virtually impossible to predict, and there often are major surprises. Any investment in anticipation of a major breakthrough is a gamble. Second, individual technological advances seldom stand alone. Almost always they are connected intellectually and economically both to earlier advances along the same lines, and to advances in other but related technologies. Third, a competitive market context provides a rather special structuring to information relevant to R&D decision making at any time, and establishes a particular set of incentives and constraints. While a competitive market environment may stimulate progress, it also causes certain built-in inefficiencies and wastes beyond those inherent in the process of technological advance itself. These "market failures" are appropriate targets for public policy. Fourth, while there surely are targets of opportunity in the sense of rather obvious shortcomings of market institutions, there are limits on the be best. But hindsight is better than foresight. While some of the failed efforts strike the contemporary reader as obvious blunders, that they were so was not obvious to the people who made the key decisions at the time in question.

There are market as well as technological uncertainties. It is no easy task to judge how much merit customers will see in a radically new design. The customers may not know themselves before they have tried it out. The favorable public response to the smoothness of jet passenger flight was easy to underestimate, and the lack of willingness to pay for supersonic flight easy to have miscalculated. Before such machines were made available, there was no apparent business demand for computers. The value of an innovation may depend on unpredictable events, as whether a complementary product is available, or on how the market develops for a product for which it is a component part. The post 1973 hikes in fuel costs surely hurt the supersonic transport, and helped Airbus.

If the problem were simply uncertainty, but everybody agreed on the structure of the uncertainty, one could define the R&D allocation problem as being something like a dynamic programming problem involving uncertainty and learning. An optimum strategy in such a dynamic programming problem well may involve exploring a variety of different possibilities, and holding off commitment to a single one until lots of evidence is acquired. I say "something like" a dynamic programming problem because in that formalism all the possible branches in the tree are assumed to be known in advance; it is their realization that is uncertain. In contrast, a well known characteristic of R&D is that surprises different ideas, is an important, if wasteful, aspect of technological advance.

<u>Connectedness</u>. Particular technological advances seldom stand alone. They usually are connected both to prior developments in the same technology, and to complementary or facilitating advances in related technologies.

Many technologies advance over time in what might be called an evolutionary manner, with today's round of R&D activities aimed to improve upon today's prevailing technologies in certain particular directions, or to create variants better designed for certain particular purposes. Thus one can see in the most recent designs of commercial jet aircraft ancestral connections to the first round of commercial jet airliners -- the Boeing 707, and the Douglas DC-8 -- created over twenty-five years ago. While, measured in terms of the rate of performance enhancement or reduction in cost per operation, technological advance in semi-conductor memory devices has been spectacular, one can recognize a natural sequencing of the generations of memory devices, from the advent of the first integrated circuits over twenty years ago.

Evolutionary change is punctuated by revolutionary change. In civil aircraft the advent of the successful commercial jet airliner in effect changed the basic nature of airliner technology from the earlier piston engine based regime. The integrated circuit represented a sharp break from the earlier discrete transistor era, which in turn had involved a revolutionary shift in electronic device technology from vacuum tubes. It is interesting that these sharp shifts in weaker form, in terms of upstream-downstream, connectedness. The modern jet engine would not have been possible without prior advances in metallurgy. Further progress in integrated circuits is going to depend on developments in the instruments that trace out the circuits.

There are several important implications of this connectedness. First, experience in a technology counts. In many modern technologies a firm must gain mastery over older or more simple aspects before it can gain competence to work at the leading edges. And firms that introduce a new product first gain learning curve advantages over their competitors, provided someone else does not come out with a significantly better design. Thus, there is room for "infant industry" arguments. But it is by no means inevitable that a protected infant will grow up to be competitive.

Also, experience and competence in a particular technological regime may count for little, or be disadvantageous, when there is a significant shift in technological regimes. A regime shift signals opportunities for new companies, and requires significant changes in perceptions and policies of established ones if they are to remain competitive. This may pose severe problems for an industrial policy that is committed to the support of a particular set of companies.

Second, to be successful in a high technology industry, a firm needs to be "plugged in" to a wide range of technologies. Recall that recognition of these interdependencies is at the heart of some arguments in favor of active national industrial policies to spur leading industries. It is an open question, that, in each of these technologically progressive industries, where privately funded R&D has been substantial, through one mechanism or another, firms are able to profit from their R&D successes.

The Schumpeterian system has been an extraordinarily effective engine of progress. It has shown sensitivity to changing patterns of demand by consumers. The pay off to a firm lies not simply in producing a technologically advanced product, but a product that consumers will buy in quantities at a price that is profitable. Profitable companies and technologically progressive industries are characterized by strong market research, as well as by strong R&D. At the same time competition among firms, accompanied by secrecy about just where each is laying its technological bets, willy nilly generates a reasonable diversity of approaches to problems and new products offered to the market for selection.

However, a careful scrutiny either of the models that capture, in abstract form, the nature of Schumpeterian competition, or of the empirical history of technological advance in any field, indicates that the portfolio generated by market competition can in no way be considered optimum. There is virtually certain to be a clustering of effort, verging on duplication, on alternatives widely regarded as promising, and often a neglect of long shots that, from society's point of view, ought to be explored as a hedge. The fact that one company has a patent on a product or process may induce competitors to try to invent around it; an effort that may in fact yield something really new, but which often is simply wasteful duplication of justification and guidance for governmental actions to complement, substitute for, or guide private initiatives. At the least their recognition guards against the simplistic position that the R&D allocation naturally induced by market forces is in any sense "optimal". However, propositions about where and how market forces work poorly cannot alone carry the policy discussion very far. In the first place, market institutions themselves constrain public policies. It is politically difficult and likely futile to try to force a policy on an industry. Second, the "market failure" language represses that, in all of the major countries studied, there long has been a strong public as well as private presence in high technology industries. These traditional policies at once represent responses to pressures to do what the market does not do, and reflect a nation's broad political attitudes regarding appropriate fields of public action. They also often constitute the reservoir of experience, and the acquired customs of policy, that inevitably shape new departures. Let me consider these matters in turn.

The fact that much of technological knowledge is proprietary acts as a constraint on public policies. In the general run of things a company will not willingly disclose to its competitors, or to a public agency, the way it thinks the technological bets ought to be laid. As a result, a government agency may be cut off from the most knowledgeable expertise on the question. In particular, market information may be very difficult for a government agency to obtain, unless the companies want to give it. Relatedly, a government agency may be sorely limited in its to the new purposes. It seems useful to distinguish among three admittedly overlapping areas of traditional public involvement: support of scientific and technical education and research, public (largely military) procurement, and general modernization policies. While the details and vigor of these three broad policies have differed from country to country in ways that will be described in the following sections, there are certain common elements that I will sketch here.

In the United States state governments, with assistance from the federal government, began to take major responsibility for training in the agricultural and mechanical arts as early as the mid-19th century. Support of research in the agricultural sciences came soon after. After World War II, the federal government gradually took on primary responsibility for support of scientific and technical education and university research generally. In Germany and France there also is a long tradition of major government support for these activities. Support by the Japanese government dates from the late 19th century. In Britain acceptance of a major governmental role came later, but was in place after World War II. The ideological bases for such support have been varied. In popular democracies like the United States, there has been long-standing acceptance of a public responsibility for broad-gauged education and training of the citizenry. In France such policies have been associated with training and support of an elite civil service. Since the early 19th century Germany, and since the late 19th century Japan, have explicitly pushed education and science as vehicles to enable into industrial policy. So long as the R&D support program sticks close to generic work, the problem of proprietary rights is partially averted. A consultative structure already stands to help map out sensible allocations. As we shall see, however, while the traditions of such policies point to support of academic institutions, a characteristic of the new policies in support of high technology industries is that much of the work is done by industry, not in universities or governmental laboratories.

Public procurement demands are another traditional source of public involvement in "high technology" industries. From way back sovereigns have maintained arsenals and other workshops producing the goods they needed, and concerned themselves with the adequacy of supplies of military and other items. Since World War II, in the United States, Britain, France, Sweden, and several other countries, the armed services have been major supporters of R&D in the industries from which they procure equipment. While defense is the largest procurement interest, in several countries space agencies, telecommunications networks, electric utilities, and television networks, are government operated and controlled, and also are important sources of demand for high technology industries.

Procurement demands particularly if they involve national security, help to break political pressures for even handedness; a log-rolled defense establishment is cause for public alarm and indignation. And such public programs are associated with direct funding of R&D in industry.

interest and much looser stipulation on criteria for so labeling an industry.

As noted above, even in the United States governments have long been in the business of promoting, supporting, and protecting, certain industries. Agriculture is a prominent example, and one where R&D support was employed early in the game. The defense related industries are other examples. The French, German, and Japanese have, however, operated across a far broader front of manufacturing industry, often motivated by a zeal to catch up with the industrial leaders of the day -- early Britain, later the United States. I suggested above that Japan's highly successful post World War II policies should be understood in this light.

However, as we shall see, the constraints on government policy hold in these countries, as well as Britain and the U.S., if in weakened form. And there is the fundamental question of whether the standard instruments of tutelage -- government guidance, protection, and general (and recently R&D) subsidy -- which can be well directed when the objective is to catch up with a leader, can be effective in establishing and maintaining a domestic industry in the forefront of fast-moving technological progress.

Let me summarize. The new policies in support of high technology industries with economic benefits the target have clear antecedents in more traditional policies -- support of scientific and technical education and generic technical research, procurement, and, in some of the major countries

Section III: Policies in Support of High Technology Industries: Quantitative Aspects

There is by now a considerable record of attempts by governments to spur their high technology industries. It certainly seems worthwhile to try to describe and analyze this experience, so that some lessons may be drawn. But even simple description is no easy task. There is a serious problem about what to describe. How ought one go about characterizing a country's industrial policies? To what extent ought one to consider a nation's military, and science and education support policies, along with expressly industrial policies? How about trade policies? What numbers are relevant? What kind of qualitative information? How much disaggregation is necessary?

In order to answer these questions, one really needs well worked out and verified theory of the determinants of performance in high technology industries so that one can identify the kinds of policies that are likely to be relevant, and irrelevant. In the preceding section I put forth not a sharp and well tested theory but some apparently salient stylized facts about the key processes and institutions involved in technological advance in leading industries, and some rough inferences drawn from those facts. This provides me with a broad perspective on government policies, and suggests roughly what kinds of policies are likely to evolve and, of these, which have promise of influencing technical progress effectively, and which kinds of policies are likely to be ineffective or worse. But the theoretical lens is fuzzy, not sharp, and it may distort as well as clarify.

governments are investing in policies in support of their high technology industries. Of course, government spending on R&D is, at best, a very partial measure of government policies. However, other aspects of government policies -- for example, the tax treatment of private R&D expenditures, or the nature of the patent laws, or the characteristics of the regulatory structures, or the strength of protection, or the extent of subsidy of investment in new plant and equipment -- are more difficult to measure. Measurements are likely to be less comparable across countries than the R&D data.[2]

Table I presents total R&D as a percent of gross national product for our six large industrial nations, 1963-1980, and breaks down the total into defense and non-defense related spending. Notice the initial large U.S. lead in total R&D and the subsequent convergence of R&D intensity of the major industrial powers. Notice also that the early U.S. lead was mainly due to our large defense R&D budget, and that in recent years, if one excludes defense, the U.S. spends less on R&D as a percent of GNP than do several of our industrial rivals. An important question to explore, therefore, is how defense R&D differs from non-defense R&D.

Most of defense related R&D is funded by government and undertaken by business firms. While space and industrial policy R&D also channels funds to industry, defense R&D generally accounts for the lion's share of government funding of industrial research. Table II presents data on the share of total R&D done by industry and the share of that financed by government, in the

TABLE II

Industrial R&D Spending

	1963	1967	1971	1975	1980
United States					
% of total R&D	68.5[a]	66.8[b]	66.8[c]	65.9	68.8
% Financed by Govt.	57.6	51.1	41.8	35.6	31.8
United Kingdom					
% of total R&D	64.5[a]	64.8	63.2[c]	62.3	66.2[e]
% Financed by Govt.	33.8[a]	29.4	33.1[c]	30.9	29.2[e]
France					
% of total R&D	48.7	51.2	56.2	59.6	59.8
% Financed by Govt.		40.3	31.5	28.0	21.6
Germany					
% of total R&D	66.0[a]	67.0	67.4	66.5	72.3
% Financed by Govt.		17.4	18.2	17.9	18.2[d]
Japan					
% of total R&D	64.6	62.5	66.5	64.3	65.3[d]
% Financed by Govt.			2.0	1.7	1.4[d]

a) 1964
b) 1968
c) 1972
d) 1979
e) 1978

Source: <u>OECD</u>

TABLE III

Sectoral Division of R&D Funding [Percentages]

		United States			United Kingdom			France			Germany			Japan		
		Ind.	Gov.	Total	Ind.	Gov.	Total	Ind.	Gov.	Total	Ind.	Govt.	Total	Ind.	Govt.	Total
Elec.	1967	20.0	28.8	24.4	22.3	27.9	24.1	22.7	25.6	24.6	25.2	29.8	25.9	24.4	33.0	24.5
	1975	20.9	30.4	21.8	20.5	34.5	26.0	27.0	35.7	31.7	30.0	31.0	29.9	26.0	32.3	26.1
	1980	19	28	22	18[b]	46[b]	26[b]	22[a]	28[a]	26	28[a]	27[a]	28[a]	25[a]	20[a]	25
Chem.	1967	21.0	2.8	11.8	21.0	1.1	14.7	27.4	3.7	19.0	33.2	4.3	28.5	27.1	11.0	27.0
	1975	21.4	3.2	14.6	29.5	1.9	19.7	26.1	2.9	19.2	35.0	2.3	29.1	22.4	2.9	22.1
	1980	19	4	15	30[b]	1[b]	19[b]	26[a]	6[a]	19	27[a]	9[a]	24[a]	21[a]	5[a]	23
Mach.	1967	17.3	6.4	11.8	14.4	7.4	11.8	7.7	2.4	5.6	12.2	37.1	16.2	10.7	22.0	10.8
	1975	21.8	6.7	18.7	11.3	1.9	7.9	7.0	1.4	5.2	13.0	20.7	13.9	9.9	7.4	9.8
	1980	27	7	20	16[b]	6[b]	36[b]	10[a]	3[a]	10	19[a]	14[a]	18[a]	14[a]	10[a]	14
Air & Space	1967	14.5	56.8	35.8	7.1	61.0	25.3	8.0	66.1	28.8	0.9	24.9	5.0	*	*	*
	1975	8.3	54.7	24.4	5.0	58.8	23.9	6.6	57.8	20.2	2.0	40.9	9.5	*	*	*
	1980	9	52	23	6[b]	46[b]	20[b]	10[a]	60[a]	19	6[a]	34[a]	6[a]	*	*	*
Other trans	1967	12.6	4.5	8.6	12.4	1.3	8.5	13.7	0.5	8.6	14.9	1.8	12.6	12.5	22.0	12.5
	1975	13.9	4.1	10.4	12.3	2.2	8.6	15.9	0.5	11.1	14.0	0.6	11.6	18.3	50.0	18.9
	1980			12	14[b]	2[b]	7[b]	18[a]	0[a]	13[a]	16[a]	4[a]	14[a]	18[a]	58[a]	18
Basic metal	1967	4.9	0.3	2.6	7.1	0.7	5.0	6.1	1.3	4.4	9.8	0.8	8.4	10.6	6.0	10.6
	1975	4.5	0.3	3.2	5.9	0.2	3.8	5.4	0.7	4.1	3.0	2.1	3.1	9.5	4.4	9.4
	1980			4			3	4[a]	1[a]	4[a]			4			9
Chem-link	1967	5.1	0.3	2.7	9.9	0.3	6.7	10.1	0.2	6.1	2.4	0.8	2.1	7.7	0.0	7.7
	1975	4.4	0.5	3.6	10.8	0.3	7.1	8.9	0.5	6.2	2.0	1.3	2.0	6.4	1.5	6.3
	1980			4			6			6			3			
Other manuf	1967	4.6	0.1	2.3	5.8	0.3	3.9	4.3	0.2	2.9	1.4	0.5	1.3	7.0	6.0	6.9
	1975	4.8	0.1	3.3	4.7	0.2	3.0	3.2	0.5	2.3	1.0	1.1	0.9	7.5	1.5	7.4
	1980			3			3	3[a]	1[a]	3[a]	2[a]	1[a]	2[a]			

Source: OECD
Except for 1980, numbers taken from Table II of *Technical Change and Economic Policy*, OECD, 1980.
* Included in "Other transport":
a) 1979
b) 1978

TABLE IV

Public R&D Spending, by Objective

	United States			United Kingdom			France			Germany			Japan[a]	
	1971	1975	1980	1971[b]	1975	1980	1971[b,c]	1975	1980	1971[b]	1975	1980	1975	1979
Defence	52.2	50.8	47.0	46.2	52.9	59.4	38.0	32.6	40.9	21.3	17.6	14.2	3.8	3.6
Space	19.2	14.5	14.4	1.9	2.5	2.3	7.0	6.1	5.0	9.4	6.8	6.0	11.8	9.3
Civil aeronautics	3.1	1.6	1.6	14.5	8.2	3.4	7.0	6.7	2.4	3.6	2.6	2.3	-	-
Industrial growth n.e.c.	0.6	0.4	0.4	4.6	3.1	3.4	7.0	8.9	7.6	8.6	9.1	11.7	17.7	13.9
Agriculture	1.9	2.2	2.2	2.9	4.8	4.5	4.0	4.2	4.3	3.1	3.0	2.6	22.2	18.4
Production of energy	3.6	7.1	11.8	7.5	7.1	7.3	8.0	9.4	8.5	16.4	16.8	20.1	12.8	17.8
Transport, telecommunications	1.6	1.8	1.1	0.9	0.7	0.7	6.0	3.2	3.2	0.9	2.3	2.9	3.2	2.2
Urban and rural planning	0.4	0.5	0.4	1.2	1.7	1.1	6.0	1.6	1.5	0.8	1.8	2.1	1.0	1.9
Earth and atmosphere	1.5	2.0	2.0	0.3	0.8	0.9	6.0	3.3	3.3	2.3	2.8	3.9	1.4	1.9
Health and welfare	12.2	14.8	15.2	2.8	4.1	3.9	4.0	6.5	7.6	11.6	14.5	13.9	9.7	8.3
Advancement of knowledge n.e.c.[d]	3.3	4.3	3.9	17.2	14.1	13.0	19.0	17.0	15.2	22.0	22.7	20.2	2.8 13.6[e]	2.5 20.2[e]
Total specified R & D funding	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

[a] Government intramural only, except for Advancement of Knowledge and Industrial Development.
[b] Not strictly comparable with following years.
[c] Rough OECD estimate.
[d] Excludes public general university funds throughout and also excludes basic research supported by US mission-oriented 'adjusted' US figure might be about 15 per cent in 1980.
[e] Total university receipts from government for specified projects including those for other objectives.

Source: OECD
Numbers taken from Table 9.2 of Christopher Freeman The Economics of Industrial Innovation (2nd Edition) Frances Pin

analysis is conducted at a quite gross level, and diminish somewhat when the analysis is more detailed and microscopically focused.

Cross country analysis of the relationship between public and private R&D spending, and growth of labor productivity or total factor productivity, is delicate and tricky. Simple regressions are not likely to tell us much. In the first place, the United States, until recently the clear leader in both total and public R&D as a fraction of GNP, was also by far the country with the highest labor productivity and per capita income. It is also apparent that in most industries U.S. technology was in the forefront. Thus other countries had the advantage of being able to learn from the U.S. For a country trying to play catch up, a little R&D may go a long way, and the level of educational attainment and the rate of physical investment may be the more important driving variables.

Thus, Japan, initially the laggard of the group in terms of productivity levels, has experienced by far the most rapid growth of productivity. Until recently she has not spent much on R&D, but her rate of capital growth has been much faster than the other countries in the comparison group. Since the early 1960s she has stood high in the group in average years of educational attainment of her work force. However, given her initial low start, despite her rapid growth rate, by 1980 Japan still lagged Germany and France, as well as the U.S., in average productivity and income.

some treatments government R&D and private R&D are treated as having independent effects upon the rate of growth of productivity. In other studies government financed R&D is treated as enhancing the effectiveness of privately financed R&D. Virtually all of the studies which treated public and private R&D as if their effects were independent found that, while the influence of private R&D on growth of total factor productivity was large and statistically significant, the estimated effect of government R&D was negligible and insignificant. The studies using a format which assumes interaction have been yielding mixed results.[6]

It obviously is important to gain an understanding of the routes through which government financed R&D influences technological advance. It is unlikely that the paths are the same in all industries, and it may be wise to distinguish among different kinds of R&D support. Thus government support of R&D on agriculture is different in form and purpose than government support of R&D on a new missile. It also seems important to be sensitive to measurement problems. Much of government financed R&D goes to defense or space (or to health) and results in radically new products. It is not easy even to specify just how "output" should be measured in the relevant industries so that technological advances can be characterized as enhancing "productivity", and it is apparent that actual productivity measures are hopelessly inadequate for getting at the impact of such technological advances. Moreover, the statistical analyses that have been done thus far beg the question raised above --

This brief survey of quantitative research reveals both the difficulties and the promise of this line of work on the question of the efficiency of governmental R&D support. Cross country, or cross industry, studies have not yet been done with sufficient care and delicacy regarding measurement and specification to lend confidence to the quanitative results. The detailed microscopic case studies are more persuasive, but describe only a few small pieces of the terrain, and it is hard to tell if they are representative. Increasing the number of careful quantitative case studies will provide both a better check on representativeness, and help to inform efforts at more macroscopic analysis regarding measurement and specification. Some of the qualitative case studies in Section IV and V also might help in this regard.

A Bench Mark: The American Experience.[9]

During the heyday of the fifties and early sixties, American economic predominance often was characterized in two different dimensions. One was in terms of higher productivity levels, in the economy as a whole, or in certain broad sectors of it like manufacturing, or in particular industries like aircraft production. The other was in terms of more narrowly defined technological competences, as ability to produce the most advanced semi-conductor or aircraft, significantly before other countries. By 1980 the U.S. lead had eroded in both dimensions. Several other countries had crept close to the United States in average worker productivity in manufacturing and, given the vagaries of the international productivity comparisons, Switzerland, Sweden, and Germany probably should be regarded as now virtually even with the United States. The United States had lost its lead in most areas of consumer goods electronics to Japanese firms. But at the high end of high tech spectrum -- civil aircraft, computers, and semi-conductors -- American companies generally continue to be world leaders. In all of these areas we remain, by far, the largest producer, and the largest net exporter. This in spite of the fact that, in the view of Baranson and Malmgren, and Magaziner and Reich, the U.S. has not had a coherent policy in support of its high technology industries, while several of the European countries, and Japan, have developed such policies.

But this proposition again flags the problem of identifying what is an industrial policy, and what is another kind of policy.

It also should be noted that, since the late 19th century, the Department of Agriculture has been supporting research and development relevant to farming. Farming was not then a "high technology" industry. However, by World War II American farming was becoming such, and the embarrassing productive success of American agriculture in the post-war era must be ascribed, in good part, to the effectiveness of what is probably the longest lived program of government support of R&D relevant to an industry's technologies, for economic purposes. Also, the National Institutes of Health, which sponsor basic and generic research relevant to health and medicine, came into existence before World War II. The NIH system, in the post-war era, has provided significant support to our pharmaceutical industry, through the basic research and training of scientists it has provided. It might be noted, however, that since the late 1960s federal support of science and engineering education in the United States has fallen off, at the same time government support has increased in Japan and the Federal Republic.

World War II and its immediate aftermath brought several important additions to the scene. First, with the establishment of the National Science Foundation, the Federal government took on acknowledged responsibility for the funding of basic scientific research in the United States, at least that undertaken at universities, and for providing encouragement and support for the training of scientists and engineers. Second, while prior to World War II defense R&D support and other means of encouraging enhancement of technological capability in the did mount a program of government support for the development of a supersonic transport. This expensive abort will be discussed later. During the Carter Administration a Domestic Policy Review was organized with the purpose of identifying government policies that could help spur industrial innovation. That discussion also did not get very far, and the proposals that did emanate from it were, in effect, "zeroed" when the Reagan Administration came to power.

Now the discussion is mounting again. I turn now to consider the European, and next the Japanese, experiences with active industrial policies, as they can be described at this broad level of discourse.

The European Experience[10]

As might be expected, the European experience differs considerably from country to country. I will use France as a bench mark, and then discuss policies in Great Britain and West Germany.

France. French attitudes and expectations about the appropriate economic role of the government, and of the relationships between government and business, of course differ significantly from the American. The tradition of a strong civil service actively engaged in encouraging, protecting, and subsidizing, particular enterprises goes back to the Bourbons. It was not unnatural, therefore, for the French to assume that the government should play a major role in guiding industrial redevelopment after World War II.

the telephone system, the railroads, and the airlines, which in the United States are private but regulated, are nationalized. This naturally gave to the French government a broad range of markets that could be guaranteed to French firms, although the individual public agencies might balk and claim independence. The French also engaged in selected intervention in industrial structures. Indeed the French government has been tinkering with a structure of its electronics industry, and its steel industry, virtually incessantly since the end of World War II.

Since the 1950s the French have been especially concerned about the adequacy of their high technology industries. From early in the post-war period, French national security objectives have included not only a formidable military capability, but also the ability to preserve or build that capability independently of constraints that might be laid down by Americans. This led France to rebuild her aircraft design and production capabilities, along with the associated electronics, and into nuclear weaponry, with reactor design a by-product. All of the standard French instruments of industrial policy were used to build and support these industries -- procurement and protection, subsidized investment -- and in these instances heavy R&D support.

While I will reserve more detailed discussion until the following sub-section, French policy with respect to her computer industry is an archtypical case. Current policies clearly show their origins in French frustration at the refusal of the U.S., in 1963, to sell France a large computer needed for its nuclear make quite detailed decisions about what fields of technology to push, and even about what particular designs to develop. Later I will summarize some case study evidence bearing on the effectiveness of French policies.

Britain. Perhaps Britain can best be understood as a mixture of American and French elements. Like the United States, and unlike the French, the British heritage is not congenial to government planning or direction of economic activity. Like both the United States and France, Britain came out of World War II with a commitment to maintain a strong defense establishment. And like France and unlike the United States, the British suffered from a sense of economic inferiority, relative first to the United States, and later to a number of other countries. The commitment to an adequate defense capability, together with concern about economic backwardness, has led Britain into periodic flirtations with various industrial policies, but in contrast with the French, the British always seem to have been of two minds about these.

Like the French, the industrial policies of Britain have, throughout the post-war era, been strongly intertwined with national security policies. Indeed, even more than in France, the vast bulk of government industrial R&D support comes from the defense budget. In the fields of nuclear power, and commercial aircraft, the British government, as the French, has been strongly directive, as well as the principal source of funding. The British reactor program is generally regarded as an expensive failure. While there are a few exceptions, virtually all the

World War I, several English statesmen called attention to the fact that Britain had lost, or was losing, her technological leadership in most industries to the United States, or Germany. As one means to get back into the race, a system of cooperative research associations was established with government providing a significant share of the initial monies. Britain long has had a collection of national laboratories and research centers. The National Research and Development Corporation, established in 1949, aimed to help commercialize inventions that came out of that network. There ~~have~~ has been a parade of ministries charged with beefing up the commercial technological prowess of British industry.

As part and parcel of long standing concerns about British technological backwardness, the British educational system periodically has been discussed, as a part of the problem. It often has been noted that, compared with the American and German, and now the Japanese, educational systems, the British system turns out very few engineers. There have been several attempts at reform, each of which led to frustrated resignation.

In summary, the right word to describe British policies probably is schizophrenic. On the one hand, there is a long standing bias against detailed government involvement in guiding the civilian economy. On the other hand, the British government has taken a very active and directive role in nuclear power and civil aviation.

West Germany. German post World War II policies in support of high technology industries differ significantly from those of sense for regional economic problems and has mounted a variety of policies to help redevelop regions that appear to be in trouble. There has been a significant program in support of power reactors. More recently the government has consciously provided special R&D support to the computer and semi-conductor industries. The Germans participate in the Airbus project. But certainly in comparison with France, Germany has done far less of picking particular industries for special government encouragement and support.

Her traditional policies of strong support of scientific and technical education and research have been sustained, however. From the days of Frederick the Great, Prussian, later German, governments have strongly supported scientific and technical education. Originally, the motivation was to establish a cadre of civilian and military government officials that could lead Germany out of economic and technological backwardness. By the mid 19th century Germany was strong, even leading, in a number of fields of science, principally those connected with chemistry. The government actively encouraged consultation between German academic scientists, and the newly founded science based companies. In the late 19th and early 20th century, government funds helped to establish and sustain a number of laboratories concerned with applied R&D as well as the basic sciences. Many scholars have attributed Germany's rise as an economic and technological power, during the last part of the 19th century, to the effectiveness of those policies. By the 1920s and 1930s, German industry had clearly established a position as a world

Japanese, the Germans have not tried to provide a protected domestic market for their firms. Also, the extent to which particular industries are targeted for general investment support would appear to be much less in Germany than in Japan.

Japan

For all the current hullabaloo, it should be recognized that Western interest in Japanese industrial policies is of relatively recent origin. It was only in the late 1960s that politicians, and scholars, began to take Japan seriously as a major industrial power capable of producing sophisticated products. Japanese textiles were one thing. But the ability of Japanese firms to take large shares of the American market for steel, television sets, and automobiles, caused us to stand up and take note, and ask what were the sources of the "Japanese miracle".

Some economists writing on that question proposed that it was not all that mysterious. Japan was a pretty sophisticated industrial power prior to World War II, and during the war demonstrated impressive technological capabilities. She came out of the war destitute, but since 1950 had been able to achieve investment rates significantly higher than Germany and France, and far higher than the United States and Britain. The educational attainments of the Japanese work force, prior to World War II, were close to European standards. Since World War II the Japanese educational mill has ground on at a furious rate and, by the middle 1970s, was turning out significantly more engineers per capita than the United States, or the major the late 1930s and through World War II. The current broad industrial policies of Japan have a long history.

The post World War II era is different, however, in that the earlier era of Japanese industrial development was driven, to a large extent, by the desire to achieve a strong independent military capability. Since the war Japanese industrial policies have focused almostly completely on economic ends, although Japan has gradually developed along the way an ability to design and produce aircraft, rockets, and the associated electronics. In this way, Japan is quite like Germany. It is interesting that when, after the war, Germany dropped her military ambitions, she also dropped her directive industrial policies. Japan abandoned the former but not the latter.

Unlike the French, the Japanese appear never to have been fond of detailed quantitative targets for investment and output for particular industries. But the Japanese have taken seriously broad "visions" promulgated by MITI about the directions Japanese growth ought to take, and even about the specific industries that ought to be stressed. A variety of instruments have been used to help that vision take concrete shape. In the early post-war years, MITI had control of access to foreign exchange and used this control both to keep foreign products out of markets where it wanted to encourage Japanese industry, and to determine which Japanese industries could import machinery and intermediate and raw materials. Detailed import licensing was gradually abandoned during the 1960s after Japan joined GATT, but MITI has retained power to keep out foreign goods in selected fields, and has used it. MITI also has had the authority to keep foreign firms from

Japanese, including Japanese businessmen, that government leadership is not only legitimate but desirable, even necessary, if Japan is to prosper, although there is occasional strong resistance.

Our particular interest here is in high technology industries. In the late 1960s and early 1970s MITI began to put forth a vision of the Japanese economic future which placed heavy emphasis on the knowledge intensive industries. The new vision forecasted a gradual shifting in industrial emphasis away from shipbuilding, steel, and automobiles -- which had been the industries stressed during the 1960s -- and into consumer electronics, semi-conductors, computers, and telecommunications. Japanese prowess in consumer electronics was already present and visible at that time. The policies in support of high technology industries have involved the same blend of instruments used to further industries in the earlier era -- initial protection of the home market, keeping foreign firms out of Japan, assistance in learning about and gaining access to foreign technologies, favored access to credit, some efforts to mold the structure of the Japanese industry in a matter better suited to MITI's likings, and various endeavors to influence investments so as to take advantage of opportunities for cooperation, and to avoid what appeared to be likely wasteful duplications. What seems special about Japanese policies toward their high technology industries is that MITI has played an active role in funding and orchestrating various large scale cooperative research efforts

Section V: Electronics, Aircraft, and Power Reactors

The foregoing discussion of government policies was broad and sketchy. This seems innate in efforts to describe a country's policies in a general way. While I could have provided more detail, and many of the studies from which I have drawn do, presentation of such detail inevitably reveals that policies have varied from sector to sector, and even from program to program. Relatively detailed case studies of industries and programs, therefore, seem useful in providing another view of industrial policies.

Case study evidence has the liability of being piecemeal, scattered, and perhaps not representative. Also, in my view at least, only a few of the available case studies present enough detail so that one is confident that the picture being drawn is tolerably reliable. The advantage of good case studies is that they show more detail, so that one can begin to assess what particular policies actually were, and the impact they had. Where detailed studies exist of different national policies in the same industry, one can begin to hazard analysis of what works and what doesn't and why.

There are available case studies, of uneven detail and reliability, of the American, European, and Japanese, experience in semi-conductors and computers, aircraft, and nuclear power. Continuing in the spirit of comparative analysis, below I attempt to sketch the similarities and differences in these experiences.

Department of Defense very quickly understood the potentials of the new technology for military hardware. There was considerable R&D support, but perhaps even more important there was a clear willingness on the part of the Department of Defense to buy new products which met its needs. Miniaturization of electrical circuits clearly was an important goal. It is interesting that the particular R&D projects financed by the government aimed toward meeting this need turned out to be failures. The work that led to integrated circuits was not directly financed by the government. However that work was undertaken with the clear understanding that, if it were successful, there would be a massive government market. As with the case of computers, government support was motivated by a procurement interest, not any interest in establishing an industry that would be a national economic asset. Yet, as with the case of computers, the latter was one of the results.

It is important to note that the U.S. Department of Defense, and NASA, stood ready to buy semi-conductors from any firm that provided a superior design. The key integrated circuit innovation, and the development of the planar process that turned out to be by far the best one for making integrated circuits, came not from firms that had a long track record in electronics, but from firms that were quite new to the game. Prior to the integrated circuit, while DOD interest in semi-conductor was strong, this was largely in anticipation of the advantages that improved semi-conductors could lend. When the integrated circuit became available, both the DOD and NASA made critical decisions

A number of observers have questioned whether defense, and space, R&D programs still have the potential of pulling civilian technology in their wake. Thus executives of several semi-conductor companies remarked, when The Department of Defense's recent Very High Speed Integrated Circuit program was mounted, that that program would likely divert resources from the kind of efforts needed to keep U.S. firms in the technological forefronts relevant to commercial, principally computer related, markets. Others have argued that the fear is misplaced, and that the VHSIC program is stretching the state of the art sufficiently, in broadly relevant directions, so that involvement is likely to help a company in commercial markets as well as in the defense market. I shall return to this discussion of the role of the DOD later in this paper. It is an important part of the debate about whether the U.S. needs an express industrial policy.

<u>The U.K.</u> Although the funds have been modest and the ambitions restrained compared with the U.S., Britain has invested non-trivial amounts of public funds in procurement related R&D in computers and semi-conductors.[13] Britain also has funded R&D with the express objective of boosting commercial competence of these industries. Despite the rhetorical objective, it appears that explicit assessment of commercial promise has played little role in the allocation of these monies. The British government also has involved itself in attempting to rationalize her computer and semi-conductor industries with the rationale of enhancing competitive capabilities. International Computer Limited was formed under government guidance. In the late 1970s the National Enterprise Board helped to establish and support

objectives, and French pride, required that French companies try to match the Americans where the latter were strongest. Public R&D support programs, allegedly commercial as well as military, have been quite directive. And company proposed projects have been judged on the basis of how they fit government, not necessarily commercial, objectives. Thus the French companies could not hunt for commercial niches which could be developed into areas of major commercial strength.

While Zysman does not stress the fact, it is clear that the French would have liked to have developed their industry by providing a protected home civilian market, as well as a procurement market. And she has tried; general protection has been a hallmark of French policy in support of her electronics industry. However, the French interest in developing a uniquely French industry has been stymied by two factors. The first is that the incentives built into the French programs led to some major tensions. As a prominent instance, CII, the subsidized computer company, resisted buying semi-conductors from Sescosem, the subsidized semi-conductor company, and rather bought from American firms that were producing more advanced products. Similarly, the French telecommunications companies had incentive to buy their inputs not from French companies but from American. Second, there always has been a problem about what being a "French" company meant. Recall the episode regarding Machines Bull. More generally, the strongest computer and semi-conductor firms in France have been branches of American, and Dutch, companies. The French have found this extremely frustrating. During the 1970s, French policy shifted from trying to establish is interesting, also, that the major areas of commercial success of the German industries have not been ones where they have had to confront directly the most advanced American products, but rather in producer goods electronics. Philips, the Dutch based international firm, also has done reasonably well in a niche-consumer goods electronics, at least up to recently.

Japan. Like the German and unlike the French, Japanese policies have not been driven by an interest in the capability to produce weaponry, but rather by the desire to establish a commercially profitable industry.[14] Since Japanese success in electronics is perhaps the most often cited example of successful government policies in support of high technology industries, it is worthwhile to discuss this experience in some detail.

The rapid takeover of the American color television market by Japanese manufacturers in the late 1960s came as a shock to many Americans, and was, rightly, widely regarded as an indicator that American preeminence in consumer electronics was under threat. It should be noted, however, that this episode followed earlier Japanese successes in capturing a large share of the American market for transistor radios, and later, black and white television sets. The data show that by 1960, Japan was employing many more semi-conductors than any European country, including France and Britain, despite the absence of any major military procurement program. So, when the Japanese began to go into color television, it was from a base of considerable experience in consumer good electronics. By far the largest market for Japanese made television sets was the protected home market, and the earlier Japanese sets were designed with that market in mind.

telecommunication uses, and a more broadly oriented program sponsored by MITI to bring Japanese companies to the forefront of semi-conductor technology relevant to computers. The letter involved several corporative research laboratories, staffed by scientists and engineers drawn from the involved companies, with the funding shared between the companies and MITI. This program, as the earlier one directed toward color television technology, was largely generic in nature. While a large number of patents came from that program, the basic purpose and result of the program was to bring Japanese companies up to the state of the art along a rather wide front. However, while MITI did not attempt to push particular commercial product developments, the projects were carefully chosen for their likely commercial relevance. Companies whose personnel engaged in a particular successful project got a definite leg up toward a commercial design advantage.

The involved companies felt this very much. This led, on the one hand, to restrictions on the program to stay away from areas where particular companies already had a proprietary interest, and on the other, to jealousies among the companies regarding the projects they were assigned to work on. Apparently it took strong and subtle leadership to hold the program together. Analysts diverge on how important they think the program was in bringing Japanese semi-conductor capability up to the frontiers. Certainly the funds were small relative to those involved in the in-house efforts of the Japanese firms. But the program is regarded by some observers as having played an important catalytic role.

rivalrous firms. More recent Japanese programs have stressed more basic and generic research. Unlike the earlier program, the fourth and fifth generation computer programs do not appear to involve particular companies in commitments regarding the nature of the computers they ultimately will design and market.

Peck (1983) notes the comprehensiveness of the fourth and fifth generation programs. They clearly are designed to develop the capabilities of the major Japanese computer manufacturers to move in a variety of possible directions, as the technologies develop and the nature of the markets becomes clearer. As with the earlier MITI R&D support programs, the public money involved is very small compared, say, with the funds the DOD put into the U.S. industry in the 1950s and 1960s. The funds are small compared with the proprietary research funded by the Japanese computer companies. What MITI appears to be trying to do is not direct the commercial developments of computers in Japan, but to see to it that the Japanese companies have the technological capabilities to compete with IBM and the other major Western companies in designing and developing the next generation of computers.

As earlier was the case in the U.S., a dynamic computer industry increasingly is providing a market inducing technological advance in semi-conductors, principally integrated circuits. Unlike the case in France, in Japan the computer manufacturers buy largely Japanese made integrated circuits. This certainly is partly due to the fact that the large computer manufacturers are also the producers of semi-conductors. But it also is the result of strong MITI urging.

By the late 1930s NACA began to concentrate more specifically on problems of special interest to the military, and the flow of civilian benefits diminished. After World War II, much of the "generic research" mission which had been shouldered by NACA was shifted to the aircraft companies through DOD contracts explicitly with them. By the late 1950s NACA had been transformed into NASA and the orientation shifted largely towards space.

While technology relevant to military and commercial aircraft always have differed in important respects, until 1970 or so there was considerable overlap. During the post World War II era, design and procurement of a new aircraft, or a new engine, for military use often has led the advance of technology, with civil technology following. As noted, the American post-war preeminence in the commercial aircraft business arose directly out of military research and development and procurement contracts. The Boeing 707 was designed in parallel with a plane bought by the Air Force, and had many design elements in common. The American wide-bodied jets show their origins in military cargo planes and the engines that powered them. Until the supersonic transport episode, which I shall discuss later, there were no programs of the U.S. government aimed expressly to help in the development of commercial airliners, nor was there any pressure for such from the major aircraft producers.

Europe. The situation in Britain and France has been quite different. In Britain, during World War II, a relatively explicit government plan was drawn up for post war support of the engine manufacturing industries, and through mergers reduced significantly the number of independent companies. The government hoped thereby not only to better exploit economies of scale, but also to reduce pressures on it to sponsor so many projects in order to keep the many companies employed. At the same time the government changed its method of financing, becoming a formal business partner in the development of aircraft, expecting to share in the profits as well as share in the costs. As noted, there were no profits to share. And the losses of the airlines, as well as the companies, had to be picked up by the Treasury.

In the middle 1960s, partly in response to the financial losses being accrued, a committee was formed, headed by Lord Plowden, to consider the future place and organization of the British aviation industry. One of the committee's most important recommendations was that future efforts should be focused on collaborative efforts with other European countries. It already was clear that one ongoing such effort -- the Anglo-French Concorde -- was likely to be a financial albatross. However, the logic of the Plowden recommendation seems to have persuaded the British government that attempts to develop a purely national industry through subsidization and a guaranteed home market were extremely expensive and ultimately futile, and foreshadowed several cooperative ventures during the 1970s, notably Airbus.

The French story has some similar and some different aspects. There has been subsidy and government direction of civil aircraft development, and a built-in home market in the French airlines, sensitive those markets would be to price. Nor was the experience in military R&D heeded -- that the cost of ventures aiming for a radical advance in technology tends to be greatly underestimated. The original $450 million estimate for development costs proved low by a factor of ten. Only the captive French and British airlines could be forced to accept delivery of the Concorde when it was finally ready for commercial operation in 1976, and both governments have had to subsidize the operation of the plane. Production was terminated in 1979. Only 16 aircraft were produced.

The United States government also was drawn, or jumped, into subsidy and direction of a supersonic transport project. The U.S. effort, which was begun several years after the European effort was launched, was a direct response to it, as well as a desire to exploit expected "spillover" from the development of the B-70 strategic bomber prototype. Instead of the normal procedure in the development of specifications for a new commercial aircraft, in which there is significant interaction between the airlines and the company considering the venture, in this case the lead government agency -- The Federal Aviation Administration -- stipulated the performance requirements, with not much consultation with the airlines. Boeing won the contract competition. Serious technical problems (the original design proved infeasible), cost escalation, and opposition from environmental groups, led to the program's demise in 1971. The experience with Concorde suggests the U.S. was lucky that the program never achieved a technically viable aircraft.

original partners were Deutsche Airbus, and Aerospatiale. Later the state owned Spanish aircraft firm joined the group. The British firm Hawker-Siddeley invested its own money as a subcontractor. In 1979, as the prospects for Airbus brightened, the British government again joined the group of participants.

There were, and are, certain important features of the governance of Airbus Industrie. The top management of the involved firms has the authority to define both technical and marketing objectives for the project. While the participating governments hold the purse strings, and thus ultimately can veto decisions, government officials do not become directly involved in formulating design or marketing proposals. The top executives also have the authority over administration, and thus control how the decisions are implemented. The contrast with Concorde or the SST program is dramatic.

Despite a design apparently well aimed for a market niche, (actually, by the late 1970s two designs) and despite a promising management system, during most of the 1970s the financial prospects for Airbus seemed dim. Through the late 1970s orders for Airbus were slim compared with those for the Lockheed and McDonnell-Douglas planes. Beginning in 1979 Airbus orders began to pick up dramatically. While it is still to early to tell if the consortium will make a profit, its planes have sold better than any other European-designed airliner ever made.

The fierce competition among the Airbus consortium, Lockheed with its L-1011, and McDonnell-Douglas with its DC-10, for roughly the same market reveals extremely sharply the conflictual

Nuclear Power[16]

In the field of nuclear power, the government of the United States, as well as that of the major European countries and Japan, has spent enormous sums of money over a long period of time with the objective of creating a commercially viable and internationally competitive power reactor industry. In all of these countries a special government agency has been charged explicitly with the job of guiding reactor development, and in several has done this in great detail. In a sense the nuclear energy programs of these countries have much in common with what some commentators have argued MITI is doing in Japanese electronics, but which we have seen they are not. While, by some standards, the French and Japanese programs might be regarded as reasonably successful, and the German one potentially so, it is not at all clear that the rate of return on any of the programs has been positive, up to now.

However, the issues are complicated and tangled. In the first place, even more than in the case of aviation, or electronics, policies in support of the development of nuclear power technologies have been tightly intertwined with explicit national security objectives, at least in the United States, Britain, and France. Second, in the early days of atomic power, concerns about environmental impact, and safety, were muted. As these concerns became better articulated, and represented in the political process, new design requirements and more stringent licensing requirements were imposed. The financial costs of nuclear power thus were significantly increased. Further, at and built quickly, which marked the Eisenhower speech, and also reflected the views of the Atomic Energy Commission, meant that the bulk of attention was focused on the light water reactors for which some experience had been accumulated in the naval programs. Light water reactors used enriched uranium as a fuel, but the U.S. had ample enrichment plant capacity, built in support of the nuclear weapons programs.

The major companies that got into the business of designing and producing reactors, and the utilities, were bullish about the prospects and invested significant amounts of their own money. The Price-Anderson Act of 1957 limited the liability of utilities in the case of nuclear accident. The Atomic Energy Commission supported research, offered some financial backing for experimental and demonstration plants, and, most importantly, urged and pushed the companies and the utilities to get on with the show.

It was apparent from the outset that, if nuclear power was to be competitive with conventional power, the plants would have to be very large. Thus during the late 1950s the companies committed themselves to produce, and utilities to buy, nuclear power plants very much larger than any that had been actually built, and tested. In this era of optimism very little attention was paid to issues of reactor safety, or to the question of what to do with burned out fuel elements.

The Shippingport demonstration plant went into operation in 1958, and was followed by the Yankee Nuclear Power Plant in 1961. Both of these plants were subsidized by the Atomic Energy Commission, and operated at scales far smaller than the ones the nuclear plant costs associated with new environmental and safety requirements, and the now much more complicated and time-consuming regulatory process, deterred many utilities from taking the nuclear route. Aside from the bringing into operation a number of plants whose construction started some time ago, nuclear power expansion in the United States has come to virtually a dead stop.

In the early 1960s, on the belief that its first round objectives had been achieved, the Atomic Energy Commission shifted its attention toward research and development on a breeder reactor. The case for the breeder reactor rested, in large part, on forecasts that there would be very considerable growth during the last decades of the 20th century in the number of regular nuclear plants, and that supplies of uranium would therefore relatively quickly become mined out. As with the case of conventional reactors, the Atomic Energy Commission relatively early in the game committed itself to a particular type -- the liquid metal fast breeder reactor. Considerable funds have gone into research and development on this reactor. By the middle 1970s, however, skepticism began to be voiced strongly. In the first place, projections of growing scarcity of uranium no longer seemed justified. In addition, concern that breeder reactors generated materials that could be used in bombs intensified. A number of studies have shown that no economic case can be made for going ahead with at least this particular breeder reactor program. Nonetheless funds continued to go into the Clinch River breeder reactor project. While the old Atomic Energy Commission had been dead for more than a decade, the political momentum of government, and in part because of a desire to stay with British designed and built reactors, until very recently the conflicts have been resolved in favor of the AEA's designs. There has been a virtually endless tinkering with the structure of the reactor industry, in hope that reorganization there would resolve the increasingly obvious shortcomings of the plants placed on line.

Britain's reactors have not found a market abroad and have been employed domestically only because the Electricity Board has been, in effect, ordered to do so. In the late 1970s and early 1980s this situation was reluctantly recognized at the top. The power of the Atomic Energy Authority to dictate the path of nuclear power development in Britain apparently has been attenuated.

The French case has something in common with the British, although from the beginning the authority responsible for the nationalized power network, Electricite' de France, has been a more effective counterweight to the Atomic Authority, than has been the case in Britain, and the French program shifted orientation significantly before the British did. As it gradually became more expert, EdF became skeptical about the economics of gas cooled graphite moderated reactors, just as had the British Central Electricity Generating Board. In the middle 1960s in France, as in Britain, the central government authorities ruled for the atomic energy authority and against the electricity authority when there were cases of conflict. However EdF was able to itself fund work on light water reactors, and to keep the options open. By the early 1970s, with the passing of

British and French experience, and to a lesser extent the U.S., never took shape in Germany.

After the war, for a period to time, Germany was expressly prohibited from engaging in nuclear research activities, and only in the 1950s did the constraints loosen, and the Ministry for Atomic Questions come to be formed. Historically, the Länder have had major responsibility for funding research at the universities and as Germany began to re-establish a nuclear research capability, the responsibilities were not centralized as they were in other countries. Also, like the U.S., and unlike France and Britain, in Germany electricity production and distribution is not centralized -- there are a number of independent utilities -- and cannot be directed from the capital. The larger German companies, principally Siemens and AEG, had been watching reactor developments for some time, and when the German program got under way, had some judgments of their own as to the most promising roads to follow.

The programs of the federal government, therefore, must be understood as, from the beginning, being only a part of the action. There were a number of different sources of initiative.

In the late 1950s the federal government took steps to coordinate efforts and provide more central guidance. The Eltville program, initiated in 1957, had the express aim of helping German firms develop capabilities to do more than simply copy foreign (generally American) designs. The companies received subsidies to work on designs they, as well as the funding authorities, deemed promising. In the late 1950s and early 1960s, the Ministry attempted to lay out a comprehensive

Less than a decade after Hiroshima and Nagasaki, government and industry leaders in Japan, encouraged by the Americans, began to lay plans for the development of nuclear power. After having briefly shown an interest in British gas cooled reactor designs, the Japanese fastened on American technology and adopted the long-range plan for nuclear power development laid out by the Americans. This meant light water reactors for the short and medium run, with an accompanying commitment to obtain enriched uranium, increasing use of fuel reprocessing, and ultimate adoption of a breeder reactor. This strategy has been worked out and implemented in Japan through the close cooperation of several industrial and governmental bodies. The key actors have been the major regional electric power companies, the companies that design and produce the reactors and their components, the science and technology agency which has had main responsibility for managing nuclear R&D effort, and the Japan Atomic Energy Commission. MITI's role has been mainly that of licensing, safety regulation, and plant inspection. Since 1978, there has been, as well, a Nuclear Safety Commission.

As in the other countries, government provided funds have accounted for the main share of nuclear basic and generic research and experimental development. The companies and the utilities have paid for the production and implementation of designs that are regarded as relatively well worked out. The Japanese producers, as the Germans, relatively quickly mastered American light water technology. By 1980 Japan was second only to the United States in the amount of nuclear power on-line.

citizen concerns involve both environmental issues -- in particular shore-based reactors are feared to hurt Japanese fisheries -- and safety ones. The nuclear accident that occurred in one of Japan's reactors in 1981 has highlighted safety problems and in Japan, as in the United States, gaining agreement about the siting and design of a plant, its construction, and final approval for operation, now is a very time consuming and costly business.

have diminished, we still have a larger ratio of scientists and engineers to the total work force than any other country in the non-communist world. From the late 19th century on, Germany has been noted for the quality of her scientific and technical education, and the skills of her work force, from scientist and engineer to technician and mechanic. Japan's rapid surge toward the frontiers clearly was associated with the fact that a remarkably large fraction of her population was getting a technical education. Britain's decline relative to Germany and the United States, and recently relative to France and Japan, has been attributed by many observers as at least in part due to weaknesses in the British educational structures.

I read the evidence as suggesting that the key is a system of scientific and technical education that both trains well and which points a good fraction of graduates towards industrial careers, not necessarily preeminence in academic science. These are of course not disconnected. It is virtually impossible to train high level scientists and engineers for work in industry unless one has a university faculty operating at or close to the frontiers of knowledge in their fields. But Britain has stayed in the forefront of the relevant academic sciences, but has not managed to establish a culture wherein a significant number of young people train in science and engineering and go into industry. Japan has been thin at the forefronts of academic science, but has established a system and a culture wherein a sizeable fraction of young people gain scientific and technical training with an objective of going into industry.

groups considered. Much of the current discussion of "industrial policies" seems to refer to the kinds of policies countries have directed towards their semi-conductor and computer industries, so let me begin by focusing on these. Then I will turn to the lessons that might be drawn from the aircraft and nuclear power stories.

Lessons from Electronics Oriented Policies. The U.S. and Japan clearly lead the pack in electronics, and both have had strong and effective policies in support of computers and semi-conductors. The policies that resulted in early American dominance in electronics after World War II were associated with our national security programs. In Japan the policies that facilitated fast catch up have been associated with MITI economic direction in general. Virtually all analysts agree that these programs have had a lot to do with the two countries' success in these industries. Without trying to make these two obviously different policies appear the same, it nonetheless is worthwhile searching for common elements, for perhaps these can provide clues as to what kinds of policies are and are not effective. In fact there are several elements in common.

Both programs involved a large protected home market. In the United States, this was basically a government procurement market. In Japan, the procurement market was far less consequential, but the civilian market was preserved for Japanese high technology firms as well. Both the American military and the Japanese civilian markets were large enough so that a number of domestic firms could compete. In both cases, the relevant technological prowess was rewarded, and significant R&D support for firms in that market. In the Japanese case stimulus of commercial competence was direct and intended, and in the U.S. case commercial competence was created because military technology pulled civilian technology in its wake.

Much of the current discussion of policies in support of high technology industries involves the term "picking winners". To what extent can the successful programs in the two countries be characterized in that way? If by that term one means relatively sharply focused attention on achieving certain practical results, the proposition is apt. The U.S. programs of course were aimed at military objectives, not commercial ones, but the purpose certainly was to assure that the U.S. lead in the relevant technologies. Relatively clear-cut military hardware objectives lent a certain direction and thrust to the program of generic research as well as hardware procurement. It should be recognized, however, that a central feature of the U.S. program was that it supported a wide range of options.

Picking and supporting winning industries in a commercial race might be an apt characterization of the Japanese programs, if the breadth of support is recognized. Thus semi-conductors and certainly computers have been singled out for special attention; however a wide range of electronics industries have been given favored treatment.

Within particular industries and technologies, both the DOD and MITI picked particular areas for intensive attention, because of military potential in the former case and perceived potential the R&D support program got tangled with the objective of establishing or preserving a French capability to design and produce military equipment. As a result clear commercial targets were not pursued, but the industry was given shelter and subsidy simply to keep it operating. I already noted that the French military program aimed only to stay close to the Americans, not break radically new ground, hence little innovation has come out of it. Support of generic research in the British electronics industry, even aside from that associated with defense procurement, has not specially focused on areas judged commercially promising in the same way as the Japanese programs.

At the same time, the British and French programs have been prone to sink public funds into particular commercial designs. This has not been very fruitful in electronics.

Lessons from Aircraft and Nuclear Power. Undoubtedly it is the very great expenditures required to design and develop a particular new plane that has drawn such highly focused government attention, and support. But, whatever the rationale, in the British and French aircraft industry the government has been drawn, or jumped, into the role of entrepreneur. For all the reasons cited earlier, this is a difficult role for a government agency to play and, in most instances it has been played badly. However there seems to have been some learning. In the Airbus case the government(s) did a much better job of tapping commercially relevant expertise than in earlier episodes. In effect, instead of leading in its own preferred directions, in the Airbus case the governments organized, orchestrated, and politically to the programs. This may be the most serious policy problem of support programs that involve huge lumpy public investments.

The nuclear power programs sharply reinforce these lessons. Like aircraft, nuclear power involves huge lumpy investments. While the nuclear programs are special in their intimate connection with non-commercial goals and values, they reveal vividly the kinds of problems that arise when a government commits itself to major investments in particular designs. The German and Japanese cases are noteworthy, in that from the beginning the customers - the elective utilities - played a significant role in guiding R&D allocation. In the U.S., Britain, and France, on the other hand the lead government agency called the shots, and simply presumed that the utilities would buy the reactors they got developed. It took a long time before this kind of policy was abandoned.

As in the case of aircraft, there is clear evidence of learning. In the U.S. this took the form of a cutting down to size of the reactor programs, and in Britain and France a reorientation of the programs that took stronger account of economic calculus. However, as noted earlier, a recent study calculated that only in Japan and France is reactor technology now more economic than power generators using fossil fuels. In all countries, the government has acted as if it had a huge stake in the reactor technologies it was pushing, deep pockets, and a reluctance to cut bait.

strength, it should stand separate from procurement oriented programs.

MITI's programs are the best example of relatively successful R&D support programs aimed specifically at creating a commercially competitive industry. In the following section I shall argue that a good case can be made for certain features of MITI-like programs, even in, or especially in, the United States. However in thinking about that, it seems wise to try to unpack the MITI experience.

The R&D support programs of MITI were complemented by considerable protection of the home industry, and by a strong governmental role in picking the industries and designing the program. Protection is becoming increasingly difficult and fractious, even for Japan. For the U.S. active industrial policies are being offered by their proponents, not as a complement for protection, but as a substitute. The sharp industry targeting of the MITI programs was made possible both by well established Japanese customs -- which do not exist in the United States -- and by the fact that U.S. industry and technology could provide a clear target for emulation by a nation that was, then, clearly operating behind the frontiers. I suspect that, with no clear target established by other countries to shoot at, MITI will now find it more difficult to decide where to aim.

But a policy of providing support of cooperative generic research can be considered on its own stand-alone merits. Such a policy seems well aimed at the kind of R&D where the externalities are greatest, to be welcomed not resisted by technology products. This may be a difficult task for diplomacy. And one can ask if the game is worth playing.

And this raises the question:

__Are Leading Industries Strategic__?

The radical technological advances that we have seen in semiconductors, computers, aircraft, if not yet nuclear power, have had enormously wide ramifications. These surely are "leading" industries and technologies, in the sense of Schumpeter. While the fraction of national value added, or employment, or capital stock, contained in these industries has been quite small throughout the post war era, the products of these industries have shaped the new products that have emerged and the productivity growth that has been achieved in a very large number of other industries. Information processing, communications, and long distance transportation of people, have been, literally, revolutionized. And it is possible to trace the sources of this wide spread economic revolution back to a very few leading industries.

But it is less obvious that leading industries have been strategic ones in the sense that the nations that have had strength in these industries have gained a wide-spread general advantage. It seems likely that the United States was specially advantaged during the 50s and through the middle 1960s. However, it should be recognized, and pondered, that from the early 1950s the other major industrial powers, with the exception of Britain, achieved much faster rates of growth of productivity, and real per capita income, than did the United States. To the extent governments block exports for national security or other reasons, competition in the high technology industries is sufficiently strong that product trade rapidly makes available internationally products carrying the new technologies, regardless of where they are produced. The relevant scientific and technological communities are increasingly international and generic knowledge spreads rapidly. The rise of first the American multi-national corporation, later the European and the Japanese, and more recently the surge of international joint ventures in R&D, design, and production of high technology products, is spreading hands-on design and production capability among nations. The advanced industrial nations today are closely tied together technologically.

There are many reasons why this is so. One is the very nature of the leading industries of this half century. ~~The electronics and aircraft industries~~ Advances in communications and air transport have made the advanced nations one technological world as never before. Another, ironically, is the aggressive policies pursued by governments to see that their home industry not get too far behind in high technology.

Because of the strength of competition in high technology industries, it is no longer apparent that these necessarily support especially high wages, or rates of return on capital, unless they are heavily subsidized. While technological advance and productivity growth in these industries is especially rapid, the gains go largely to those that buy the products of the industries, not the firms in the industries. In the nature of the case, five countries can't all be winners in the product capabilities, as well as can Japanese firms. Japanese and Europeans are convinced that the U.S., Department of Defense, has, and will continue to, block international technological cooperation and flow of information. My suspicion is that countries will continue to try to make their technological capabilities national, but will have more and more difficulty in doing this. But this is a matter that requires more careful research than I have been able to give to it as yet.

and procurement related R&D will for the foreseeable future continue to be by far the major source of government support for high technology industries in the United States. And, in these industries, national security considerations will strongly resist being cleanly separated from economic ones.

The high technology industries are inextricably connected with perceptions of national security and vulnerability. As we have seen, in nations with a significant military procurement program, it is hard to draw clean lines between procurement policies, and industrial policies. It is true that, at least up until recently, the United States has not explicitly concerned itself with the commercial strength of the firms in its defense industries, but perhaps this is because those firms were doing very well in commercial markets so there was nothing to worry about. Because of our status as the arsenal of democracy, the United States is going to continue to spend significant funds on R&D in these industries, enough so that we do not perceive ourselves as lagging technologically in any important area.

What is new in the current context is that the technological threats we see may be coming more from our allies than from the Soviet Union, and appearing in the form of commercial products rather than weaponry. I suspect that, try as we may to distinguish between pre-eminent military design capability, and commercial success in high technology industries, these aspects will be blurred in people's minds. If the Japanese can build a fifth generation computer before an American firm can, this surely will undermine confidence that we are at the top of the field so far as military applications are concerned. Both more explicitly oriented towards economic objectives. In pondering such policies both the particular American political context, which surely constrains our range of actions, and the issue of international policy conflict ought to be considered carefully.

<u>Support of Generic Research Done by Industry</u>

By my reading, support of generic research done by industry is the most promising way to go. This is where MITI R and D support appears to have been most effective. To the present time, the DOD and NASA have been virtually the only governmental supporters of such work in the United States. There are strong reasons for establishing a basis of support that is independent of DOD.

American companies now are giving strong indications that they would like to band together to jointly fund cooperative generic research, even in industries where the DOD finances substantially such work, and even where no public funds are provided to catalyze the industry cooperative effort. In particular, a number of our semi-conductor and computer manufacturers have already banded together to do such research through the newly formed Microelectronics and Computer Technology Corporation. The Department of Justice, in a preliminary ruling, has indicated that it does not see any antitrust issues at stake, so long as the supported research stays generic in nature. The proprietary interests of the involved companies probably will assure that this cooperative endeavor not venture too close to what individual companies consider to be matters of great of the antitrust laws, it seems to me. But regarding such endeavors that do not involve public funding, I would argue a rule of reason.

For cooperative generic research groups employing public funding, I take a different stand. I believe it is in the interest of the United States, and of all countries taken together, that participation in publicly subsidized programs be open to all companies with a research and development, and production, presence in the sponsoring nation. I would propose that U.S. government funded programs of this sort be open to foreign firms, provided reciprocity is shown by a firm's home government on comparable programs. This, of course, is another argument for sponsoring these programs in the United States through a vehicle other than the Department of Defense. It will not always be easy to get other countries to abide by these ground rules, but the pursuit of reciprocity provides one useful guide star for American diplomacy. A significant program of government funded cooperative generic research, backed by a reciprocity policy, gives promise of giving us leverage on the programs of other countries, most notably Japan, that we presently do not have.

Direct and Indirect Support of Commercial Design and Development

The issue of reserved or protected markets, and of government subsidization of particular commercial products, always has been a much more fractious aspect of national policies in support of their high technology industries. And it is these aspects which promise to cause considerable international gander. It is likely that, except possibly for Japan, the firms themselves increasingly will frustrate home firm oriented procurement policies by joining together in joint ventures.

The growing tendency of firms in different countries to band together in joint ventures on large expensive projects is also likely to complicate national efforts to help its own industry by R&D or general subsidy. But such efforts, encouraged and subsidized by governments, are likely to become increasingly common. I see no reason to believe that government agencies are going to greatly improve their ability to "pick winners". If the lessons of Airbus are heeded, however, there may be less of a proclivity to support big losers that cannot seriously compete even with heavy continuing subsidy. While the rate of return to the European countries on Airbus is likely to be low if not negative, that plane is competitive on world markets, at least with the subsidies governments seem willing to provide. The American companies clearly feel they were hurt, unfairly, by Airbus. What should be our policy in the future like cases?

I think it important to distinguish three different aspects of the Airbus program. First, under governmental auspices, a consortium of companies was organized to work together on a major commercial product. Second, significant government funding -- subsidy -- certainly was involved in the research and development stage, and probably in production as well. Third, the governments of the major countries that participated in the Airbus consortium attempted to pressure their national airlines to buy Airbus. In my view the second and third aspects of the Airbus experience should be sharply distinguished from the first.

designs, when there are available a number of foreign designs, and there are significant fixed costs involved in each entry. While I would distrust a U.S. governmental authority that initiated design and production partnerships of this sort, I suggest that it is time to loosen the present scriptures against design and product cooperation by U.S. firms under certain circumstances. The circumstances are, first the existence of competitive foreign efforts. Second, the presence of significant fixed costs per entry such that it can presumed that the market will be able to ultimately to support only a small number of designs.

Regarding the matter of subsidization by foreign governments of particular designs I think the U.S. government should take a hard principled stance that, so far as the U.S. market is concerned, this is unfair competition. We should stand ready to impose tariffs commensurate with the degree of subsidization. While calculating the degree of subsidy is a complicated business perhaps with no right answer, I think that the U.S. should advertise its intention to offset the advantages of foreign subsidies, when the competition is on our home markets.

I would think it prudent to separate the issue of whether we should try to offset the effect of foreign subsidization in competition for the U.S. domestic market, from that of how we treat subsidized or protected foreign markets. The former is under our direct control; the latter is not. While we can bend our negotiation efforts to opening up foreign markets and reducing the degree of discrimination in favor of home companies, that can be a hard road to plow.

certain classes of industry, and to provide considerable if broad-gauged industry guidance, simply will not go in the United States, unless they are tied to national security, real or symbolic. And, if the national security connection is largely symbolic, the likely result will be either a new project Apollo, or a pork barrel, but almost certainly not a policy that looks like MITI's. This may be a liability, or an advantage, but for the forseeable future it is a fact.[18]

We need to pick and choose from the policies that have been piloted by other countries, considering seriously only those that have showed promise abroad, and look as if they might be implemented effectively here. I have given my judgments of what those policies are.

We need to pay more attention to our assets in the race. U.S. defense R&D expenditures will continue to dwarf those of our industrial competitors. While in some areas military R&D may have little to do with the creation of commercially relevant technologies, it is important to recognize that, for better or for worse, military R&D and procurement will be the dominant specific influence on our high technology industries. As noted, I believe that these will continue to keep American firms competitive commercially in those areas that are close to military interests.

The U.S. has had, at least up until recently, the broadest gauged educational system in the world, and we still have a significantly higher fraction of young people going on to post secondary education than anywhere else except Japan. The economy of the United States has an internal competitiveness and openness

It is intellectual nearsightedness on the part of many advocates of free enterprise not to see the importance of public institutions. On the other hand, a weakness of many of the recent proponents of industrial policy is failure to understand how Schumpeterian competition works, and its strengths as well as its limitations. Industrial policy in the United States needs to be nicely designed to alleviate the latter, without hindering the former.

Many years ago, in his Capitalism, Socialism, and Democracy, Schumpeter took the position that modern man was close to routinizing the innovation process, that the uncertainties and divergencies of judgement were being eliminated from it by rational calculation and discussion, and that the hurly burly of capitalist competition, which he acceded had been a fount of creativity and energy, would not be missed if lost. This seems a false forecast. The U.S. may be handicapped relative to other countries in the extent to which efforts at innovation can be coordinated. This may hurt us in some areas, particularly those in which the costs of the endeavors drive out much chance for sustaining many different approaches. However, the sheer size of our corporations and our internal market may help us to avoid being closed down in these areas, if we adopt sensible policies. And in most areas, economies of scale are not that overwhelming. The U.S. economy continues to have as openness to entry of new firms, new ideas, rivalry, that other countries do not, and which they increasingly seem to be discouraging, in the name of industrial policy.

If MITI does not seem likely in our future, the flexible

Footnotes

1 Three of the most sophisticated recent statements are by Baranson and Malmgren (1981), Magaziner and Reich (1982), and Zysman and Tyson (1983).

2 Piekarz, Thomas and Jennings (1983) present an analysis of the R&D statistics similar to mine. They also hazard some comparisons across countries in such variables as tax treatment of R&D spending.

3 For a heroic attempt to assess the role of "advances in knowledge" (not explicitly R&D) in the productivity growth experience of different countries see the work of Edward Denison (1967 and 1976).

4 Stein and Lee (1977) have provided the best study I know of about differential productivity growth rates across countries at the sectoral level.

5 One of the best early studies was that by Nestor Terleckyj (1974). Edwin Mansfield's more recent study (1980) divides R&D into basic, and applied, and into privately, and publicly financed.

6 Terleckyj (1974) and Mansfield (1980) are representative of studies that treat private and public R&D as (logarithmically) separate factors of production. Link (1981) and Kalos (1983) treat public R&D as affecting the productivity of private R&D. Kalos provides a good review of this literature.

15 My principal source for the U.S. study was the chapter by Mowery and Rosenberg in Nelson (1982). William Spitz collected the materials on the European experience in his paper "European Policies in Support of the Civil Aviation Industry". The Airbus story was drawn in part from Newhouse (1982).

16 The most important sources of the following discussion were Walker and Lönnroth (1983), Keck (1981), Suttmeier (1982) and Hazelrigg and Roth (1983). Michael Sullivan ably surveyed the European experience.

17 The "super computer" project of the Department of Defense is a good example of a program triggered in part by the the perception that a friendly country, Japan, might get ahead of the United States in a technology that might be relevant to national security.

18 For a compatible view see Schuck (1983).

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7 Robert Evenson (1982) has recently ably reviewed that literature.

8 See _Mathematica Inc._ (1976).

9 The following draws from a number of sources, and partly recapitulates my earlier discussion of U.S. policy in Nelson, Peck, and Kalachek (1967) and Nelson (1982).

10 The following draws from a variety of sources. See in particular Vernon (1974), Gershenkron (1962), Pavitt (1980), Pavitt (1976), Rothwell and Zegveld (1981), Warnecke and Suleiman (1975), and Katzenstein (1978).

11 My principal references for this account are Patrick and Rosovsky (1976), and Johnson (1982).

12 This account of U.S. policy towards semi-conductors and computers draws heavily on the essays by Levin, and Katz and Phillips, in Nelson (1982). See also Wilson, Ashton and Egan (1980) and Kalos (1983).

13 The following discussion of the European experience draws in particular from Sciberris in Pavitt (1980), Zysman (1977), Dosi (1981), and Malerba (1983). I am expecially indebted to Franco Malerba for helping me to understand the European record.

14 The following discussion is based principally on the following sources: Peck and Wilson (1982), Peck (1983), Pugel, Kimara, and Hawkins (1983), Wheeler et al (1983) and Doane (1983). I am particularly indebted to Donna Doane for having made available to me her draft manuscript.

industrial structure of the U.S. should not be discounted as a formidable competitive engine of progress. We may be lucky that it so stubbornly resists being targeted, coordinated, or planned.

to new ideas, and new firms, that none of our industrial competitors presently is close to matching. Our policies should exploit these advantages, and not let them erode.

[redacted] gauged educational front, an arena that may be overlooked if the hunt starts out with the premise that industry specific policies are the key. It is hard to say if expressed concerns about inadequate supplies of young well-trained engineers and applied scientists in central fields are overblown; but it does appear that we have worked ourselves into a position where the university departments training the needed people are short of faculty, in part because non-academic jobs are so lucrative. Perhaps the time is ripe again for the large public programs in support of higher scientific and technical education that marked the post Sputnic period. However, the indications are that our educational problem is much deeper than appears when one looks only at advanced training. Over the long run doing something about the performance of primary and secondary schools in teaching kids science and mathematics may be more important in the preservation of an American lead in the high technology industries of the future than specific programs aimed to help on a narrow front our high technology industries today.

And it is exactly the internal competitiveness of U.S. industry that makes policies, that are appropriate even needed in other countries, infeasible and counterproductive here. I have been stressing throughout this essay that the Schumpeterian engine of progress involves public as well as private components.

Reprise

The guidelines for new policies sketched above certainly will seem insipid to those who are looking for bold new departures. They certainly seem weak tea compared to those that other countries have put in place, or those which have been talked about by advocates of a far more activist industrial policy for the U.S.

But if the description and analysis presented above is close to the mark, there is not much about the active industrial policies of other countries that we ought to be trying to emulate. For the most part, the foreign record has been one of expensive frustration. Active policies in support of their high technology industries keep on being tried, not because past ones have been deemed successful, but because their high technology industries continue to be weak, and there are strong national urges to do something about it.

The exception, of course, is Japan. But I have stressed that many attributes of Japan have contributed to her remarkable economic performance (until recently), and that it is hard to assess how important were her industrial policies. In any case, MITI must be understood as part of a package of political institutions and cultural predispositions. While earlier I argued that MITI likely will in the future have greater difficulty targeting industries than when the U.S. provided a clear model for Japan's, I believe MITI will continue to play a useful role in Japan. However policies aimed to strongly favor

At present U.S. policy is ambivalent regarding design and production joint ventures. The United States antitrust laws currently are not being interpreted as ruling out cooperation among American companies that produce different components of a system -- as between an airframe manufacturer and engine producer. Nor do we rule out joint ventures between an American firm and another firm in the same line of business, if that other firm is foreign. Where the market clearly is international, one can question then the logic of ruling out horizontal consortia of American firms. Actually, the issue is delicate. On the one hand international consortia have special advantages, in that they make it difficult for governments who subsidize or provide protected markets to target their policies to help home firms only. On the other hand there surely is an issue here akin to the older ones about trade creation and trade diversion. And, the United States is in a special position, perhaps along with Japan, in that in the industries where such consortia are likely to be common, we often have several firms, not one. Thus our firms have the opportunity to look for national partners, not just foreign ones. It seems odd that we would discriminate against a national partnership if each partner judged this more promising economically than joining an international consortium.

Behind the scenes is the more basic question -- what stance should the United States take when there is an obvious trade-off between number of rivals and degree of wasteful overlap of effort. It is not evident that the United States or the world is better off having two or three similar but competitive U.S.

conflict, and economic waste, in the future unless they are somehow reined in.

In fact, the increasing internationalization of technology, and in particular the growing proclivity for companies to band together in joint ventures, already is visibly undermining these traditional national policies. Also, the most important of the previously closed civilian markets, that of Japan, is slowly and painfully opening up, at least to a degree. On the other hand, rising international competition in high technology products is sure to threaten weak national industries, and invoke import barriers of various sorts. Recall the recent French blockage of Japanese video cassette recorders. But also recall the results which was a joint venture with a Japanese firm. The U.S. high technology industries have not shown themselves shy about requesting protection. The tide of Japanese T.V. sets soon triggered such a response. It could happen in semi-conductors, computers, or aircraft.

I think it important that the U.S. take a strong position against protectionist policies, but not be sacrosanct about it. We probably will be on better grounds arguing against general protection than against procurement policies which cater to national firms. Among other things, we undoubtedly will preserve the largest protected procurement market in the world -- that tied to our defense budget. We should not be surprised if our arguments to other countries that they should open up telecommunciations equipment procurement are met with the reminder that what is sauce for the goose is sauce for the potential proprietary interest to them.

[redacted]try sho[redacted]ment en[redacted]ce the [redacted]il. The Cooperative Automotive Research Program, initiated under the Carter administration, and aborted under the Reagan administration, was for support of generic research of the kind discussed here. However, the automobile companies had no part in the initiation or design of the program, and felt it was being rammed down their throats. The program might have gone quite differently had the automobile companies been urged to design it for themselves.

As the Microelectronics and Computer Technology Corporation indicates, the private firms themselves may be willing to invest considerable amounts of their own monies in such cooperative generic research programs. However, I would endorse the idea of having government funds sweeten the kitty. Such public financial assistance might be provided on a formula basis, as through the provision of matching funds. Alternatively, the decision about whether or not to provide public support might be made on a case by case basis, although I am uncomfortable with the political and organizational problems that such a policy would engender.

One important policy issue regarding such generic research cooperatives that is sure to arise involves the terms of exclusion from such groups. This is a delicate issue. A generic research cooperative that involves, say, the three largest firms in an industry and excludes others ought to be ruled in violation symbolic, and real, elements are involved.

For all these reasons, our policies in support of high technology industries are going to continue to be intertwined with national security objectives.[17] Indeed, such intertwining may be a political requirement for significant government support.

On the other hand, we should understand that it is likely that other countries increasingly will accuse us of having major industrial policies disguised as military R&D programs. Europeans, pressed on the fairness of their express industrial support programs, long have responded that we have done much more under DOD auspices. As DOD R&D support programs became identified with matching or beating the explicitly commercially oriented programs of other countries, the flack will get thicker. We will lose much of whatever credibility we now have in arguing that other countries programs amount to unfair subsidization. Also, to the extent the DOD continues to press to keep American technology out of foreign hands, we lose force in arguing for other countries to open up their R&D support programs to American companies. More on this shortly.

In any case, military and civilian technology inevitably will be tangled. As a result, it is a good bet that national security related R&D and procurement will suffice to keep American firms at the technological forefront in commercial technology as well as military, if these are at all connected. However, where commercial demands have little contact with plausible military needs there will be pressure for new policies. It makes sense, therefore, to begin to think of a set of complementary policies,

Section VII: What Implications for U.S. Policy?

All of the foregoing points to the proposition that the United States should proceed cautiously in new initiatives in support of high technology industries. Devising new policies that are effective and not fractious is likely to be difficult and frustrating. And the stakes may not be as high as often argued. Nonetheless, some rethinking, or fresh thinking, certainly is in order. Such rethinking should not presume, however, that we can start with a clean slate. U.S. policies in support of high technology industries will almost surely continue to be heavily influenced by national security interests. And more than any other of the major industrial nations, the U.S. government will continue to be constrained in the modes of interaction with industry that will be politically acceptable.

The National Security Connection

Such commentators as Magaziner and Reich have argued that U.S. policies towards high technology industries, traditionally based as they are in defense procurement interests, provide less economic advantage than would more commercially oriented policies, and have proposed that we establish a set of policies more explicitly aimed at economic objectives. This might be a good idea. But it would be a mistake to forget about the national security connection. In the past, defense oriented policies have had enormous commercial impact, and in many areas there continues to be significant spillover. Even under the most optimistic assumptions about arms control, military procurement cycle race. And the very competition appears to have reduced the size of the prize and increased the entry costs. The argument that leading industries are strategic nationally because they feed into national downstream industries is, to a considerable extent, vitiated by the growing strength and breadth of the international networks, and the export orientation of the strongest firms in these industries. Indeed to push one's domestic industry and encourage home reliance upon it, may disadvantage the closely linked industries, rather than help them.

The questions here are very difficult. My purpose above was not to dismiss the proposition that leading industries are strategic ones for high wage countries, but to stimulate thought and research. Scholars of the semi-conductor, computer interface attest to it's closeness, and that it calls for integrated companies, or very close inter-company relationships. To a lesser degree, the relationship of airframe and engine designs is obviously close; a company in one area can't proceed effectively without close interaction with one in the other. The future will see more integrated companies, and more tight inter-company relationships. But the question I am asking is whether national borders are strong hinderances to intra-company (multinational) communication, or to inter-company relations. I suspect the answer is "less and less", except in so far as national governments establish barriers.

American companies involved in the semi-conductor, computer interaction believe that they cannot really tap into Japanese that American R&D in the leading industries was a basic growth engine, that American engine certainly was pulling European and Japanese boats in our wake.

While the European countries, and Japan, were especially concerned about "technological gaps" in the high technology industries, and clearly presumed that these gaps were strategically disadvantageous for them, it is not clear that their closing of the general productivity gap came about because they were closing the gap in capabilities in high technology industries. In all of these other countries, as in the United States, the leading industries continue to account for a relatively small fraction of value added and employment. The fraction of exports accounted for by leading industries is much smaller in Germany, and Japan, than in the United States, but this does not seem to have impeded their growth. For Japan, exports of semi-conductors are small compared with exports of automobiles. The value of German computer exports is swamped by the value of her chemicals and machinery exports. While Japanese excellence in the production of automobiles and motorcycles, and German excellence in chemicals, machine tools, and related capital goods, certainly rests on considerably technological sophistication in the "high technology" industries, Japanese and German successes in these fields came about before their semi-conductor and computer industries began to come close to challenging the American.

It appears that, increasingly, technological knowledge and capability is becoming international, not national. Except where private industry, and not to involve government agencies in trying to make judgments they are not equipped to make. And such a policy does not force a government agency to protect the industry or to make detailed commercial judgments.

Governmental involvement-partnership - in the development, design, and production of particular commercial products poses a different set of issues, particularly if the costs are very high, and there is only room in the world economy for a small number of competitive designs. I suspect that, absent this latter condition, specific designs created under large government subsidy are not often going to be playing a major role in international competition. Private companies can afford to have a go at it on their own, and have shown every inclination to be independent of government guidance or overview when they can. In particular, companies have a strong interest in keeping government away from their most promising product ideas. But when the costs of product development became very large relative to the assets of even the largest companies, it is a different game, if a government stands ready to provide significant support.

And if that game is played out internationally with some products receiving major government subsidy, it is a very fractious game. If governments have learned enough to put SST's, and gas cooled reactors behind them and to place public moneys on designs that are reasonably attractive on international markets, they will soon have to learn what kind of ground rules to place on a game of heavily government subsidized competition in high

In Summary. How to summarize the lessons? What do they tell us that is germane to the present policy discussion?

The clearly powerful effects of the U.S. defense and space programs provide a complex subtle message. These programs surely do not provide us with a model for future policies in support of high technology industries. The fact that U.S. procurement and procurement related R&D had such a strong effect in building commercial leadership of U.S. firms certainly doesn't provide a persuasive argument that we should augment our present defense and space programs in order to increase "spillover". The massive expenditures we mounted then, and are incurring now, surely cannot be justified by the commercial returns.

It also seems likely that the large spillover from the defense and space programs of the late 1950s and 1960s was the product of a rather special set of circumstances. The military, at that time, greatly valued capabilities that could be realized through certain new technologies that were just emerging, and these capabilities, and the technologies more generally, also turned out to have great commercial value. Many analysts have suggested that "spillover" has diminished markedly since the middle 1960s.

The temptation will be to add on commercial objectives to military ones in decisions about particular procurements or fields of R&D support. But one rather clear lesson of the post World War II experience is that it is a mistake to try to blend commercial objectives onto military procurement ones. If a program is to be aimed specifically to enhance competitive subsidized, a design and production cooperative, closely tied to the articulated demands of the potential customers (the European airlines). The financial and organizational involvement of MITI in the case of the Boeing 767 also reveals keen attention to commercial promise.

Much more than in the case of government support of semiconductors and computers, in the case of aircraft government help is readily identifiable with particular commercial products. The investments are far more lumpy. Aside from the giant American aircraft companies, private firms have shown reluctance to "bet the company", if they are not supported by their government. Thus the support programs are forced to aim for "winners" in a much narrower sense than in the case of programs in support of electronics. Programs in support of aircraft engines (which I have not discussed at any length) seem to have a similar structure. A consequence is that governments end up having a large financial stake in particular commercial products. Governments become partners with business, and partners with deep pockets.

As indicated, governments have displayed increasing sophistication about the importance of good market as well as technical analysis, prior to placing bets. In the field of aviation, it is likely the lesson has been learned, and efforts like the supersonic transport are behind us. But what is not clear is whether governments will learn when to cut losses. The Airbus may, or may not, ever yield a positive rate of return. The game certainly is chancy. But the involved governments do not act as if they could abandon the endeavor; they seem hooked commercial importance in the latter. In both cases particular companies or groups of companies were singled out for support in these areas. The big dollars in the U.S. program have gone to particular companies on R&D and procurement contracts. However, the DOD, of course, has not gotten in the business of supporting particular commercial ventures. And, contrary to some popular impressions, MITI has not in general tried to dictate to companies what kinds of products to design for sale on commercial markets. In both countries the enhancement of commercial competitive prowess has been through the strengthening of the design, development, and production capabilities of involved national firms which in turn they used for what they judged to be commercially advantageous.

It is interesting to compare the U.S. and Japanese experiences with those of the three European countries. While France tried, and to a lesser extent Britain, neither of these countries established the same technology pull in their defense and space programs as did the U.S. The total funds involved were vastly smaller. The efforts were less ambitious and generally aimed to catch up with the Americans, not to establish new grounds. While France has tried to protect her civilian market, her membership in the European market has forced her to be more open than Japan. In addition, branches of foreign owned firms established within her own borders greatly complicated the business of even defining a domestic industry.

The generic research support programs of these countries have been much less coherently oriented than those of the U.S. and Japan. In the French case the commercially oriented aspects of government agencies were unwilling to set up a particular "national champion". While the domestic industry has been sheltered from foreign competition, there was and is vigorous internal competition and this has been the intent of those who have guided the policies.

This meant several things. Maintenance of a domestic presence at the forefront of an industry was not dependent on the performance of any particular firm. In the industries where backward or forward linkages were important, as computers and semi-conductors, a firm was not locked into one supplier, or one purchaser (except the Department of Defense). And the strong demand for innovative products manifest in both markets motivated intense competition among domestic firms.

In both the United States and Japan publicly funded R&D programs significantly enhanced the capabilities of the involved firms to produce advanced design products for commercial markets. In the Japanese case the principal programs involved support of generic research, done by company employed scientists and engineers, with the express purpose of enhancing the company's technological strength relevant to commercial markets. In the U.S. the dominant programs were oriented to defense and space exploration and involved both support of generic work and massive expenditures on hardware development. While not specifically intended to augment a company's commercial capabilities this often was the result.

Put another way, while the two programs differed significantly in purpose and structure, each provided both a strong competitive market for domestic firms wherein

One also should note that the countries which have had economically successful leading industries have been strong across a wide spectrum of industries. One could read this as suggesting that strength in leading industries causes general economic strength. However, the inference I draw is that the workings of a nation's basic economic institutions -- those that determine its performance in education and broad-gauged science, incentives and organizations supporting R&D and physical investment, mechanisms for achieving reallocations of labor and capital -- have a broad atmospheric effect. If they do not work generally, it is unlikely that they will work particularly well for the high technology industries. The contrast among Japan, Germany, and the United States -- arguably the best economic performers in the post war era -- suggests that there are a wide range of viable institutional structures.

The most important lesson here is that nations that aspire to strength in high technology industries had better attend to their general strength in technical education and establish and maintain a set of policies and institutions that supports economic growth generally. A possible danger of the recent rhetoric about the importance of high technology industries is that it may take attention away from these broader less specifically focused policy arenas.

What Industry Specific Policies Seem to Have Worked?

However, there is no question but that industry specific policies have had important effects. The preceding analysis revealed major differences in policies toward the three industry

Section VI: What Lessons?

I concluded Part I by raising several broad questions. Are leading industries "strategic" and if so, in what sense? Is it general economic and technological strength or special policies that enable a nation to have prowess in leading industries? If the latter are important, what kinds of specific policies? We now have the basis for hazarding answers to these questions. Earlier I stressed that the way I characterized technological progress, and what I chose to describe about government policies, was very much influenced by my theoretical preconceptions. It is even more evident that the way I interpret the record, the tentative answers I provide to the basic questions, comes from my mind's eye and not simply from objective observation.

Is it General Strength or Special Policies that Lead to National Capability in High Technology Industries?

The answer to the first question is, probably both. I read the record as indicating that general strength is a necessary condition. However, given basic technological and economic strength, the right policies specially aimed at the high technology industries certainly seem to have lent advantage to national firms.

It is hard to escape the conclusion that general strength in scientific and engineering education and research is a prerequisite for strength in high technology industries. The technological preeminence of the United States in these industries, since World War II, surely has something to do with the fact that, while in recent years our educational advantages

From the beginning of the program, a key Japanese objective was to cut back on requirements for imported petroleum, and high cost domestic coal. The oil shocks of the '70s strongly reinforced this objective. A recent study reports that, in Japan, the cost of producing power with nuclear reactors is less than the cost of using coal fired plants. The strikingly low cost of capital in Japan must be an important factor in that calculation, and also the high cost of coal there. By some standards, however, the Japanese program looks successful.

It is worthwhile to consider, however, two major problems the Japanese faced, and still face, regarding nuclear power. In the first place, the Japanese decision to use light water reactors in the early days made them dependent upon American providers of enriched uranium. Their adoption of the broad American strategy of nuclear reactor development led them to begin to develop enrichment capacity, and capacity to recycle spent fuel elements, as well as into a commitment to the breeder reactor as the technology of choice for later in the century. As noted earlier, under the Ford Administration the United States backed away from this strategy, on grounds both of changing beliefs about the future demand and supply for uranium and concerns about nuclear proliferation. It also exerted considerable pressure on other countries to abandon plans for reprocessing. Japan has not bowed to this pressure. But the situation has been quite uncomfortable on a number of occasions.

Japan also has seen rising citizen resistance to the locating of nuclear plants in places close to population centers, which greatly narrows the available sites. As in the United States, plan, with priorities, but while a number of projects were funded under the plan, the companies continued to lay their own money on what they thought were the best bets. And at that time the companies were much less concerned than the Ministry about the fact that they were basically simply learning to build American designs. The utilities also were more narrowly economically oriented than was the Ministry, and the signals they gave to the companies reinforced inclinations to proceed relatively conservatively.

By the late 1960s German companies had acquired sufficient competence to cut their ties with American firms. German reactors were competitive on world trade.

The post oil shock experience of the German industry, however, has been more akin to that of the American than the French. As in the United States, citizen group opposition to nuclear power has become quite strident, and has not been squelched. Falling expectations about future energy demand has cut back on orders. The prospects are quite unclear.

Japan. The Japanese case is marked by fewer sharp turns and obvious technological mistakes than is revealed by the histories in the other countries, but Japan, too, currently is experiencing citizen resistance to a technology widely regarded as oversold, and dangerous. Also, the Japanese case, as the others, clearly reveals the entangling of the reactor development programs with international politics, although in the Japanese case, the tangle was not of their making.

Charles de Gaulle, EdF began to win the upper hand, and to call the tune regarding reactor development and purchase.

By the middle 1970s France had shifted over virtually completely to pressurized water reactors as the technology of choice for the short and medium-run. To a greater extent than in the United States, the designs were standardized, and the French company engaged in the production of such plants, Framatone, began to get advantage of economies of scale and experience. According to one study, while U.S. nuclear plants cannot produce electricity as cheaply as modern coal fired ones, French plants can, at least given high French coal costs. As in the United States, questions have been raised about the environmental impact and safety of reactors; however the French government has been quite authoritarian in putting down protests. While recognition that future demand for electricity will not be as great as forecasted has slowed down the pace of construction, all new electricity generating capacity in France now is nuclear, and production is planned ahead at a modest rate. France continues to work, now increasingly in consort with other European countries, on a breeder reactor.

Germany. The German story diverges from the British and French. Again, the fact that Germany was not trying to build up a military capability is important to recognize. Also, there was no strong resistance in Germany to dependence on the Americans for fuel. Given the questions being explored in this essay, the most important difference, however, probably is that the strong centralized control of reactor development that marked the

the projects it initiated proved hard to slow down. In late 1983 Congress stopped funding the program.

Britain and France. The stories of the British and French programs have some essential things in common with the American experience, and some important differences. One major difference is this. After the war both the British, and the French, opted for a gas-cooled graphite moderated reactor design for two central reasons. First, these reactors used natural uranium as a fuel, and their employment in a power grid therefore did not require access to enriched uranium which, in the early post war era, only the U.S. could produce. Second, this kind of reactor produces plutonium as a by-product. Thus these reactors were a natural part of a program aimed to develop a military nuclear capability.

The British Atomic Energy Board, later the Atomic Energy Authority, has at least until recently exerted even more detailed control over the development of nuclear power than did the U.S. Atomic Energy Commission. From the beginning it has been committed to its own designs, which have basically stuck with the early commitments to gas cooling. Electric power generation and distribution in Britain is nationalized, and centralized. The Central Electricity Generating Board was, after its early experiences with experimental plants, increasingly skeptical about the economic merits of gas cooled reactors, and over the years has pressed for light water reactors. There have been a succession of committees charged to resolve conflicts between the AEA, and the CEGB. In part because the AEA remained the principal source of technical expertise heard by the British companies and the utilities already were committed to produce and use commercially. The objective was to gain experience from their design, construction, and use. The faith was that "scaling up" would pose no serious problems. In 1963 a contract was signed for the first full-scale reactor, judged competitive without subsidy.

As it turned out, the companies who contracted to build the reactors could not do so at costs anything close to the agreed upon price. Relatedly, there were major technical problems with the large scale reactors, that had not been apparent with the smaller demonstration versions. The first generation of commercial reactors were not competitive. The companies who produced them lost money. The utilities that procured them undoubtedly could have produced electricity at lower cost had they built up-to-date conventional plants. And this despite the heavy front-end subsidy of the Atomic Energy Commission, and subsidization of fuel costs.

During the 1960s, despite this unfortunate early experience, the companies continued to try to sell, and utilities continued to order, versions of the light water reactors. Disenchantment set in gradually. As noted, there was first a rise in concern about environmental impacts and safety, and then, somewhat later, a sharp fall in projected growth of demand for electric power. The large jump in oil prices, and more optimistic beliefs about future availability of uranium relative to demands, by themselves made the nuclear power alternative look more attractive relative to conventional plants. However, the sharp rise in estimated roughly the same time that these factors were slowing the tide of nuclear energy, economic hard times set in and forecasts of future energy demand growth were scaled down drastically.

The entanglement with national security objectives made it more or less inevitable that a government body would exert detailed control of the development of the technology and that non-commercial values would be given a prominent place. The rising concerns about safety, and the changes in perceived long run economic prospects, turned somewhat sour the initial high hopes about the economic advantages of nuclear power. Scrutiny of the general lessons that can be drawn must recognize these important complications of the experience with nuclear reactor development.

The U.S. Shortly after the war the American Atomic Energy Commission was established and assigned responsibility for future nuclear developments, civilian as well as military. At the same time the Congressional Joint Committee on Atomic Energy was established. For the next quarter century the executive agency, and the Congressional committee, worked closely together and, in effect, jointly reigned over the governmental programs in question.

The programs in support of civilian nuclear power grew out of the programs to design and develop nuclear power reactors for submarines and surface ships. President Eisenhower's "atoms for peace" speech in 1953 signaled, and put in place, a commitment of the U.S. government to develop civilian nuclear power reactors. The sense that it was important to get power reactors designed nature of national policies in support of high technology industries for economic purposes. The American companies complained, naturally, that foreign governments were heavily subsidizing their competitor.

Japan. The Japanese aircraft industry, like the German, was dismantled after the war. The industry got into operation again with production, under license, of the Lockheed F-104, and other military aircraft. Several small commercial aircraft projects were pursued in the 1960s, and in the early 1970s. It was only during the late 1970s, however, that big chips began to be put down. The present largest Japanese commitment to developing a commercial design and production capability involves participation, with Boeing, in building the 767 aircraft. To achieve the needed industrial capabilities, MITI organized a consortium of firms, and has contributed half the funds, in the form of interest free loans, to be repaid only if the project turns a profit. Japan also is engaged in a collaborative engine project with Rolls Royce. Recently Pratt & Whitney, and the major German aircraft engine firm, have joined the endeavor. MITI is providing substantial funding assistance to this project as well. Well informed analysts believe that in the coming years, Japan will be an important player in the competitive aircraft production game. And the charge of R&D and production subsidy is sure to be levied at them, as well as at the European nations.

The Airbus case is an entirely different story, and since not much has been written on it, warrants telling in some detail. As early as 1963 Britain and France had begun discussions about possible joint venture to produce a large commercial subsonic aircraft. By the mid 1960s, the Germans, who were eager to expand their presence in the aviation industry, joined the discussions. The German aircraft industry had been dismantled after World War II. During the 1960's, under encouragement by the U.S. government, German companies began to produce the Lockheed F-104 fighter under license. There were also a few small commercial endeavors, but nothing major prior to Airbus.

An agreement to start development on a 260-300 seat wide-bodied plane was signed by the three governments in the fall of 1967. By that time the Douglas DC-10 and Lockheed L-1011 were well under development. Both were planes of roughly this size, but aimed for mid-distance flight. The Airbus consortium tried to avoid competition with the Americans by choosing a two engine design tailored to the short-run market. (The American planes each had three engines reflecting both their intended longer range, and certain regulatory requirements relevant to the routes they were expected to fly.) This market niche was defined in discussions with the European airlines regarding the kinds of planes they would like to procure.

The British were concerned that the niche sought by Airbus might not be large enough to justify development costs, a concern heightened by the rapid growth of orders for the American planes. Their withdrawal from the agreement left France and Germany, who officially launched Airbus Industrie in December 1970. The but the French effort has been less scattered and, by-and-large, less unsuccessful. During the 1950s the French government authorized the development of the turbojet Caravelle. The plane was designed for the short and medium-range trips and, thus, found a niche in the first generation jet market, where the other planes -- 707, DC-8, Comet -- were designed for longer range. The Caravelle was dominated, however, by the Boeing 727 which appeared in the early 1960s.

Except for the Caravelle, during the 1950s the French government did not really push or try to direct commercial aircraft design and development. Her efforts were focused on military aircraft. There appears to have been little of the sense of urgency to establish or preserve a commercial aircraft industry that marked the British case, perhaps because during the war Britain had built-up a large employment in her aircraft industry and France, of course, did not.

After Caravelle, the next major venture in civil aviation was the supersonic aircraft, the Concorde, a joint venture with the British. The French interest in the venture flowed from deliberations as to the appropriate successor to the now obsolete Caravelle. The British, frustrated by their experience trying to develop and produce a long range plane directly competitive with American planes, were interested in a technically advanced transoceanic plane. The joint Concorde project was born in 1962.

Enough has been written about the Concorde sc that only a sketch is required here. In contrast with Airbus, which will be discussed shortly, in the case of Concorde, very little attention was paid to the nature and size of potential markets, or to how design, development, and production of civil aircraft. During the early post war years a number of subsidized designs were developed, according to the plan. Most of these efforts were aborted short of a vehicle ready for a market test. The few that were fully developed turned out to be dominated by American aircraft.

It is interesting that the British designed and built plane that marked the largest technological step forward -- the De Havilland Comet -- was developed and produced without government support. Turbojet aircraft were not in the plan. Comet, which got into production and use six years before the Boeing 707 and the French built Caravelle, turned out to have fatal technical problems. Government funds did go into efforts at redesign, but not sufficient funds so that the needed modifications could be effected in time to beat out Boeing.

The experience of the British government of betting right was no better during the 1950s and 1960s than it was in the immediate post war period. During this time the government subsidized the design of more than a dozen aircraft. Only one -- Viscount -- can be regarded as close to a commercial success. The nationalized British airlines, BEA and BOAC, were coerced into buying British planes, and as a result, often were disadvantaged relative to other airlines that had freedom to shop and who flew competitive routes.

In addition to involving itself in the selection and finance of aircraft development projects, and in decisions regarding what planes the British airlines should buy, the government during the 1960s pressured a reorganization of the British airframe and

Aviation[15]

The story of government policies in support of civil aviation contains a number of elements in common with the electronics story. However, to a far greater extent than in electronics, governments -- particularly the British and French -- have financed the development and subsidized the production of particular designs aimed explicitly for a civilian market.

The U.S. Experience. Except for the case of the supersonic transport, the United States government has been unique among the five in not involving itself in deliberate direct subsidization of civil aircraft development. As noted earlier, during the inter-war period the government took a direct interest in the development of the U.S. aircraft industry. The National Advisory Committee on Aeronautics was established in 1915 to "investigate the scientific problems involved in flight and give advice to the military air services and other aviation services of the government." As the statement of mission attests, the program was justified in terms of direct government (largely military) needs but, from the beginning, the problems NACA worked on were common to commercial as well as military aircraft. NACA's work on engine and airframe streamlining played an important role in enabling the design of the Douglas DC-3. That aircraft, and planes that evolved from it (DC-4, DC-6, DC-7), dominated the commercial airliner market from the mid-1930s until the advent of passenger jet aircraft. During this pre-war period, the government subsidized the airlines, and indirectly, therefore, civil aircraft design and development through contracts to carry airmail.

The case of computers is somewhat special because of the presence in Japan of IBM. IBM got into Japan before the war and its leverage on the Japanese also was enhanced by the fact that it held some of the basic computer patents. MITI successfully bargained licenses out of IBM, and got IBM to agree to limit its Japanese sales but IBM remained, until 1981, the largest computer company in Japan at which time she was surpassed by Fujitsu. To help offset IBM's advantage, MITI helped the Japanese computer companies establish a computer leasing company, so that they as IBM could offer their machines on lease. Japanese government purchases of computers have virtually all been from Japanese firms.

It would appear that in the late 1960s MITI made a judgment that Japanese computer capability was too fragmented, and that merging would be in order. The large Japanese electronics companies proved unwilling to separate out their computer design and manufacturing capabilities and to merge these. (It might be noted that earlier MITI had similar trouble when it tried to get the Japanese auto industry to "rationalize".) As a compromise, MITI organized and helped support several different research and development groups, each group oriented around a particular strategy for computer design and commercialization. The target for these efforts was not a government market which could be assured and shared by the cooperating firms, but the highly competitive general commercial market. Because of this, the cooperative R&D arrangements often proved fractious since the work being done touched on the potential proprietary interests of

It turned out that there also was a large U.S. market for small color television sets, which American companies were not producing. Japanese color television exports to the United States began by hitting that market.

What kind of a role did explicit industrial policies play? There was, certainly, broad encouragement, protection of the Japanese home market, and the standard Japanese assistance for exports. In addition, MITI helped to fund a cooperative research program that enabled Japanese television producers to get ahead of American companies in fully exploiting the opportunities afforded by integrated circuits. The support here was for generic research, not for the design and development of specific products. The Japanese companies themselves initiated and funded product design and development. Sony's work, which led to its special tube design, was not funded or even encouraged by MITI. Peck and Wilson have remarked that color television was not an industry targetted by MITI. But it is clear enough that the issue is a matter of degree not kind. MITI certainly encouraged and aided the industry.

Japanese policies in support of their semi-conductor industry have a similar flavor. In the case of semi-conductors the large protected home market was supplemented by policies of government controlled enterprises, like Nippon Telephone and Telegraph (NTT), to procure equipment that used Japanese made semi-conductors. The VLSI (very large scale integration) effort of the middle 1970's involved both a program by NTT designed to develop and ultimately procure integrated circuits suitable for a strong strictly French semi-conductor and computer industry, towards encouraging joint ventures with American firms. Not many American firms would play the game, at least not under French rules.

Under Mitterrand, policy has shifted again towards a stricter nationalism. Pressures have been placed on certain branch firms to sell out to French owned companies. In the case of video cassettes, the French blocked imports of Japanese products, and then arranged a joint venture of French and Japanese firms to produce in France. It is clear, however, that the need to have Japanese participation is regarded as a thorn.

West Germany. The Zysman proposition, that French policy has foundered in part because it mixed military and commercial objectives, is given some support if one contrasts the German experience. As noted, the German government has, in recent years, poured significant R&D funds into the German semi-conductor and computer industries. The objectives behind these programs have been self-consciously commercial. While military R&D spending has increased significantly in recent years, the military and commercially oriented programs have been kept separate administratively. In the commercially oriented program, the German companies have been in a position to propose their own preferred projects, as contrasted with being directed by a governmental mandate or procurement order. While the German industry has not achieved outstanding success in the market for either semi-conductors or computers, these German industries are recognized as being significantly stronger than the French. It

INMOS, a new company specializing in integrated circuits and oriented towards commercial markets. Total public R&D support, however, has been tiny compared with U.S. funding under defense and space auspices. British owned firms have not been effective in generating exports, and even in the home market have been relegated to niches.

France. The French have been much more aggressive than the British about building commercial competence. However their programs in support of computers and semi-conductors have been marked by dual purposes.

As noted earlier, French interest in developing a national capability to produce computers was motivated initially by restrictions imposed by the U.S. government cutting off access to an American computer judged necessary for the French nuclear program. The response was to establish a new "national champion" in computers -- CII -- and to mount a program of R&D support. Somewhat later, the French government also established a national champion for semi-conductors. Significant R&D funding was provided under a series of programs. These moves marked a desire both to build a French capability to meet the needs of military procurement, and at the same time a capability to compete effectively on commercial markets. Zysman (1979) has argued that this built-in schizophrenia virtually guaranteed failure to achieve the latter objective. As with the British, French military R&D spending was not large enough, nor were the objectives ambitious enough, to pull the technologies beyond where the Americans already were. At the same time, the military to procure electronics equipment based on the new technology. The new firms were in the forefront first in the military and space procurement market and then in the civilian market for semi-conductors that soon arose.

It is important to understand that these American defense and space programs were massive, compared with European and Japanese public expenditures on R&D in these industries, and were far more ambitious in terms of the technological advances sought than anything tried by other countries. Prior to World War II American industry certainly was not laggard in electronics, but was not noticeably superior to British industry and, if anything, German firms were considered to be the technological leaders. It also should be noted that several European firms were quite quick to get into transistors and, until the integrated circuit era, did not lag greatly behind American firms. But by the early 1960s, largely as a result of these defense and space programs, U.S. firms were the acknowledged technological leaders in computers and integrated circuits.

It should be noted that, in the eyes of some observers at least, after 1960 the lead in computers and the lead in semi-conductors went hand in hand. (See in particular Malerba (1983)) The leading American computer companies increasingly provided the key market for advanced semi-conductors. In turn, American strength in semi-conductors supported our computer lead. By the mid-1960s it probably was the civilian computer market that was exerting the dominant pull for new technology, with military and space less important than before.

Semi-Conductors and Computers

The U.S. Experience. The U.S. semi-conductor and computer industries, still clearly the strongest in the world, were enormously helped in their early days by a Department of Defense interest in the underlying technologies. While the details differ, the broad stories in the two industries are similar.[12]

Almost all of the exploratory research and development efforts that led up to the early electronic computers was financed by the armed forces. The government was virtually the sole market for the early operational computers and continued to be the dominant market into the early 1960s. Governmental funding of R&D and procurement was motivated strictly by national security interests. There is not a hint that anybody in government had in mind that they were creating an industry that would be a major economic asset. Very few of the companies involved in the early work for government believed that there would be a large civilian market, as well as a government one. Of course it later turned out that there was a very large non-governmental market for computers. The massive government support to computer technology provided U.S. companies with a head start that still has not been overcome by foreign companies.

The U.S. experience with semi-conductors has some similar elements and some differences. Perhaps the key difference is that the bulk of the early R&D was privately, not publicly, financed. The work leading up the transistor was motivated by perceptions of the utility of such a devise for the telephone system. Once the transistor had been invented, however, the that aim to help the Japanese firms to catch up with and then to surpass foreign technological capabilities. I describe these programs in the following section.

establishing branches in Japan, and while policies have liberalized somewhat in recent years, by and large foreign firms have been kept out of industries MITI has judged strategic.

The Ministry of Finance in Japan long has had policies that restrict the ability of Japanese banks and other financial institutions to send funds abroad. Also, the equity market is much less well developed in Japan than is the United States. The bulk of the large private savings in Japan thus flow to Japanese banks or insurance companies, where they in effect form a pool reserved for Japanese industries. The banks pay low rates to savers, lending rates are low, and credit is rationed. As Zysman (1983) and Flaherty and Itami (forthcoming) have pointed out, this financial system is ideally suited for government guidance of investment. The leverage is in part exerted through government lending institutions, but mostly through MITI guidance of private bank lenders. MITI in some cases has effectively exerted quite detailed control over the timing and allocation of new physical investments in an industry.

MITI has played an important role in helping Japanese learn about Western technologies and manufacturing methods. Scientists, technicians, and managers have been sent abroad to observe and sometimes to study. MITI has regulated and channeled the flow of technology licenses. And over the last decade or so MITI has both provided R&D support and a mechanism for coordinating R&D allocation decisions in the high technology industries it is pushing. Perhaps more important than any particular instrument, has been the general agreement among

European countries. From this point of view the miracle translates into very high rates of investment and physical and human capital. The question then becomes how the Japanese are able to sustain these high rates.

Other scholars turned their attention to peculiarities of Japanese culture and institutions. Lifetime employment and its alleged implications was a trendy topic a few years ago. Recently it has been the Japanese style of management.

Interest in Japanese industrial policies, and MITI in particular, is a Johnny-come-lately. I say this both to warn that, while recent scholarship is clearing up the matter somewhat, there still is some question exactly how Japanese industrial policies work, and to flag that these industrial policies are only one of a number of features that distinguish Japan from the United States, and from the European nations.

The active, shaping, role of the Japanese government in industrial development is not new. It goes back to the Meiji restoration which was, after all, triggered by the shock of awareness of Japan's great technological and economic inferiority compared with the Western powers. Since that time Japan has been playing catch up. By the advent of World War II Japan clearly was highly competent in most of the industries that mattered for military production, a fact that Americans strangely seem to forget in talking about the Japanese "post war" miracle. The instruments used in the post war period were used, effectively, in the pre-war era. The post-war MITI has recognizable connections with the agency that ran the Japanese economy during technological leader in most fields of chemistry, electronics, machinery, and aviation. Her system of scientific and technical education and basic research was widely regarded as preeminent.

The traditional policies have been reaffirmed in the post World War II era. Strength in scientific and technical training has been stressed, and the government supported laboratory structure extended.

Perhaps the most interesting part of the German industrial policy apparatus is the Ministry for Research and Technology, formed in the early 1970's. It stands separate from, not joined with, the Ministry of Economics, and is focussed on enhancing German industry technological competence. The Ministry has come to act as a sort of National Science Foundation for industry. Within certain broadly defined areas, companies submit proposals to the Ministry for evaluation by a committee consisting of government and non-government experts. In general it is required that company funds, as well as public monies, go into the projects that are accepted. The public funds involved now are substantial. The percentage of industrial R&D financed by government in West Germany is not much lower than the fraction in the United States, the United Kingdom, and France, despite the fact that military R&D spending is much less in Germany.

The German policies in support of high technology industries are well worth following closely. As with Japan, German policies pursuing economic objectives have not been tangled with narrow national security objectives. By and large, the present German policy looks like an R&D support policy and the support is provided through an agency specialized in that. Unlike the

France and Britain. Perhaps the major reason is that Germany does not now have and still is not aiming for a major defense design and production capability. Like Britain she has not viewed dependence upon the United States for certain technologies as cause for embarrassment, or alarm.

Prior to World War II, German governments seldom were shy about pushing an industry, or an industrial development, that they thought ought to be advanced for the national good. In this sense, the German tradition had been quite like the French. Government policies to support the development of industrial strength were explicitly justified by the objective of building military strength. Since World War II, the attempts of German governments to direct resource allocation have been quite constrained. The contrast with the pre-war view of the role of government certainly is partly due to self-conscious efforts, monitored by the victorious allies, to distance post war Germany from earlier traditions that had culminated in two world wars. In any case, inducements to government direction are diminished when there is no defense industry to support and no desire to build one, (although Japan is a counterexample). Recently, Germany has moved to engage in some military production but, for obvious reasons, this has been restrained.

While post war Germany has been touted as a bastion where market forces reign and the government does not try to plan or direct, this is something of an exaggeration. In the reconstruction period there was a considerable amount of government guidance, and tripartite discussion about appropriate directions. Later, the German government developed a strong airliners designed and produced in Britain and France have been money losers. The Airbus is an exception; I shall discuss it later. Britain also is similar to France in that her basic public utilities are nationalized. Thus the British airlines can be strongly urged to buy British made planes. The electrical network will buy British reactors. Telecommunications can be urged to buy British made electronic equipment. Britain has subsidized commercially aimed work in her computer and semi-conductor industries, but not as heavily as France.

While the British have been much concerned with national security and, where plausible, has preferred to make military equipment at home, there has been nothing like the French paranoia about dependence on the U.S. The British generally (not always) have been willing not to develop a national capability, if it were judged very costly to do so, and if a deal could be worked out with the Americans.

While from time to time, generally but not always under the auspices of a Labour government, Britain has toyed with the rhetoric of some kind of general economic planning, this never has amounted to much. Zeal for nationalization of key industries has waxed and waned. Nuclear power, aircraft, and to a lesser extent electronics aside, efforts at industrial reconstruction have largely been directed toward industries that were in deep financial trouble, and where serious job loss was occurring and more threatened.

In Britain there has been a long tradition of broad governmental concern for the R&D activities of firms, and of government encouragement and occasional support. Shortly after programs. Before the French government decided on its response, France's second largest computer company (after IBM), the then French owned Machines Bull, got into financial difficulty, and came under the control of General Electric. When the government's plan to create a self-sufficient French computer capability got into action, Machines Bull was excluded from the consortium of French firms put together to form a "national champion". Clearly a lot more was driving that policy than a striving for simple economic gain.

In the 1970s the notion that France's economic future rested on her high technology industries began to take hold; it has been trumpeted by the Mitterrand government. As our earlier statistical analysis showed, the bulk of government funding of industrial R&D in France continues to be channeled through defense agencies. However, over the years the French government has developed a variety of instruments to share in the cost of commercial industrial R&D projects. When it came to power, the Mitterrand government had every intention to use these instruments heavily. In addition, and with the objective of gaining more control by government agencies over the R&D and investment policies of high technology firms, a number of those that had been left private, up to then, were nationalized.

In sum, the contemporary French policy in support of its high technology industries for economic objectives remains intimately intertwined with its national security policies. Both long standing beliefs that government should direct industry when the stakes are high, and the national security interests in high technology industries, has led the French government to try to

As some of the more basic and obvious measures of reconstruction were completed, old habits of thought, newly reinforced, turned toward planning long range economic growth. A quite detailed economic plan, drawn up in dialogue between civil servants and people from industry, became the symbol if not necessarily the substance, of French industrial policy. The direction of French policies came to be fought out in connection with the formulation of the plan. The planning bureacracy became an important voice arguing that France must modernize.

Many influencial French citizens came out of the war with a strong sense of French economic as well as military inferiority, and a determination to catch up. If the explicit planning structure was a new departure, the instruments of industrial policy were the traditional ones, if used in heightened degree. These included access to low cost credit, outright subsidy of certain kinds of activities, protection from imports, and in certain cases government procurement. Bank finance in France is "rationed" to a far greater extent than in the United States, and the influence on the banks by the French government is much tighter than is the case in the U.S. Zysman (1983) has presented a powerful argument about how the nature of a nation's investment financing system affects the ability of the government to steer allocation of funds. In France, and Japan, the system is amenable to effective government steering. Also, in France the government controlled market extended far beyond military equipment. France came out of the war with a sizable nationalized sector. As in many other European countries, in France utilities like electricity generation and transmission, relevant high technology industries was piecemeal, and sporadic, after World War II the Department of Defense systematically funded R&D in aircraft, engines, and electronic systems. As we shall discuss later, Department of Defense programs were directly responsible for American preeminence in electronic computers, and semi-conductors, as well as jet passenger aircraft. Later, NASA funding provided support to roughly these same industries. The role of the Atomic Energy Commission in sponsoring the development of civilian power reactors was strongly linked in the early days with its role in the development of nuclear weapons and nuclear reactors for submarines and aircraft carriers.

The presence of the American policies described above, and a general self-confidence of the American people that they were the technological and economic leader, has, until recently, restrained any major moves toward the development of policies in support of high technology industries expressly for economic purposes. However there have been several episodes where such policies were seriously discussed at high levels in government. During the Kennedy Administration, proposals for a civilian industrial technology program were put forth. For the most part the suggested programs were not aimed at high technology industries, but lagging ones. In any case, not much came of this discussion. Another discussion surfaced in the first Nixon Administration. The occasion was the fall-off in military and space R&D spending which occurred during the late 1960s and growing apprehensions that other countries were beginning to gain on us. Again, very little came out of this endeavor. It might be noted, however, that during the late 1960s the United States

The United States certainly has not been passive regarding its high technology industries. In the first place, for many years the United States was far ahead of the rest of the world in terms of the fraction of its youth who went through secondary education, and college. While in recent years Japan has surged past us in engineering education, if numbers of students gaining a degree be the index, the United States continues to rank high in the fraction of the entering work force with a college level degree in science or engineering. Virtually all the secondary education, and the lion's share of the advanced education, has taken place in public institutions and has received large influxes of public funds. Scientific and engineering education has been singled out for special help.

The United States, like other countries, came out of the first World War impressed with the importance of certain high technology industries for national security. During the inter-war period a variety of measures were taken not only directly to procure new military aircraft, but to build up the technological strength of the industries producing airframes and engines. I shall give more detail on this experience later in this essay. It might be noted here, however, that the Pratt and Whitney aircraft engine company was formed with considerable governmental encouragement. There was like encouragement, and governmental restructuring, of the radio industry. The Radio Corporation of America was formed, under governmental prodding, to increase American strength in radio technology and to cut through certain tangles about patents; the express purpose was to get our industry to the forefront of radio technology.

Section IV: Qualitative Characterizing of Broad Policy Positions

A different view of the industrial policies is contained in broad qualitative characterizations of them and the institutions of different countries as these bear upon the performance of their high technology industries. This is an art form which has been used to good avail by Raymond Vernon (1974), and more recently by Jack Baranson and Harold Malmgren (1981), Ira Magaziner and Robert Reich (1982), and Laura Tyson and John Zysman (1983). Sometimes, as in the forementioned studies, the analysis is explicitly comparative. In other cases the focus is on a single country, with other countries being treated as benchmarks.

Such analyses aim to identify similarities and differences, and to try to assess the consequences of the observed differences. The latter exercise is especially difficult. And because of limitations of our ability to evaluate consequences of various differences, even the first part of the exercise -- simply identifying the relevant differences -- becomes problematic. The policies and institutions of the different countries that conceivably could bear on the performance of their high technology industries are extremely rich and variegated.

There are many strategies I could follow for presenting a broad comparative analysis. For the purposes here, it seems convenient to proceed by, first, sketching the situation in the United States. I then describe what I think are the salient differences between the United States and the major European countries, and among the European states. Finally I turn to Japan.

does it matter, or it does it not matter, whether government R&D funds flowing to the electronics industry are part of a defense program, or part of an industrial policy? While we now understand somewhat better the nature of the government programs that are associated with various government R&D flows to industry, and have a stronger appreciation of how the activities financed by those monies interact with other activities in influencing technological advance, we are not yet in a position to specify the form of the equation to be fitted.

There are several quantitative studies in which these problems have been avoided because the focus was on a particular relatively narrowly defined area, a program or even a project. Almost all of these studies have been of the effects of publicly supported agricultural R&D in the U.S. The largest group of these have been concerned with estimating the returns of a flow of public R&D investment, often accompanied by private ones, aimed to create a new kind of agricultural input (hybrid corn seeds) or improve a particular product (poultry). These studies have been detailed enough so that the relations used to permit estimation of a social rate of return have considerable plausibility. The estimated returns have generally been very high.[7]

There also have been some studies that have examined, in some detail, the contribution of NASA R&D to technological advance of importance to the civilian economy. Despite the fact that civilian benefits usually were not the principal objective, for some of the projects studied the civilian benefits were substantial.[8]

In the early 1960s, Britain, France, and Germany were quite close in levels of per capita income and average productivity. Since then, the capital-labor ratio in France and Germany has grown much faster than in Britain, or in the U.S., and so has output per worker. By 1980 France and Germany, but not Britain, had come close to catching up with the U.S. in productivity levels.

Clearly the relationships are complicated. I believe in the analysis sketched above, but reliable quantitative estimates of the role of R&D and other factors are hard to devise.[3]

The analytic difficulties diminish somewhat, but remain severe, when the analysis is concerned with data at the industry level. Unfortunately, to my knowledge there has been no study tracing the relationship between various measures of technological progress in an industry in different countries and various kinds of R&D inputs in those countries.[4] Virtually all studies using industry level data have focused on the United States, and been concerned with cross industry comparisons. The attempt is to explain the cross industry differences in some measure of technological progress, usually growth of total factor productivity, by R&D, broken down in various ways, and other variables. An important finding of many early such studies was that an industry's growth of total factor productivity was strongly influenced both by R&D done in the industry, and R&D done by supplying industries.[5]

These early studies usually did not distinguish between government financed R&D and privately financed. More recent studies have. Various functional forms have been explored. In labeled as for industrial growth. The defense and space R&D funds naturally flow to the "leading industries". The countries without a large defense or space program apparently have partially compensated by devising explicit R&D support programs associated with an "industrial policy", at least for their electronics industries.

It seems important to know in what ways funds that are labeled as for "industrial growth" are allocated differently than funds that are labeled as for "defense" or "space". While certain gross differences would appear to be obvious -- in most cases items procured by the military differ in significant ways from items that are sold on commercial markets -- there may be less here than meets the eye. First, what is learned in a program aimed to design and develop a piece of military equipment may lead relatively directly to a follow-on product for the civilian market. As we shall see, there are a number of examples of this sort. But second, a portion of defense and space related R&D is not tied up in work on particular designs, but is much more generically oriented. It appears that a considerable share of the R&D financed by governments in pursuit of the goal of "industrial development" also is generic in nature. To what extent then do defense oriented programs, and industrial development oriented programs, finance much the same thing? It clearly is important to get behind the data and examine the programs in more detail.

The same kind of difficulties should make one skeptical about what can be learned from studies aimed to measure the impact of government R&D spending. The problems are most severe when the

R&D in the air and space industries is largely financed by governments. In the late 1960s such spending was closely tied to defense. The increase in Japanese and German public R&D funds going into air and space since the late 1960s is associated with some rise in their defense R&D budgets, and an increase in their funding of R&D on commercial aircraft.

Considerable public R&D goes into these two large industry complexes in all countries. In Germany and Japan there also is considerable public finance of R&D in the machinery industry. The other large R&D intensive industries, chemicals and chemical linked products (largely pharmaceuticals), and "other transport" (largely automobiles), are financed mostly by industry.

Table IV describes the distribution of government R&D by social objective. Notice the small percentage of government R&D going to "industrial growth, not otherwise classified." If one adds in transport and telecommunications the numbers still are small. In some countries energy related R&D is significant; most of this is nuclear power. In a few instances civil aeronautics is significant. However the dominant impression is the very limited scope of government R&D support for high technology industries for commercial purposes.

But it is dangerous to draw any quick conclusions about the unimportance of government support, and reasons to suspect that the numbers above that purport to measure a country's active industrial policy may not tell us much. Notice that the two countries with the greatest commitment to government financed defense and space R&D spending -- the U.S. and the U.K. -- put relatively little government money into R&D programs explicitly countries in question. While there is some variation across the countries in the ratio of industrial to total R&D, the range is relatively narrow. There are differences, however, in the fraction of industrial R&D financed by government. Note the strong correlation of governments' share of financing of industrial R&D, with the emphasis on defense R&D. Japan and Germany, the countries with the smallest fraction of national R&D given to defense purposes, are at the bottom of the list regarding the government's share of industrial R&D. While Germany is close to the pack, government industrial R&D spending in Japan is very low compared with the rest.

Table III presents data on the distribution by industry of industrial R&D spending, broken down by source of finance. In all countries the electronics-electrical complex of industries attracts between a fifth and a third of both private, and public, industrial R&D funding. While the countries are roughly similar in the fraction of the governments' industrial R&D budget going into these industries, the fact that in Japan and Germany the government accounts for a relatively small share of total industrial R&D means that the public share of electronics R&D financing in these countries is small compared with that in countries with large defense R&D efforts, like the United States. Most of government R&D spending in these industries is for defense. Programs in support of reactor development channel funds into the electrical equipment industry, but these moneys are relatively small. As we shall see, programs in support of commercially oriented R&D in electronics are very small compared with defense related programs.

TABLE I

R&D Expenditures as a Percentage of GDP: Total, Defence, Non-Defence

	1963	1967	1971	1975	1980
United States					
Total	2.90	2.90	2.60	2.30	2.45
Defence	1.37	1.10	0.80	0.64	0.57
Other	1.53	1.80	1.80	1.66	1.88
United Kingdom					
Total	2.30	2.30	2.10[a]	2.10	1.83
Defence	0.79	0.61	0.53	0.62	0.72
Other	1.51	1.69	1.57	1.48	1.11
France					
Total	1.60	2.20	1.90	1.80	1.83
Defence	0.43	0.55	0.33	0.35	0.41
Other	1.17	1.65	1.57	1.45	1.42
Germany					
Total	1.40	1.70	2.10	2.10	2.27
Defence	0.14	0.21	0.16	0.14	0.12
Other	1.26	1.49	1.94	1.96	2.15
Japan					
Total	1.30	1.30	1.60	1.70	2.04
Defence	0.01	0.02	-	0.01	0.01
Other	1.29	1.28	-	1.69	2.03

Source: OECD

Except for 1980 numbers taken from Table I of Technical Changes and Economic Policy OECD 1980

a) 1972

In this and the following two sections I describe and analyze the policies of the five major industrial nations towards their high technology industries from three different angles. I will, first, consider certain quantitative aspects of these programs, presenting data on R&D spending, and reviewing some of the studies that have been made attempting to assess the returns to private and public R and D. In section IV I will describe, qualitatively and in broad terms, the policies of these nations, and how they have evolved. Then, in section V, I focus on three major industry groups - semi-conductors and computers, civil aircraft, and nuclear power.

Each of these views reveals certain things, but obscures others. Together they provide a rich, but certainly still not complete, picture of post war experience. Available evidence and plausible inference does, I believe, enable one to discern at least the outlines of what the policies in fact have been - no trivial issue in view of the several conflicting statements about them. As we shall see, however, while certain things can be said with some confidence about the effects of these policies, there are many puzzles, blank spots, and open questions.

Attempts to Measure Policies, and Their Impacts

To begin, it is useful to review the data on differences and similarities across nations in patterns of total and government R&D spending. For some time now the OECD countries have been collecting and publishing R&D statistics that are roughly comparable. These numbers would appear to enable us to assess, to a first approximation, the magnitudes of the R&D resources involved, government tutelage of industries deemed in the public interest. These traditional policies have, willy nilly, served as starting places for the new industrial policies. But only as starting places. The new policies face different objectives and constraints than the more traditional ones. As we shall see, some very specialized structures have been developed to deal with the new targets and problems. The question is the efficacy of these new structures to the new assumed tasks.

Policies in support of high technology industries seeking economic benefits have grown at least as much out of traditional defense procurement policies as from traditional policies in support of generic research. But the technology relevant to products that a government agency wants to procure may or may not be a basis for products that will sell profitably on a civilian market. One key question is whether, and if so how, variants of the old procurement policies, more consciously aimed to enhance civil capabilities, can advantage the domestic industry in international competition. Another is whether security and economic interests are complementary, or whether they tangle each other.

Among the present day major industrial powers, the United States and Britain are extreme in the extent to which government involvement in the detailed guiding of the economy is seen largely as a danger to be avoided unless a clear-cut public interest, like national security, is involved. In other countries government guidance, protection, and support, are seen as natural instruments to be used whenever appropriate to further the national interest. Part of the difference undoubtedly lies in the Anglo-Saxon, and American, legacy of defining freedom largely as freedom from government. Part of it comes from the fact that neither Britain nor the United States developed a tradition of strong state economic guidance, accompanied by protection and subsidy, as occurred several centuries ago in France, and during the 19th century in Germany and Japan. In these countries there is far less resistance to the idea that tutelage is appropriate for industries that are in the national them to catch up with those they perceived as the technological leaders.

While much of governmental support of academic research and teaching goes to the traditional basic science disciplines, like physics, a good portion goes to the applied sciences -- like pharmacology, or computer science, or electrical engineering -- which are quite close to certain technologies and industries. Public support partly reflects, and partly assures, that technological knowledge has an important public component as well as a private one. The public part of technological knowledge generally does not relate to the design or operational details of a particular product or process, but to "generic" knowledge -- broad design concepts, general working characteristics of processes, properties of materials, testing techniques, etc. Such knowledge often is not patentable. While such knowledge sometimes can be protected by industrial secrecy, this may be difficult. Also, this is the kind of knowledge that must be imparted to those trained to be engineers, or advanced technicians. Therefore, it would seriously interfere with the ability of technical schools, and universities, to provide good training if the relevant knowledge were proprietary. Thus, there are strong incentives for such knowledge to be treated as public. In many fields there is a well established research community, with participants both in universities and in industry, who contribute to generic knowledge.

The presence of well established networks of generic research, with roots in academic institutions, and traditionally financed in good part by government, provides one important road ability to find out where firms are allocating their own R&D efforts. To the extent that public monies aim to "fill gaps" in the private portfolio, it may be no easy matter to find where these gaps are. There also is the danger that public funds may duplicate, or replace private funds.

Also, private firms are likely to resist governmental programs that they see as cutting into their own turf, or helping competitors. In a democracy industrial policies must be regarded as "fair". Put more generally, it is a mistake to think that an industrial policy can successfully be imposed upon an industry. To be effective a policy requires a degree of cooperation and participation from the industry, and members of the industry inevitably are going to be influential in shaping any policy.

New policies in support of high technology policies, in search of economic advantage, also are constrained and molded by the fact that they are not planted in new ground. The Schumpeterian view of technological progress and competition, sketched above, is one-sided. It highlights proprietary technologies, private institutions, and the profit and power motives of private parties, and leaves hidden in the shade the very considerable long-standing public involvement in high technology industries. In many countries this involvement has intensified significantly in recent years as the new industrial policies have been consciously set in train. However, the modern policies have recognizable roots in more traditional ones which at once gives them a certain legitimacy, and a set of habits of thought and action, which may or may not be appropriate effort. The premium placed on achieving an invention first, so as to get a patent, or at least a head start, may lead to undue haste and waste. That three companies -- McDonnell-Douglas, Lockheed, and the Airbus consortium -- all tried to compete in the market for wide-bodied, medium-sized airliners surely meant that total costs were excessive, if it also meant that the airlines got a good deal.

On the other hand, the fact that certain kinds of technological advances are not well protected by patents, and are readily copied, deters companies from investing in these, even though a significant advance would lead to enhanced efficiency or performance. Before the advent of hybrid corn seeds, which cannot be reproduced by farmers, seed companies had little incentive to do R&D on new seeds, since the farmers, after buying a batch, simply could reproduce them themselves. The farmers themselves had little incentive to do such work since each was small and had limited opportunities to gain by having a better crop than a neighbor. Within an industry, different kinds of problems vary in the extent to which the problem solver gains a special advantage. In an industry where scientists and engineers are mobile it is hard to keep secret for very long information about the broad operating characteristics of a particular generic design, or about the properties of certain materials. Such knowledge is not patentable and, if patentable, would be very hard to police.

<u>Constraints and Bases for Public Policies</u>. It is tempting to regard these kinds of "market failures" as providing both

however, whether the communication networks are, or can be, truncated at national borders. The presence of multi-national corporations in high technology industries further complicates this question. We shall return to it later.

The Competitive Market Context. Joseph Schumpeter, more than anyone else, has shaped the way scholars view competition in technologically progressive industries. Schumpeter's core message was that the most socially valuable form of competition, in capitalist economies, was through technological innovation.

It is proprietary technological knowledge that drives the capitalist engine. The principal ways to achieve proprietary benefit are secrecy, patent protection, and through a head start. There are significant differences among technologically progressive industries in the extent to which these different mechanisms are effective. In the pharmaceutical industry, where it is easy technologically for one company to copy another's drugs, patents play an important role both as a spur for product innovation and as a protector of a company's successful products. In semi-conductors, on the other hand, patents do not appear to play such an important role in part because they are difficult to enforce, and in part because a simple head start down the learning curve often gives a company a durable, and profitable, advantage. In industries like those that design, and produce, large commercial aircraft, or mainframe computers, the technologies are sufficiently complicated that they simply are difficult to imitate, even when they are not well protected by patents. But while the mechanisms differ, what is noteworthy is technological regimes often were marked by changes in the nature of the predominant companies. Thus, as jets replaced piston driven planes, Boeing replaced Douglas as the leader in the design and production of airliners. With the advent of the integrated circuit, the old electronic equipment producers, like General Electric and Westinghouse, failed to stay competitive, and were replaced as technological leaders by such companies as Texas Instruments, Mostek, and Intel.

Technological advances often are linked together because certain products form relatively tightly integrated systems. The development of more efficient and powerful bypass jet engines in the 1960s made possible the wide-bodied jet passenger airliners. Integrated circuits are the heart of the modern computer. In a systems technology, an advance in one part of the system may not only permit, but require, changes in other parts. Thus a computer designed around integrated circuits is a very different machine than one designed around vacuum tubes.

The term "system" connotes a recognized strong interdependence between components. Institutionally this recognized interdependence leads either to the development of companies that design several of the key components themselves, or to strong interactions, sometimes contractual, among companies producing different components.

The tightness of interdependence, and of organizational connectedness, of course is a matter of degree. When ties are relatively loose, the concept of systems connectedness comes somewhat awkward, but some of the same phenomena show up, in occur; things happen that no one thought of, and which call for a rethinking of the whole program. But if everyone saw the problem, and the uncertainty, in the same way, one still could think of trying to broadly plan R&D, in the spirit of dynamic programming, around the consensus ideas of knowledgeable people. There is merit in this perception.

Yet a key characteristic of the R&D environment is differences of opinion and vision. Human beings, and organizations, seem to be innately limited in the range of things they can hold in mind at any time, and even in the way they look at problems. Some individuals simply see things about a problem, or about an alternative, that others don't see; what is seen may or may not be actually there. But the fact that different people look at a problem in different ways and see different things about it means that terms like insight, creativity, genius, often are applied to successful inventors or laboratories. It usually is not clear in advance to anybody in a position to make judgments about the matter just who is going to bet right this time. Committees of experts are unreliable judges of these issues, even if, or particularly if, they are forced to arrive at agreement.

The implications are important. The uncertainty that characterizes technological advance in high technology industries warns against premature unhedged commitments to particular expensive projects, at least when it is possible to keep options open. The divergences of opinion suggest that a degree of pluralism, of competition among those who place their bets on ability of public policies to hit these. Certain constraints are caused by the implicit guide rules of market competition which limit what government actors can do in the game. Others have to do with more general limitations on the policy tools that governments can fashion to spur and guide technological progress.

Uncertainty. It is important to recognize the essential uncertainties which surround the question -- where should R&D resources be allocated -- in an industry where technology is advancing rapidly. There generally are a wide number of ways in which the existing technology can be improved, and at least several different paths toward achieving any of these improvements. Ex-ante it is uncertain which of the objectives is most worthwhile pursuing, and which of the approaches will prove most successful. Before the fact, aviation experts disagreed on the relative promise of the turboprop and turbojet engines; those that believed in the long run promise of commercial aircraft designed around turbojet engines were of different minds about when to go forward with a commercial vehicle. Whether and when computers should be transistorized was a topic on which computer designers disagreed; later the extent and timing of adoption of integrated circuit technology in computers was a subject which divided the industry.

In a certain sense, technological advance is a wasteful process. There inevitably is a litter of abandoned ideas and projects, some of which cost plenty. Hindsight suggests that there ought to be ways to tidy up the process, to avoid marching down false paths, to figure out in advance which technology will policies are feasible and effective, and what kinds infeasible or ineffective or worse?

In order to begin to explore these questions, in Section II I review some of the salient features of the process of technological advance, and of industries where technological advance is rapid. Such a review helps to identify, in a preliminary way, the opportunities for and the constraints on public policies aimed to achieve more effective allocation of resources to further technological advance. Then, in Sections III through V, I turn to the actual experiences the major economic powers have had with industrial policies. This recounting is partly description, but also partly analysis, since the choice of what policies to describe, and how to describe them, innately involves judgments about what is important. The countries studied are the U.S., Britain, France, West Germany, and Japan. As mentioned earlier, three industry groups will be given special attention: semi-conductors and computers, civil aviation, and nuclear power. In Section VI I return explicitly to the three basic questions raised above, and try to provide tentative answers to them. In the concluding Section I make some remarks about plausible directions for U.S. policy.

is posed in terms of the education and banking systems that arose in Germany, but not in Britain. The American supremacy in average worker productivity in manufacturing in general, and in per capita income, preceded the rise of our semi-conductor and computer industries. Several scholars have noted that the American system of higher education had unusual strength in the post World War II era. Many have noted that the extremely high investment rates in Japan, and the development of an educational system that outstripped the United States in the production of engineers, came before Japan gained strength in electronics. Keith Pavitt (1976) has argued that ability to exploit the technological opportunities afforded by leading industries requires strong technological capabilities in a wide range of industries - chemicals, machine tools, and other metal products are good examples. If strength in the high technology industries and their downstream partners is basically a concomitant of general and broadly based economic and technological strength, rather than a basic cause, then it may make little sense to try to stimulate these industries specifically.

And, there is the related question of what, if anything, narrowly aimed government policies can do to help its domestic companies get and stay in the forefront of industries where the technology is advancing very rapidly, and there is considerable international competition. In the view of several American writers on the subject, a policy in support of high technology industries is to be distinguished sharply from a policy of supporting more traditional ones because they are in trouble. Indeed the proposal is to shift our industrial policy emphasis

One can piece together two plausible counter arguments, as to why high technology or leading industries are also strategic ones for high income countries.

One is based on a product cycle theory of trade, amended by a proposition that the returns to R&D are not fully appropriable by the undertaker. A starting premise is that high wage countries need to be competitive in high technology products, if they are to be competitive in anything. Given a considerable degree of international capital mobility, high wages can be maintained, and increased, only if a country has a special capability for producing things that low wage countries cannot. In some cases these capabilities may be related to special access to certain raw materials, or climatic advantages. Mostly, however, if high wage countries are to be able to compete, they must be ahead of other countries in the creation and implementation of new technologies. Add to the product cycle theory an argument that, while many of the relevant investments in new technologies are appropriately made by private individuals and business firms, some of the most important investments, specifically R&D, yield significant externalities. Then one has a case for public support of these latter kinds of investments, which indeed are of strategic importance to high wage countries.

The argument above is not tied to the notion that high technology industries are necessarily leading. A second and different argument is concerned explicitly with leading industries. The core idea is that, since technological advance in leading industries yields opportunities for innovation in the industries that buy from them, firms in these connected

(1939) he observed that economic progress is not steady but occurs in "long waves" -- an idea put forth earlier by Kondratieff -- and proposed that these were caused by periodic surges of technological innovation. He associated each upswing of the Kondratieff cycle with a cluster of innovations in particular leading industries -- textiles and machinery in the first part of the 19th century, iron and steel and railroads in the second part, automobiles and chemicals and electrical equipment during the beginning of the 20th century. He argued that technological advances in these industries had wide effects and, indeed, more or less determined the general economic climate of an era. The notion that the second half of the 20th century is being shaped by innovations in electronics, particularly as applied to computation and communication, and to a lesser extent by vastly speeded long distance transport, clearly is in the spirit of Schumpeter's theory.

The leading industry notion involves some combination of significant ongoing technological advance, and widespread economic effects. An industry can be leading without being particularly high tech and clearly not all high technology industries are leading. However the three industry groups that will be the particular focus of this essay -- electronics, aircraft, and nuclear power -- all have been highly R&D intensive and have had, or were expected to have, major shaping effects on a wide range of economic activities.

The idea that high technology, and particularly leading, industries are "strategic," in the sense that they warrant special favor and support, also seems to have been around for