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Bringing science to market: The policy implications of U.S. and Japanese patterns of science, technology, and competitiveness

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BRINGING SCIENCE TO MARKET

THE POLICY IMPLICATIONS OF U.S. AND JAPANESE PATTERNS OF SCIENCE, TECHNOLOGY, AND COMPETITIVENESS

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to Dick,
for his remarkable suggestion

and in the memory of Papou John,
for his courage and sacrifice

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Contents

Introduction

Today the peoples of every nation are engaged in vigorous competition. The victors will be those pioneering in new areas, progressing in new directions and establishing new industries based on science. Looking at such competition throughout history, we find that those who pioneered in new areas, created important new industries or stimulated their expansion almost without exception had to rely on new scientific discoveries.

Wilhelm Siemens, founder of Siemens AG (and the electrical industry), *circa 1885*

This dissertation tries to explain why, and with what likely consequence, the U.S. policy response to the competitiveness crisis of the early 1980s has been dominated by the science and technology arena. As competitiveness was elevated to buzzword status, science and technology issues and concerns so defined the nature of the crisis that one cannot help but suspect they were ultimately confounded. Stagnating productivity, declining real standards of living, and extraordinary trade deficits hence came to be addressed in the language of science, technology, research, and innovation.

Obviously many other areas of national policymaking have been called on to alleviate the crisis, principally U.S. trade policy but also the education, labor, and monetary arenas. *Science policy*[1] is nonetheless the lead arena because of the degree to which it is perceived as the core determinant of competitiveness. Science and technology policies and programs, initiatives and institutions are measured against the competitiveness "yardstick" far more than any others. Their merits are as a result increasingly evaluated in terms of their ability to correct present economic weaknesses and contribute to the nation's future competitive strength. All other factors notwithstanding, it is believed that the failure to develop leading-edge science and technology is tantamount to economic failure. In a nutshell, "bringing science to market" became the heart and soul of competitiveness policy efforts in the 1980s, and was primarily

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[1]Following convention, science and technology policy will be frequently referred to simply as "science policy". Although there are identifiably separate policies for both science and technology, these activities are typically conflated into a single category of policymaking. There are those who would argue that this pairing is inappropriate; however, the ideas presented here do not require any rigorous distinction between these two areas of public policy. Moreover, one can make the argument that the policy/political arena for science and technology issues are the same; consequently, it seems unwarranted to force them into separate regimes.

based on widely held convictions about the causal relationship between science, technology, and economic health.

But the heart and soul of policy analysis is always the question "will it work?" Convictions about the way the world works aren't necessarily so, and in the case of science and competitiveness, the "anecdotal evidence of history" is in direct conflict with a contemporary paradox over the seemingly diminished economic potency of rapid technological advance. If nothing else, scholarship should always challenge prevailing wisdom, for it is precisely when events become too easy to explain (or a paradox ignored) that we should be most concerned our fundamental presumptions are wrong.

The significance of this study nevertheless goes far beyond a theoretical exploration of the validity of policymaking assumptions about the relationship between science, technology, and competitiveness, for it tries to verify empirically associations between scientific and technological innovation (as proxied by R&D expenditures and various R&D "output" measures such as publications and patents) and patterns of competitiveness between Japan and the United States. In the process of doing so, the study sheds considerable new light on the nature of the competitiveness crisis itself, reveals a far more "scientifically" oriented Japan than previously thought, and provides evidence of the difficulty in establishing a systematic relationship between R&D and competitiveness.

As part of assessing whether or not our competitiveness policies "will work," this dissertation tries to determine whether or not we can explain patterns of U.S. industrial competitiveness vis-a-vis Japan by virtue of patterns in these two nations' scientific and technological innovation. Since Japan is the singlemost troublesome U.S. competitor, the second largest market economy in the world, and a "self-confessed" technological imitator, how it uses science and technology for competitive advantage is of consequence not only for the United States and the world economy, but for how we have traditionally theorized about the commercial role of science. More than one observer has wondered how it is that Japan can become such an economic powerhouse exclusively on borrowed or marginally adapted technology, and how it is that the United States has failed to make comparably successful use of its own know-how.

Data on competitiveness and scientific and technological innovation are analyzed for the years 1970 to 1987 at the 2- and 3- digit standard industrial classification (SIC) level for both

Japan and the United States. Notably, this is the first time that the competitive status of the entire U.S. manufacturing sector has been profiled; measures of national competitiveness have previously been indirect proxies for the macroeconomy as a whole. Lack of appropriate data has prevented a more disaggregate scrutiny of U.S. (and Japanese) competitive performance.

The time period selected is useful for a variety of reasons. Not only does 1970 pre-date the movement to floating exchange rates and the economic disruptions of the following decade, but most scholars agree that Japan's post-war industrial reconstruction was complete by that time. This year thus serves as a significant place to begin a competitiveness analysis; it benchmarks the United States near the peak of its international economic preponderance, and anchors Japan at the conclusion of its intensive period of industrial and technological "catch up," and hence prior to its extensive efforts at indigenous innovation.

The last year in the period of study (1987) marks the bottoming out of the U.S. competitiveness crisis, at least in terms of the trade deficit. These seventeen-odd years therefore capture one of the most unstable decades in the international economy, dramatic shifts in competitive performance between Japan and the United States, and the historical unfolding of Japan's considerable technological strengths. If changing patterns of scientific and technological innovation had anything to do with the crisis in U.S. competitive performance in the 1980s, they should show up during the years under review. Importantly, these patterns must be distinguishable from competing "causes" in the international economy and the periodicity of business cycles. The key competitiveness indicators developed here--U.S. import penetration ratios, balances of trade, and revealed comparative advantage--are consequently analyzed in 4-year increments which overlap the troughs and peaks of U.S. business cycles, and are evaluated in association with key developments in the international economy.

Many readers will undoubtedly be disappointed by both the methodology and the innovation indicators used herein. There are no econometrics or even simple statistical correlations. While these techniques represent the appropriate next stage of analysis, they were not used for the simple reason that prior to this study there was essentially nothing to model. We effectually had no patterns of competitiveness--or their association with science and technology--to explain. Such a substantial amount of indicator development and exploratory analysis was (and still is) required that it constitutes stand alone work in its own right, and that is what is done here. The methods employed are ones of pattern matching, competitiveness typology construction, and R&D performance classifications.

Similarly, many may take issue with the use of R&D expenditure data and the crude bibliometric and patent statistics as indicators of innovative activity and output. These are admittedly imperfect measures of the *quality* of innovative activity, and they do not capture the full scope of innovative efforts or outputs. Nevertheless, years of study have demonstrated that these data represent relatively well the dimensions of organizationally-based innovation. One of the findings of this research is that there does seem to be a reasonable degree of association between the R&D inputs into scientific and technological endeavors and their innovative outputs.

What does not emerge from the data is any obvious evidence of the key assumption upon which virtually all of the science and technology-oriented competitiveness policies are based: clearly identifiable, common patterns of performance in both competitiveness and scientific and technological innovation. To some this may be a stunning revelation, to others a ho-hum fact. While this finding clearly warrants further and more refined statistical investigation, what it points to is the need to re-examine the basic principles of science-based competitiveness policies. What *does* seem to explain U.S. and Japanese bilateral competitiveness patterns are differentials in their rates of change in total factor productivity, suggesting that productivity is a "blacker" black box than we suspect. Since productivity is presumed to be driven by technological change, patterns of productivity and R&D performance should likewise be similar.

There are also a number of other important findings suggested by the data. The crisis in U.S. competitive performance during the 1980s was largely an industry- and country-specific phenomenon; it did not appear as a manufacturing-wide crisis and was confined to a handful of manufacturing industries (autos, steel, electronics, textiles, and the newly non-competitive machinery industries) and a handful of countries (principally Japan, but to a lesser extent the East-Asian NICs). However, the durable goods industries as a class evidenced seriously weakened competitive performance, a decline that cannot be accounted for by the typical impact of economic recoveries on import volumes.

Macroeconomic factors of the 1970s and 1980s thus seem to have played an important role in the crisis. The 1970s business cycle disruptions constrained the ability of price-elastic industries to rationalize and adjust during cyclic downturns and recessions; overvalued exchange rates in the 1980s systematically distorted prices of products that are highly price sensitive, namely durable goods. How permanent these effects are has yet to be determined; we are only now sufficiently far along in time to detect any real trends since the mid-1980s. Exchange rate adjustments were not executed until 1985, and trade must proceed through the resulting "J-curve" effects first. From all appearances, this adjustment was complete in 1990, and we can now begin distinguish the impact of exchange rate valuations from more intrinsic competitive problems and the role of business cycles.

It would additionally appear that Japan is a far more "scientifically" oriented innovator than given credit for. A detailed comparison of U.S. and Japanese expenditures on basic scientific research show that Japan may in fact have a very healthy and substantial strategic basic research system, an attribute that flies directly in the face of conventional wisdom on this subject. The basic research data that are analyzed here have been "cleaned up" to significantly reduce comparability problems, and it is likely that "noise" in these aggregate data have been masking important features of the Japanese R&D system. Although there is abundant anecdotal evidence (and heresay) diminishing and discrediting Japan's scientific research strengths, as is illustrated later, patterns of Japanese competitiveness may be partially explained by its basic research efforts (although the same cannot be said for the U.S.).

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The analysis that follows is organized into four parts. The first, composed of chapters 1-3, overviews the nature of the competitiveness crisis and explains how the accompanying policy response became the property of the science and technology arena. Chapter 1 presents a brief discussion of the crisis as it evolved from the productivity crisis of the 1970s to the trade crisis of the 1980s, summarizes the supply-of-science orientation in the policy response, and introduces the possibility of a "paradox" between policy assumptions about the role of science in the economy and the reality of the past two decades. Chapters 2 and 3 deal with issues of policy design; that is, how national problems are perceived and shaped into a policy response. What is notable about science policy is the extraordinary influence of ideas on the policy design process, largely because they lend themselves to seemingly rational political exploitation. Chapter 2 therefore presents the intellectual roots of U.S. science and competitiveness policies, while Chapter 3 shows how political interests and the American liberal tradition interact with "the ideas" to fashion a supply-of-science solution to the competitiveness crisis.

Chapter 4 is the sole constituent of Part II, which represents the transition between the policy issues and the empirical work that follows in chapters 5-7. This chapter reviews the literature on the role of science and technology in the economy, and demonstrates that there is compelling theory and evidence that supply-of-science competitiveness policies may fail completely to redress weaknesses in U.S. competitiveness. Two contending sets of explanations may be advanced to explain the role of science and technology in competitiveness; one is the supply-sided emphasis contained in our public policy, the other is an innovation "contingency" approach. The latter argues that supply and "demand" factors are interactive, mutually dependent determinants of competitiveness. Chapter 4 concludes with a set of propositions about expected patterns in science, technology, and competitiveness if the supply-sided approach is a valid and effective understanding of bringing science to market.

Part III contains all of the quantitative work "testing" the propositions developed in chapter 4. Chapter 5 analyses competitiveness indicators, and orders the 24 manufacturing industries into a 4-factor typology of competitiveness (non-competitive, newly non-competitive, at-risk, and competitive). Patterns of "science" (basic research expenditures and scientific publications) are explored in chapter 6, patterns of "technology" (industrial R&D and patenting) are similarly evaluated in chapter 7. The major findings and their implications for policy-making, innovation theory, and industrial political economy are provided in chapter 8 of the last section. Part IV concludes with a brief epilogue, which presents the most recent manufactures trade data and assesses its implications for a future competitiveness research agenda.

Part I
Paradigm and Politics

A nation which depends upon others for its new basic scientific knowledge will be slow in its industrial progress and weak in its competitive position in world trade, regardless of its mechanical skill.

Vannevar Bush, *Science--The Endless Frontier*

CHAPTER 1

Policy and the Paradox of Macro Crisis

The "catastrophic event" which signalled the competitiveness crisis was a serious decline in the U.S. current account balance during 1982-84.[1] Although the current account was balanced throughout much of the 1970s, 1982 marked the beginning of an erosion that did not end until 1987 (figure 1-1). The source of this downturn was a growing deficit in U.S. merchandise trade, which had actually been in deficit since 1976; the critical development was a dramatic deficit in manufactured goods, historically a surplus trading category.[2]

What is now a seemingly permanent manufactures deficit began in 1983 with a substantial deficit of nearly $23 billion (figure 1-2). The deficit tripled to about $68 billion in 1984, and peaked in 1987 at $125 billion. Exacerbating the manufacturing deficit was a reversal in U.S. international investment income, which in the period of one year (1984-85) moved from a net surplus of $4 billion to a deficit of $112 billion, making the U.S. a "debtor" nation for the first time.[3] Within the space of two to three years, the United States witnessed the extraordinary and unprecedented reversals in two critical balance of payments accounts.

The U.S. policy response to these developments was somewhat unusual, given the fact that--at the time--the country was beginning the longest period of sustained growth in the entire post-war era. In spite of this nascent economic health, the country was declared to have a "competitiveness crisis" of the worst sort; American manufacturing industries were alleged to be intrinsically unable to prevail in the marketplace because of parochialism, stagnant

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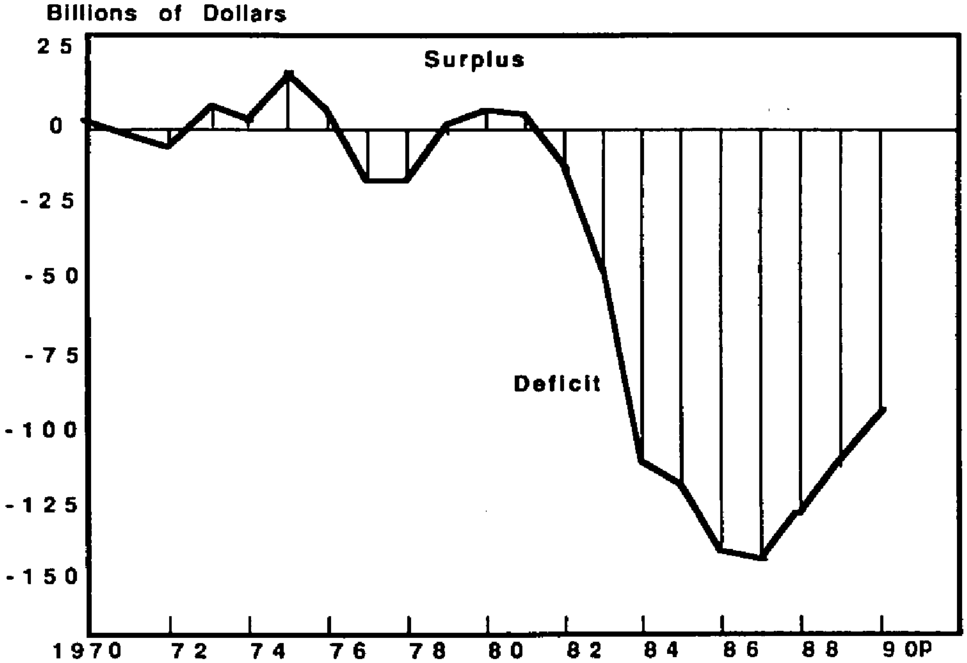
[1]The current account is the national income account for all U.S. international transactions, including merchandise trade, business and other services, and investment income.

[2]U.S. merchandise trade is composed of agricultural products, mineral fuels, manufactures, and "other products". The merchandise trade account went into deficit initially because of the rising cost of imports of mineral fuels and a declining surplus in manufactured goods. Although this decline was the temporary result of a faster U.S. "oil shock" recovery, the resumption in manufactures surpluses in 1979 was quickly offset by the second round of oil price increases.

[3]The international debt burden of the United States likewise continued to increase; this growth, in conjunction with the burgeoning trade deficit, consequently caused the current account to worsen in both absolute and relative terms. As a percentage of GNP, the current account worsened from +0.2% in 1981 to -3.6% in 1987.

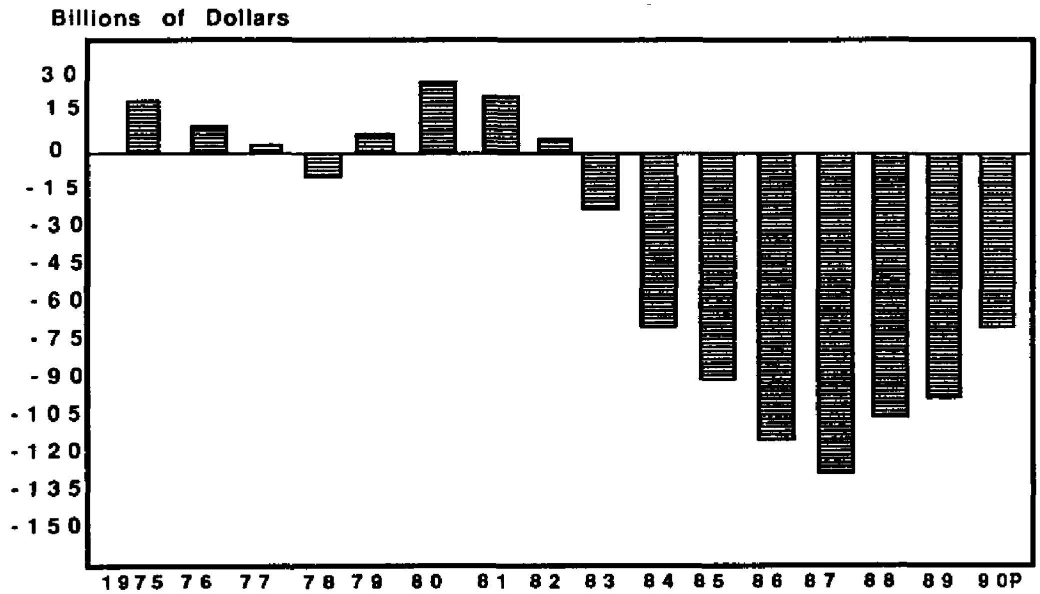
Figure 1-1. U.S. Current Account Balances, 1970-1990



P= Preliminary

Source: Survey of Current Business

Figure 1-2. U.S. Manufactures Trade Balances, 1975-1990



P = Preliminary

Source: U.S. Department of Commerce, International Trade Administration (1988,1989, and unpublished data) productivity, inappropriate business practices, market arrogance, and insufficient technological innovation. For a variety of reasons (most of which are explored in the next two chapters), productivity and scientific and technological innovation became the focus of policies attempting to remedy intrinsic competitive disabilities. Interestingly enough, both problems were perceived to be remediable through more science.

While competitiveness policies were emerging, the U.S. was also trying to deal with the trade dimensions of the crisis via trade and exchange rate policies. At the time of the crisis, there were a number of credible "extrinsic" explanations for the seeming lack of competitiveness, namely the leading recovery of the U.S. economy and substantially overvalued exchange rates. Extrinsic causes of competitive disability were addressed through exchange rate adjustments, pressure on major trading partners to stimulate their economies, and contentious bilateral trade negotiations with Japan. These negotiations--as well as the Omnibus Trade and Competitiveness Act of 1988--tried to level the playing field for U.S. industry by correcting unfair trade and business practices of the major U.S. competitors, and also tried to "negotiate" the macroeconomic structures of the Japanese economy.

It was the "intrinsic" policies that nonetheless took on a life of their own, and the U.S. science policy arena experienced a rejuvination that has not been seen since Sputnik. In many respects, these policies are also more interesting than those of the trade arena, because they try to get at the organizational core of U.S. competitive abilities. But they are also characterized by a remarkable consensus. Not only do most political actors seem to agree that science and technology are the appropriate and preferred remedies, but also that these prescriptions should be administered in the form of more scientific research and efforts to enhance the flow of knowledge between science, government, and industry. As with the trade policies, there is a considerable degree of Japan bashing and strong industrial lobbying.

Most troublesome about the science-based policy response to the competitiveness crisis is its extreme faith in the ability of science and technology to resolve the problem, which is itself rather ambiguous. It is not at all clear whether the crisis is due to bilateral imbalances, macroeconomic factors, instrinsic competitive disability, or some combination of the above. Uncertainty over the *nature* and *cause* of the competitiveness crisis is accompanied by yet another puzzle, which is the inability of the advanced industrialized nations to translate rapid technological advance into higher levels of economic welfare. Economists have been frustrated for more than a decade in their attempts to explain why growth and productivity among the OECD has become indifferent to the pace of technological innovation.

Such disjuncture between the convictions of the policy response and the uncertain and paradoxical nature of "reality" is the theme of this dissertation and the particular subject of this chapter. Most of the discussion to follow is a justification of the question "will it work?" by identifying evidence that conflicts with the basic policy assumptions. What is important to note is that the paradox is at the *macro* level of crisis--that is, with indicators that reflect *national*, as opposed to more disaggregate, levels of analysis. The paradox (at this point) is essentially one of macro crisis.

This chapter is organized into three sections. The first overviews events leading up to the competitiveness crisis, the second presents the foundations of the U.S. policy response, and the third illustrates how the supply-of-science response is contraindicated by the suggestion of numerous paradox.

The Crisis in Historical and Economic Context

While the abrupt worsening in the U.S. trade and investment position marks the crisis as a 1980s phenomenon, it cannot be considered in isolation of pre-existing concerns about the health of the U.S. manufacturing sector and the difficulties of U.S. macroeconomic management in a highly integrated global economy. Several issues in particular have concerned economists and policymakers. First, beginning in the early 1970s, analysts detected steady declines in the rate of increase in manufacturing productivity, a trend that started in the mid-1960s and continued throughout the 1980s. The decline in productivity was especially severe during 1973-79, when the multifactor productivity growth of three-quarters of U.S. manufacturing industries[4] slumped below their post-war average (Baily and Chakrabarti, 1988). The declining (or stagnant) growth in the majority of individual industries continued through the mid-1980s even though the manufacturing sector as a whole rebounded to "match or surpass [its] pre-1973 trends" (BLS, 1988). As Baily and Chakrabarti explain of this seeming contradiction, "The manufacturing recovery is heavily tied to the performance of a single industry,

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[4]At the 2-digit SIC level.

computers...Removing SIC 35 data from the manufacturing sector lowers the rate of multifactor productivity growth for 1979-85 a full percentage point" (1988, p. 5).

Even though the manufacturing slowdown affected other industrialized nations as well, their declines in employment were not nearly as severe. Eckstein, *et. al* observe that "In the United States, the manufacturing share of all jobs declined by 27% between 1965 and 1982. In Germany and France, the decline was 8%. In Japan, despite a surge in productivity, manufacturing employment was as large a share of the total as in 1965" (1984, p. 11). The simultaneous reduction in both productivity and employment (and in some cases, output) was thus unique to the United States, and characterized as the "deindustrialization" of America. This development represents the second major economic concern, that of the lessening contribution of manufacturing production to U.S. economic growth and employment after 1966.[5]

Third, by the time the competitiveness crisis hit in the early eighties, the United States was still learning how to manage its macroeconomy in conjunction with growing global interdependence. The suspension of the Bretton Woods monetary system in 1971-72 created a dramatically new international political economy, whose uncertainty was aggravated by double oil shocks in 1973-74 and 1979. For most of the seventies, the U.S. economy was buffeted by the interactive effects of domestic business cycles and the new international trade and monetary regimes. To appreciate just how significant a challenge this was to the United States, it is useful to remember that 1978 marked the first time in the post-war period that U.S. *domestic* economic policy was changed because of events in the international monetary system (Spero, 1981).

Characteristic of the 1970s was an inability by the United States to sustain full recoveries in its business cycles. The first oil shock, the lagging recovery of the other industrialized nations in the mid-1970s, and the second oil price increase created premature downturns in two cycles; moreover, the entire 1978-82 period reflected severe economic stagnation, and contained two recessions and the infamous double-digit inflation. Real output declined in many manufacturing industries during these four years, and the principal adjustment response to these stringent economic circumstances was to cut employment rolls

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[5]From 1920 to 1966, manufacturing fueled the U.S. economy, accounting for increasingly greater shares of GNP. After 1966, the manufacturing sector made decreasing contributions to national growth, and the rate of decline in the manufacturing share of total U.S. non-farm employment began to accelerate.

and eliminate excess production capacity. Both of these recession management tactics are considered to be harmful to a firm's competitive stature at the onset of recovery as well as to its long-term competitive advantage (Dumaine, 1990).

By the late 1970s the U.S. was additionally experiencing a dramatic rise in import penetration in a number of key industries. The auto, textile, steel, and consumer electronics industries were increasingly beleaguered by high quality, low cost imports from abroad. Although the movement to floating exchange rates had opened up international markets to a considerable degree, other manufacturing industries did not undergo the rapid rise in international competition that these four industries did. For a number of reasons, trade and competition with Japan became a particular sore point; a widening bilateral trade deficit and depression in the domestic auto industry (when Japanese auto imports were booming) were especially troublesome. Japan became the scapegoat for U.S. industrial decline, even though its market presence in many industries was limited (e.g., steel). Ezra Vogel's *Japan As Number 1* (published in 1979) was a national shock, simply for its portrayal of Japan as a highly driven, well-organized, competitive threat. Vogel succeeded in nailing shut the coffin on outdated Japanese stereotypes, especially those of the obsequious, low-quality copycat.

At the time of the competitiveness crisis there was obviously extant concern about slackening productivity, the demise of the manufacturing base, techniques of successful domestic and international macroeconomic management, and rising competition from Japan. By 1978-79 the Carter Administration was speaking of these problems in terms of the lack of "industrial competitiveness," and attributed its causes to the loss of America's innovative capacity. When the United States experienced the unprecedented reversal of its manufactures trade account during 1982-84, the imbalance was quickly perceived as the result of America's industrial decline and associated inability to compete against its major foreign rivals.

However, there were also a number of indications that the manufactures deficit was a temporary trade imbalance created by the U.S. recovery in 1982 and compounded by an overvalued dollar, the lagging recovery in Europe, and barriers to trade with Japan (USTR, 1989). There was certainly a precedent for such a deficit from the 1978 experience,[6] and it was

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[6]It is pretty well demonstrated both theoretically and empirically that a strong macroeconomic recovery in one nation--if unmatched by its major trading partners--will result in stagnant (or internally redirected) exports and rapidly increasing exports. The phenomenon (continued...)

argued that the overvalued dollar amplified the deficit by artificially discouraging exports and encouraging imports.[7] Analysts argued that there was no inherent inability of American industry to compete, rather the problem was rather a set of macroeconomic policies that interfered with the U.S. competitive position (e.g., Lawrence, 1984).

In sum, the nation was confronted with a series of unexplained and unresolved economic problems by the early 1980s: stagnant productivity, protracted recession, poor competitive posture vis-a-vis Japan, a troublesome decline in manufacturing employment and growth, trade deficits, and a macroeconomy vulnerable to international events and uneven policy treatment. How these problems became equated with industrial competitiveness is unclear, and somewhat troublesome. While there may be threads relating them, they are nonetheless discrete economic phenomena. To a large extent this conflation of developments is irrelevant for the purposes of policy analysis, science policy claims to speak to all of them except macroeconomic management, which is dismissed as a lesser determinant of economic health than science. We can superficially attribute the basis of these attitudes to the Carter Administration, but as will be seen below, the roots of even the Carter competitiveness policies derive from far older beliefs about the role ot science and technology in the economy.

Policy Response and Paradigm

All U.S. competitiveness policies were generated during the Carter and Reagan years. This is not so surprising since Carter was the first president to be stuck with the cumulative difficulties of the new international political economy, and the competitiveness crisis itself spanned all of the Reagan years. What is a bit surprising is the high degree of conformity in

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[6](...continued)
is temporary, however, as international and home prices, domestic supply, and aggregate demand eventually stabilize and result in "balanced" trade. In 1978, the U.S. ran its first manufactures deficit when the recovery outpaced that of its major trading partners (even an undervalued dollar did not help).

[7]Analyses at the time of the dramatic growth of the deficit indicated that one-third of the deficit could be ascribed to improper valuation of the dollar, another one-third to sluggish growth among the U.S.'s major industrial trading partners, and another third to rising competitiveness among the NICs and financial problems in Latin America (Morgan Guaranty Trust Company, 1984).

policy approach between these two very different political eras. Although the Carter Administration flirted with distinctly "demand side" science policies, most initiatives were confined to supplying more science and technology. The Reagan Administration, originally hostile to scientific interests, subsequently embraced the competitive powers of science and infused policy with an undeniably supply-sided orientation. As will be argued in later chapters (but overviewed below), what superceded the disparate political ideologies of these two political regimes was a paradigm of science-induced economic development. For the better part of this century, scientific progress and economic progress have been considered one and the same.

The stage was set for U.S. competitiveness policy during the late 1970s, when Jimmy Carter tried to come to grips with the stagflation that plagued his administration. This malaise was not confined to the United States alone; most of the advanced industrialized countries likewise needed to rethink their macroeconomic policies and seek additional stimulants to economic development. Stagflation, low rates of GNP growth, and declining productivity in the manufacturing sector were increasingly understood as consequences not only of dislocations in the global economy and unsound economic policies, but also of insufficient attention to science, technology, and innovation:

> A swing has been observed in the OECD countries...toward *explicit* priorities in government S&T policy, policy mainly designed for functional purposes. S&T for increased international industrial competitiveness is being emphasized as an objective, a trend that began in most countries towards the last half of the 1970s...Several governments and societies see the strategy of increased international competitiveness of domestic industries encouraged by appropriate government S&T policies as a means to solve unemployment, reduce inflation, and increase economic growth. (Tisdell, 1981, pp. 202-203)

Making the first explicit policy linkage between science and technology and the nation's industrial competitiveness, the Carter Administration "emphasized two themes: the importance of science and technology in solving the nation's major domestic and national security problems and the significance of scientific and technological advances in increasing productivity and economic growth" (Barfield, 1982, p. 11). As President Carter himself said, "We expect science and technology to find new sources of energy, to feed the world's growing population, to provide new tools for our national security."[8]

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[8]Science and Technology Message to Congress, March 27, 1979 (as quoted in Barfield, 1982, p. 11).

During his administration, Carter implemented a number of science policies intended to reverse the decline of the federal R&D establishment that occurred during the Nixon years and to enhance the competitiveness of U.S. industries. Carter boosted federal spending on basic research and revitalized a number of research programs in the Departments of Energy and Defense and NASA; the Administration also promoted several initiatives designed to stimulate industrial innovation. The justifications for these policies were tied directly to perceived problems in U.S. international competition and the need to reindustrialize the manufacturing sector.[9] Significantly, a few of the Carter innovation programs were much further along the innovation "continuum" than the typical federal support for basic and applied research; they instead focused on development projects demonstrating the commercial potential of new technologies.[10]

Carter Administration policies thus focused on increased funding for basic research ("the federal government has a responsibility to fund basic research and R&D both to solve national problems and to permit sustained economic growth") and encouraging industrial innovation ("[we must] restore what we have begun to lose in a very serious fashion, and that is the innovative nature of the American free enterprise system").[11] Consistent with previous science policy, the Administration viewed basic research as a national investment and pledged to provide real funding increases for NSF and mission agencies with basic research programs.

Carter innovation proposals were much more extensive and involved regulatory and patent reform, technology transfer, the establishment of generic technology centers, and government-university-industry partnerships. However, a certain ambivalence characterized the Administration's assessment of both the degree of seriousness of the nation's competitiveness problem and the proper role of government in fostering innovation:

> There was a general consensus within the Carter Administration that public and private R&D investment was connected in important ways to innovation, which in turn enhanced productivity and economic growth. Beyond these

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[9]For more detail on Carter policies, see Barfield (1982), NSF (1988a), and Ronayne (1984).

[10]Several analysts have suggested that because Carter himself was a nuclear engineer, he was far more sensitive to the product development needs of industry.

[11]The comment on basic research is by W. Bowman Cutter, Carter's executive associate director of OMB (as quoted in Barfield, 1982, p. 13); the latter statement is by Jimmy Carter (as quoted in Barfield, 1982, p. 34).

> general precepts, however, were various shades of opinion about the actual gravity of the problem and about the steps that must be taken--particularly by the federal government--to correct it. (Barfield, 1982, p. 34)

As a consequence of these reservations, particularly those concerning the proper role of government in fostering industrial innovation, the Carter Administration's "competitiveness" policies generally did not transgress into innovative activities understood to be the prerogative of the private sector. With the exception of the demonstration and development projects, Carter programs were restricted to enhancing the supply and flow of basic scientific and technical knowledge from the public domain to the private sector.

During this brief period (1978-80), the U.S. policy response to the competitiveness crisis was set in motion. Driven by a concern over the innovative capacity of America, Carter turned to science and technology as solutions to what was explicitly identified as a problem with U.S. industrial competitiveness. Consistent with previous theme and practice, the Administration promoted basic scientific research as a principal means of encouraging economic advance. However, the Administration's efforts to enhance the commercialization of science and technology through innovation policy were held in check by an unwillingness to expand the scope of federal involvement into activities traditionally conducted by the private sector.

Innovation policies were limited to measures which would stimulate basic scientific research, encourage the transfer of such research results to the private sector, and improve the appropriability of intellectual property by business. In essense, the Carter Administration laid the groundwork for the present federal policy response to the competitivness crisis by 1) identifying competitiveness as a policy issue, 2) suggesting that science, technology, and innovation were the principal solutions to this problem, 3) explicitly linking basic research to the competitiveness policy agenda, and 4) confining the "appropriate" role of government in technological innovation to supplying--or fostering the supply of--scientific research.

These initiatives were immediately followed by the Reagan Administration's exaggerated claims about the proper scope and role of government in American society. Not only did the New Right wish to unburden the private sector from the yoke of federal regulation, but it believed that the government should not engage in any activities that might be reasonably (or wishfully) undertaken by the private sector. For an Administration fully intent upon privatizing the National Weather Service, it should come as no surprise that many

Carter innovation initiatives languished or disappeared entirely with the election of Ronald Reagan.

In keeping with the new Administration's "limited government" philosophy, *laissez-faire* economics, and budget reduction objectives, Reagan budgets preceding the competitiveness crisis (in FY82 and FY83) provided no real increases in scientific research funding, reversing increases budgeted for by the Carter Administration.[12] This in fact represented favorable treatment at the hands of OMB; unlike other components of the discretionary portion of the federal budget, science and technology did not receive severe cutbacks.[13] What protected the proposed federal R&D budgets from real *declines* in funding was the general acceptance by the Reagan Administration that basic research was indeed an investment in the nation's future. Averch (1985) notes the Administration found "market failure" hypotheses especially appealing because of their resonance with the tenets of Reaganomics.[14]

The Reagan Administration reconciled the agreed upon need for federal funding of science with limited government objectives by imposing new funding criteria in science: research funding involved a new insistence for research prioritization. The White House Office of Science and Technology Policy (OSTP) stated in 1982 that "Undisputed world dominance in all fields of science and technology is not a goal to which U.S. national science and technology can aspire" (OSTP, 1982, p. 6), a position reinforced by George Keyworth, the President's science advisor (emphasis in original):

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[12]As will be seen in chapter 3, the declines were actually only in the budgets *proposed* to Congress. Federal obligations for basic research posted substantial real gains in these years.

[13]However, NSF's research-related budget did experience real cuts during FY82-FY83.

[14]By way of example, the OMB states for the Administration: "Federal support for basic research...is an important factor in generating new knowledge to ensure continued technological innovation. It is an essential investment in the Nation's future. The Federal Government has traditionally assumed a key role in support of basic research because the private sector has insufficient incentives to invest in such research" (Office of Management and Budget, 1989, p. J-9). Market failure theory is based upon work by Arrow (1962b) which argues that, because of the public goods nature of scientific research, the private sector will fail to invest adequately in such research, leaving society with a sub-optimal production of new knowledge.

> There are a number of good reasons why we cannot expect to be preeminent in all scientific fields *nor is it necessarily desirable*....Because of the diversity inherent in industrial democracies, there are certain areas of science and technology that are more pertinent to other countries than to us....In science and technology as in all endeavors, available resources must be identified, comparative advantages assessed, tough choices made and priorities established before resources are allocated. (as quoted in Averch, 1985, p. 30)

While the Reagan Administration did support federal involvement in scientific research, the rhetoric of funding became more goal oriented. Unlike previous administrations which used science and technology in an expansionary budget environment to advance national goals (e.g., in space, energy, and health), the Reagan White House seemed intent upon prioritizing science in response to constrained resources. National defense was the chief beneficiary of the new goals orientation, but as the competitiveness crisis unfolded during 1982-84, an additional priority emerged: "Pure science should...contribute to economic growth by making the nation more competitive in a high-tech world" (NSF, 1988a, p. 26).

Kicking off executive branch competitiveness leadership, President Reagan established the President's Commission on Industrial Competitiveness in 1983 and charged it with finding ways to improve the private sector's ability to compete in world markets. The resultant study, *Global Competition; The New Reality* ("The Young Report", 1985) focused on technological leadership, human capital and resources, intellectual property rights, and international trade and marketing as the keys to restoring American competitiveness. In many ways, this report represents both the beginning and the end of the policy-related competitiveness debates; it advanced a set of arguments and evidence about competitiveness that have been little changed in the ensuing years.

In brief, the Young Report concluded that "technological innovation, fueled by research and development, is a major force for improving the Nation's productivity, industrial competitiveness, and economic growth" (p. 59). In turn, "The process of technological innovation begins with the creation of new knowledge and new ideas, largely through basic research....In contrast to the technologies of earlier times, today's technological innovations are essentially dependent on scientific advances" (pp. 63-64). The major recommendations of the report were to:

- enhance financial incentives for R&D through R&D tax credits,

- provide greater support for university-based basic research and for the education of scientists and engineers,

- improve manufacturing capabilities and technology,

- strengthen the protection of intellectual property rights,

- balance regulation with the needs for innovation and industrial competitiveness, and

- continue political efforts to remove foreign barriers to U.S. trade.

With the exception of the recommendation to improve U.S. manufacturing capabilities, the Young Report did not address the commercialization of scientific and technical knowledge, calling only for "improved private sector management of innovation".

Although there have been policies directed at restoring competitiveness through non-science and technology measures--principal among them the trade provisions of the Omnibus Trade and Competitivenss Act of 1988--most are directed toward strengthening science and technology and enhancing technological innovation.[15] By way of example, The President's Competitiveness Initiative, announced in the 1987 State of the Union Address, identifies six groups of policy measures for "assuring American competitive preeminence into the 21st Century"[16]:

- increasing investment in human and intellectual capital,

- promoting the development of science and technology,

- better protection of intellectual property,

- enacting essential legal and regulatory reforms,

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[15] While the Department of Labor has been studying the role of the workforce in U.S. competitiveness, this has so far resulted mostly in reports and policy recommendations, not actual policy directives. See *Workforce 2000* (Washington, DC: U.S. GPO, 1987) and the recent *Investing in People: A Strategy to Address America's Workforce Crisis* (U.S. Dept. of Labor, Commission on Workforce Quality and Labor Market Efficiency, Washington, DC: U.S. GPO, 1989). Concerns about America's educational "crisis" have been similarly confined to reports and discussions; federal programmatic responses have been principally limited to NSF's initiatives for enhancing science, engineering, and mathematics education at the pre-college and college levels.

[16] "The President's Competitiveness Initiative," Office of the Press Secretary, The White House, January 27, 1987.

- shaping the international economic environment, and
- eliminating the budget deficit.

Of the six areas recommended for policy action, two are directed specifically toward science, technology, and innovation; there are additionally science and technology-related subcomponents to the other initiatives, including relaxing anti-trust laws to allow cooperative R&D, limiting product liability so that firms have more incentive to innovate, making export controls less restrictive with respect to high technology, and negotiating intellectual property rights at the Uruguay Round of the GATT.[17] Surprisingly enough, congressional activity has focused on identical concerns and remedies, as the myriad of hearings on competitiveness and the new patterns of science pork barrel attest to. The divergence between congressional and presidential policymaking characteristic of other arenas is not nearly as great with respect to science and competitiveness.

About the only area of substantial policymaking that was not emphasized in the Young Report was technology transfer. Technology transfer is typically understood as the movement of knowledge and know how from one organization to another; it is essentially how knowledge gets moved across R&D sectors (university, government, industry) and between functional divisions of a company. Beginning with the Carter Administration, there was the perception that the federal R&D laboratories were failing to transmit their usable research results to the appropriate commercial users. As a consequence, there has been a series of legislation attempting to (1) eliminate technology transfer barriers between public sector institutions and those in the private sector, (2) to make technology transfer an official mission of federal R&D labs, and (3) to foster the commercialization of publicly-generated R&D.

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What allows science and technology to lay special claim to America's economic health? The sense of entitlement stems mostly from "cult of science" beliefs set in motion during World War I, canonized in the interwar years, and raised to gospel by World War II. For most of this century it has been assumed by scientists and policymakers that the knowledge gener-

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[17]Notably, all of these items were included in the suggestions of the Young Report.

ated by curiosity-driven scientific research enhances human welfare and quality of life through better health, new products, increased productivity, greater economic output, and higher personal income.

Such an understanding of the role of science in society is fundamentally rooted in American culture by virtue of the Age of Reason legacy and America's "manifest basic faith and optimism in scientific progress" (Hiskes, 1986, p. 3). This basic optimism is not unfounded, however. The historical record is replete with evidence of the social and economic impact of scientific discovery; indeed, it is frequently argued that the advance of civilization is in effect the result of scientific advance. The popular impression of science was vividly reinforced by the successes of science in World War I (notably in mass produced war materiel, but also airplanes, the submarine, and synthesized ammonia), the interwar years (with the rapid introduction of consumer goods and health-related innovations), and the overwhelming role of science and technology in the direction and outcome of World War II. By the time World War II concluded, there was a considerable consensus on the need for the federal government to have a permanent role in supporting the scientific estate.

It was at this time that a critical evolution of policy-related thinking about science took place. U.S. science policy--which emerged as a full-fledged policy arena only in the aftermath of World War II--is based on a non-falsifiable, axiomatic paradigm that reduces social and economic progress to basic scientific research. Scientific research and its accompanying discoveries are presented as a flow from basic research (science), to applications-oriented research (technology), to industrial development (prototypes), and finally to commercial sales (products). This flow of science to market is more commonly known as "the linear model of innovation"; it is problematic for its implicit determinism. Science and technology are presumed to lead inexorably to greater economic welfare.

The model, and even the concept of "basic research" itself, were artificial constructs of Vannevar Bush, a physicist and director of the World War II Office of Scientific Research and Development.[18] As an astute politician, Bush realized that a credible rationale for state-supported science was critical if a permanent funding system was to be established; as a scientist, he believed that government management of science was intolerable. The linear

[18]OSRD was the central management agency for all federally-supported, war-related research and development.

model of innovation was consequently developed as an artful explanation of why science should be funded (it causes social and economic welfare) but still autonomous (all commercial innovation derives from basic research, which will pay off only if left to follow its own course).

Simplistic understandings of the role of science and technology in society were thus transformed into a policy funding paradigm. For the better part of 45 years, the science policy arena has proceeded on relatively unchallenged assumptions about the impact of science on the economy and how science gets translated into social welfare. Since the payoff was tacitly understood to be serendipitous, there was no particular reason to use science and technology proactively; that is, as actual tools of government. Rather, the supply of science was fostered with the understanding that some of it would spillover into the civilian economy in the form of better health and products.

As a funding paradigm, this approach is useful for the ongoing justification of state funding of scientific research: such funding is certainly an investment, and we would have to be quite stupid to deny the considerable impact of scientific and technological "progress" on society. But the paradigm's deterministic (and axiomatic) nature leave us with a peculiar sort of diagnostic logic; if the economy is failing, then it must be the fault of science and technology. In essence, this is how the policy response to the competitiveness crisis came to be overwhelming concerned with the supply of scientific research. When the crisis is viewed through the lens of science policymakers, there can simply be no other explanation.

How the science arena was able to claim the crisis as its own is largely the consequence of politics. There was surely a predisposition by those outside this arena to see science and technology as appropriate remedies given (a) popular understanding of the historical role of science, and (b) the abject failure of traditional economic policy tools in dealing with stagflation and the productivity crisis. Basically, science and technology had a compelling (and preexisting) "causal" claim to the problem, and nothing else seemed to be working. However, the politics of a constrained budgetary environment were also at play, with the technoscience agencies making strident claims about their ability to remedy the competitiveness crisis. As a consequence, an exaggerated rhetoric on science, technology, and competitiveness spilled out of the science arena and into the national debate. The fact that it was also a "crisis" environment and that other potential remedies would be politically fractious further concentrated policy efforts on science and technology.

A Suggestion of Paradox

There are any number of indications that U.S. economic malaise may have less to do with a widespread problem in the supply of science and technology than with other factors. Briefly, there are several categories of "evidence" which conflict with the suppositions of the U.S. policy strategy:

- A supply of science paradox, which suggests that not only is the stock and pace of U.S. scientific and technological innovation adequate, but that as a class the advanced industrialized nations are increasingly unable to translate an abundance of science and technology into greater economic welfare.

- "Intrinsic" competitive disability on the part of firms; these intrinsic factors may be classified as either the organizational and economic contingencies of successful innovation, or factors completely unrelated to R&D and innovation.

- "Extrinsic" causes of the competitiveness crisis (e.g., those in the external environment of the firm); these may be classified as either problems in the macroeconomy or characteristics of the international economy.

- A paradox of "commonality"; with the exception of the trade deficit, U.S. economic problems are common to the other industrialized countries as well, *except Japan.*

- The paradox of Japan; how is it that this nation does substantially better than others, without the benefit (allegedly) of significant innovative capacities?

What emerges from the discussion below is that these five separate issues challenge the prevailing policy wisdom in two ways. On the one hand, the supply of science paradox, some of the intrinsic factors, and the Japan paradox all challenge the notion that the supply of science and technology can *alone* overcome the competitiveness crisis. It is not that our concern with science and technology is necessarily misplaced, but that there are critical variables intervening in the process of bringing science to market. These intervening variables are typically referred to in the literature as "demand" variables, since they derive from the economic, rather than the scientific, environment.

On the other hand, it may be that the focus on science and technology is misplaced. In this case, the remaining intrinsic factors, the extrinsic variables, and the paradox of commonality all suggest that there are alternative causes of the crisis, determinants that may have little (or nothing) to do with science and technology. We are therefore left with an unweighted mass of potential causes of the crisis; not only are each of these categories competing explanations, but within each category, the variables are themselves contending explanations.

The Supply Paradox

In regard to investments in the production of science and technology, the United States still outspends its major competitors by a large proportion, even though their expenditures on R&D have increased appreciably in the past 20 years. The United States invested more in R&D in 1987 than France, Japan, West Germany, and the United Kingdom combined (figure 1-3); when defense-related R&D expenditures are excluded, the U.S. loses this clear lead but still spends substantially more than any of the other countries individually and almost as much as they do collectively (figure 1-4). Even though these nations are roughly comparable in their relative investments in science and technology (fig. 1-5), relative levels of effort in and themselves should not be sufficient cause for the degree to which U.S. competitive abilities seem to have eroded.

Given the preponderance of U.S. investments in R&D, it is difficult to accept the notion that U.S. competitive abilities are threatened by a rapid erosion in the preeminence of U.S. science and technology, an erosion driven by foreign scientific and technological advance. Growing investments in R&D on the part of other countries may signal their enhanced ability to produce leading-edge science and technology, but this doesn't translate *de facto* into a foreign onslaught on U.S. science and technology, as these data are frequently interpreted.[19] We are far from a clear understanding of the economic consequences of international differentials in rates of change compared with absolute improvements and magnitudes. At least as measured on the input side, the U.S. still has a vastly larger pool of science and technology to draw on than its major competitors.

Not only does the United States not appear to have a "supply crisis" with respect to its competitors, but as a group, all of the industrialized nations (except, perhaps, Japan) seem to be unable to exploit their science and technology resources. As the OECD (1980, 1988) has

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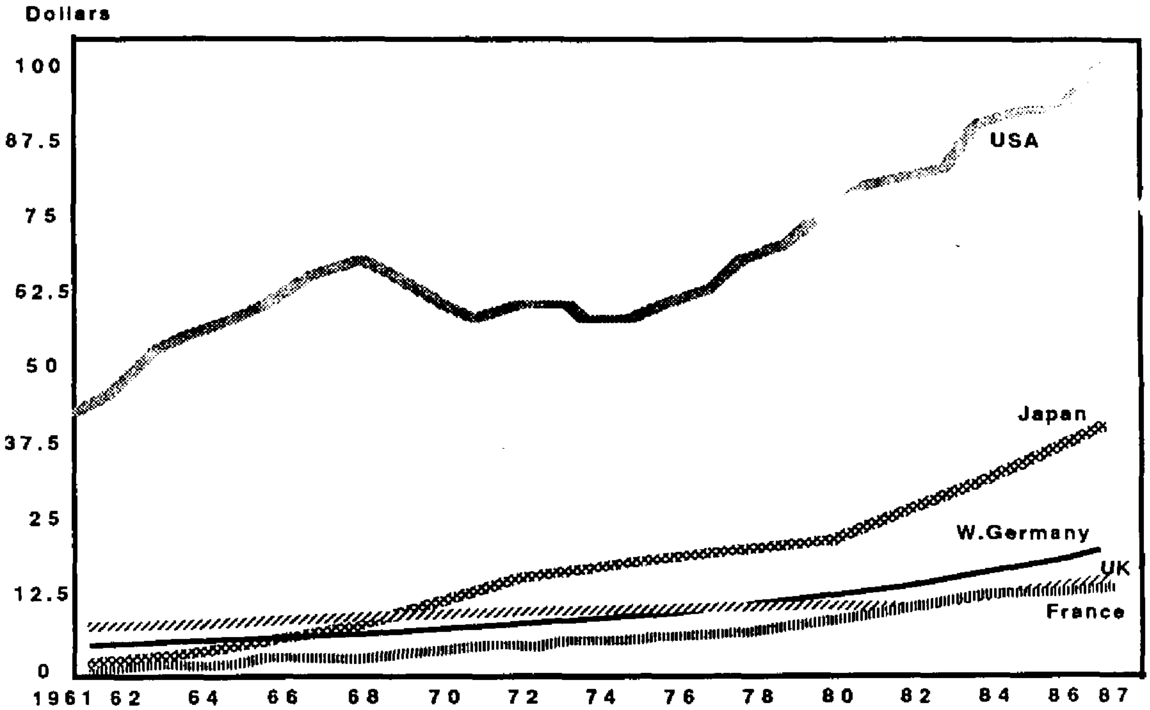
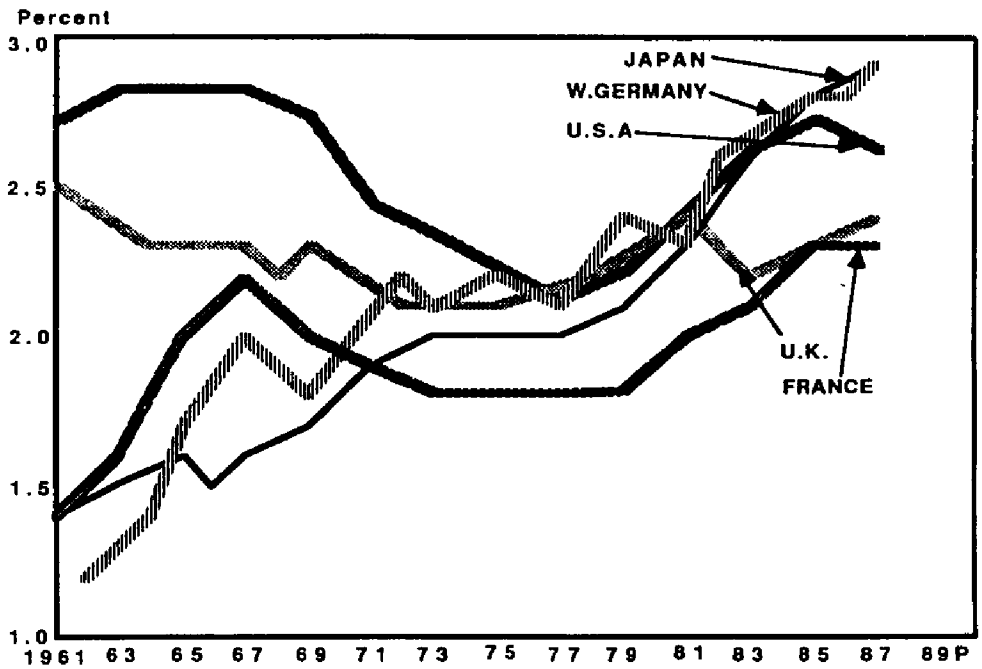
[19]For example, see Bloch, 1987; The Young Report, 1985; "U.S. Lagging in Civilian R&D and Education," *Science and Government Report*, March 15, 1989, p. 5.

Figure 1-3. Comparative R&D Expenditures
[Constant 1982 dollars in billions]



Source: National Science Foundation

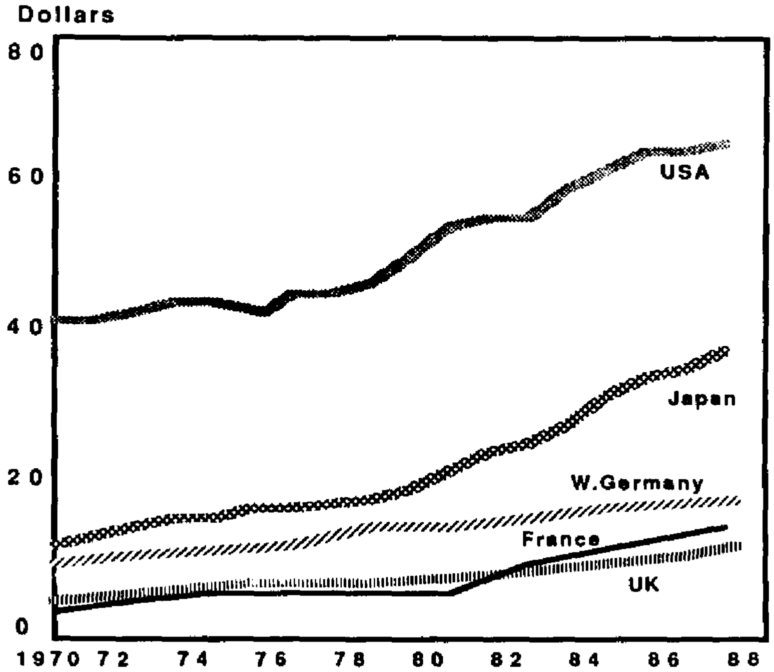
Figure 1-4. R&D Expenditures as a Percentage of GNP



Source: National Science Foundation

Figure 1-5. Nondefense R&D Expenditures

[Constant 1982 dollars in billions]



Source: National Science Foundation

observed, virtually all of the countries within the OECD endured (or are enduring) comparable economic circumstances. Declining rates of productivity, inflation coupled with unemployment, growing import penetration, and slower economic growth are all experienced in an environment of substantial increases in R&D investments and major technological innovation. As the Organisation puts it (emphasis in original):

> An unprecedented R&D effort has been made since the end of the Second World War. This effort has even been intensified since the first oil shock. The result is that an unparalleled stock of scientific and technological knowledge is now available with which to fuel, potentially at least, technical progress and economic growth.
>
> After almost thirty years of rapid economic growth, a pace of lower growth has set in since 1975 and persisted despite the somewhat improved economic climate of recent years. It might be possible simply to attribute low economic growth rates to poor economic management, were it not for the perceptible long-run fall in the growth rate of labour and total factor productivity, the indicators assumed to reflect the increase of efficiency not explainable through increases of inputs.
>
> However, *at the same time* as this fall in productivity growth has been taking place, we have witnessed some manifestation of major technological innovations, with information technology, new materials, and, to a lesser extent, biotechnology, pervading most industrial branches and economic and social activities.
>
> We are, therefore, apparently faced with the following paradox: whereas the industrialised countries have built up a hitherto unparalleled scientific and technological capacity and, whereas technological change seems to be pervasive in everyday life, at the same time *Member countries appear to be finding it increasingly hard to translate this capacity into measurable productivity increases and economic growth.* As Professor R. Solow has put it: *"we see computers everywhere except in the economic statistics"*. (OECD, 1988a, pp. 1-2)

This paradox suggests a bottleneck of uncertain origin and dynamic, but does not imply a problem with the science and technology system: the critical characteristic of the paradox is that the industrialized nations seem literally unable to capitalize on an abundance of science, technology, and technological innovation.

Just what accounts for the paradox is something of a mystery. Denison (1985) reviewed the arguments about declines in American innovative activity and diminishing returns to R&D and decided that there is no conclusive evidence, at least at the aggregate level, that creativity or its economic returns are diminishing. Griliches and Lichtenberg (1984) and Mansfield, *et al.* (1982) conclude the same, but note that there is considerable variation in patterns of innovation and economic performance among industries. Englander, Evenson, and Hanazaki (1989) also find considerable variation among industries, but additionally discover that the "potency" of R&D has declined appreciably in several industries, with similar patterns evident in most of the major industrialized nations. Variability in "potency" (as measured by patent activity relative to R&D expenditures and R&D scientists and engineers) is more strongly accounted for by industry sector variables than country of origin variables, which suggests *at minimum* that innovative activity is more strongly driven by the particular environments and structures of individual industrial sectors than unique national variables.[20]

The inability to establish empirically declines in innovation and returns on R&D investments is hence accompanied by an inability to associate economic performance with waning innovation or R&D. Economic health is apparently not explainable by declines in the science base either. The OECD (1980) states "most scientists agree the end of rapid growth of academic research has not...led to any decline in the *results* of fundamental or university research" (p. 43). Frank Press, president of the National Academy of Sciences stated it somewhat more strongly in Congressional testimony:

> Our [science] system has delivered. The problems we face [in industrial competitiveness] are not those of science and technology, our national laboratories, our research universities. I do not think we need to create a new institution to do science well in the United States. We do it very well at the present time.[21]

Moreover, Mansfield (1980) and others (e.g., Link, 1981; Griliches, 1986; Lichtenberg and Siegel, 1989) find both high economic rates of return to investments in basic research and a greater premium on basic research than for either applied research or development. U.S. basic research expenditures have also been increasing steadily since the early 1970s in real terms and as a proportion of GNP (these data will be reviewed in chapter 6).

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[20]Moreover, it suggests that in industries which demonstrate declining potency, patents may no longer be the best or even a reasonable measure of innovation. The declining utility of patents as an empirical indicator of innovation is in itself an important possibility. While Englander and Evenson's evidence on the declining patent "potency" of R&D may actually represent declines in industrial innovativeness, it could also be that this particular aspect of the intellectual property system is simply failing to capture the innovative activity of several industries.

[21]As quoted in *Science and Government Report*, April 1, 1989, p. 7. Press was testifying at a Senate Budget Committee hearing on "Science, Technology, and Strategic Economic Policy," held on March 9, 1989.

The picture beginning to emerge from these impressions is somewhat perplexing in light of the assumed relationship between science and technology on the one hand, and productivity and economic performance on the other. The rather strong sense of famine amid plenty is undeniable. Assuming that there is a serious economic performance problem in the United States, it does not seem that we may attribute it to the decreasing supply of basic research, returns on that investment, a widespread national decline in "innovativeness", or economic returns to that innovation. Additionally, the scientific community disavows any responsibility for the competitiveness crisis. The supply of American basic scientific research does not appear to be a problem, a conclusion hard to dispute with quantitative data on R&D expenditures and related output measures (these data will be reviewed in chapters 6 and 7).

The recognition of a bottleneck outside the realm of science and technology has been slow to appear in competitiveness policymaking, with the possible exception of the technology transfer legislation. Science policy doyens have however recently begun to caution against the supply-sided science orientation to competitiveness policy:

> Although a strong and vital university research system[22] is an essential ingredient in technological innovation and long-term competitiveness...it cannot be the prime solution...The present emphasis on university research is not necessarily misplaced, but I question the implicit assumption that if we just get university research right, and properly supported, everything else will take care of itself. (Brooks, 1988, p. 54)

The Role of Intrinsic Factors

A possible solution to the above paradox is suggested by the industrial innovation literature, which argues that the successful commercial utilization of science and technology is contingent upon a wide variety of organizational and market factors. For example, Teece (1986) argues that the first and foremost constraining factor on the profitability of science and technology is the degree of its appropriability. The tighter the appropriability regime--that is, the greater the ability of the innovator to secure total exclusivity through patent and trade secret laws--the less necessary are such "complementary assets" as manufacturing capabilities, learning curve lead times, distribution and service, sales, and marketing. The less able an innovator is to protect his technology (the degree of appropriability is often inherent in the

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[22]In this article, Brooks intends the university research system to mean basic scientific research.

technology itself), the more critical the complementary assets become. An innovator who cannot appropriate his technology and who has weak complementary assets will be likely to lose all profits to imitators and competitors, including those in other nations.

Others such as Cohen and Zysman (1987, 1988) identify the important roles of the structure of competition, product markets, and manufacturing technology in successful innovation. Mowery (1983) argues that it is not necessarily the supply of external technical information as much as it is the internal capability of firms to process and utilize the information. Flaherty (1982) finds that for the U.S. semiconductor industry, it is the presence of customized applications engineering that more strongly determines the long-term market share of an innovator rather than the simple technological lead alone. A new body of strategic business literature suggests that in order to compete, firms must undertake technology-based competitive strategies, something they are not presently organized or oriented to do (Rosenbloom and Burgelman, 1989; Link and Tassey, 1987). Hart (1988) notes that it was cumulative management decisions about innovation (misjudgements of consumer tastes, failure to adapt semiconductor technology quickly enough) that led to the demise of the U.S. color television industry, and that the United States simply failed to recognize and exploit the emerging consumer-driven VCR technology.

Similarly, other authors point to the importance of the functional interfaces between R&D and other divisions within the firm, as well to the importance of production technology and incremental innovation. Gomory and Schmitt conclude that:

> In technological areas where the United States has not been competitive, we have lost, usually not to radical new technology, but to better refinements, better manufacturing technology, or better quality in an existing product. (1988, p. 1131)

In these industrialists' view (senior vice-presidents for science and technology for IBM and GE, respectively):

> Our effective foreign competition to date has been characterized by close ties between manufacturing and development, an emphasis on quality, and the rapid introduction of incremental improvements in the short development cycle of a preexisting product. (1988, p. 1132)

However, other analyses doubt the role of science, technology, and innovation in the competitiveness crisis. The MIT Commission on Industrial Productivity (1989) examined eight manufacturing industries and found common sets of weaknesses in all eight industries that had little to do with the production of science and technology, ranging from outdated mass production strategies to U.S. market parochialism. The Commission concluded that available U.S. technologies are not able to guarantee better design or quality control given the way American business does its business: problems with industrial productivity (and implicitly industrial competitiveness) cannot be surmounted by science and technology alone given the existing business climate in the United States.

Hayes and Wheelwright (1984) make related arguments about the decline in the manufacturing sector, namely that the cumulative effect of contemporary management practices causes firms to underinvest in new, more efficient production equipment and to neglect the importance of the relationship between product design and manufacturing (arguments quite similar to those of Gomory and Schmitt). For example, they argue that corporate emphasis on profit centers and the use of reward incentives that are tied to short term profitability encourage an exaggerated dependence on return on investment (ROI) ratios as indicators of corporate performance. In turn, the high level of mobility of American managers discourages them from making necessary long term capital investments in production facilities. Such investments depress the ROI ratios against which managerial performance is assessed, and managers typically would not be in their positions long enough to gain reward from the higher future ROIs that would derive from long-term investment decisions. The authors conclude that there is a general inability in U.S. business to think strategically about product innovation, design, manufacturing, and plans for new capital investments.

There is additional subjective evidence that challenges the assumed role of science and technology in competitiveness. The National Governors' Association has suggested that the more common private sector understanding of the competitiveness crisis is that U.S. difficulties were "not a problem...with commercialization, i.e., bringing a product to market, rather our competitive problems have involved production and marketing" (NGA, 1987, p. 32). There is thus a related disjuncture between what the federal government is prescribing as a solution to the competitiveness crisis and what R&D managers see as reasonable solutions: "Slightly more than 50% of business R&D officials did not believe that cooperative research among industries and universities would have a critical impact on U.S. competitiveness" and "only 12 percent ranked technology transfer as one of the top two issues affecting U.S. competitiveness" (NGA, 1987, pp. 3, 31).

The Role of Extrinsic Factors

While factors intrinsic to firms and their competitive environments may be culprits in the U.S. competitiveness crisis, other evidence and theory suggest that extrinsic variables may be responsible for the decline in the U.S. trade position in the 1980s. In general, these factors--which are in the external environment of firms--may be categorized as either macroeconomic problems or characteristics of the international economic system.

Business cycle dynamics of the 1970s are of particular concern. The premature contraction in two cycles and the extended recession of 1978-82 may have done substantial damage to the competitive abilities of the manufacturing sector. Eckstein, et. al (1984) make persuasive arguments that downturns in U.S. business cycles have been increasingly severe, and disrupt the "rebound" ability of industry with each successive downturn in the cycle. As the authors observe, "the reduced growth of end markets holds down the opportunity for modernization and economies-to-scale, and limits the resources available for investment" (Eckstein, et. al, 1984, p.15). This effect is especially severe in the durable goods industries, which are typically far more price elastic than non-durable goods.

The high cost of capital encouraged recession management tactics that are usually counter-productive in terms of competitive ability. Elimination of excess capacity and reductions in workforce typically leave firms short of production capacity when demand rises during recovery periods, leaving them vulnerable to foreign competition. The durable goods industries are hence doubly affected, since they suffer more during a recession and are confronted by almost immediate price suppression upon recovery. Price sensitive industries are then left with shortfalls in profits (or low margins) that preclude them from the expansion and rationalization necessary for expanded market presence and enhanced competitive strength. Since productivity improvements are often advocated as better *qualitative* recession responses, the cost of capital becomes critical: the inability to invest in new plant and equipment usually means the inability to improve productivity beyond the margins. Notably, DeLong and Summers (1991) report that international differences in productivity and growth rates may be strongly predicted by investments in machinery and equipment.

From this discussion, it seems reasonable to conclude that the cost of capital and business cycle conditions of the late 1970s interacted to weaken the competitive base of the durable goods manufacturing industries. Since the trade deficit worsened dramatically for these industries during the recovery, it would appear that there was a competitive shift in the international economy during the years 1978-82. The loss of U.S. competitive stature may have been driven by the inability of industry to rationalize beyond superficial cost-cutting measures in the late 1970s and early 1980s.

However, diminished trade competitiveness could also be the result of other extrinsic factors, including improperly valued exchange rates and the changing nature of the international economy. Throughout the early 1980s and until 1985, the U.S. dollar was significantly overvalued, a conditioned which encouraged imports and discouraged exports. After exchange rate adjustments were introduced in 1985, the balance of trade responded rather dramatically, after proceeding through the "J-curve" phenomena first. (The J-curve explains the tendency of the balance of trade to worsen for a year or two while trade adjusts to the new prices; this may be seen visually in figure 1-1.) Recent improvements in the balance of trade could nevertheless be due to the slowdown in the U.S. economy; to the extent that the 1990 deficit is still greater than that in 1984, there would appear to be a more fundamental problem in U.S. trade dyamics.

Alternative (or additional) explanations of poor U.S. trade performance thus emphasize the changing nature of competition in the international economic system. Some critics argue that U.S. export performance is poor because of American business parochialism, which causes neglect of overseas business opportunities. Yet others have suggested that the U.S. has responded to increasingly liberal global markets by relocating plants abroad; this allows them to take advantage of both global product cycle dynamics and the market opportunities that derive from local production facilities. Thus, Lipsey and Kravis (1987) find that the world export shares of U.S. multinational corporations remained constant from 1966 to 1984, even though the U.S. "national" share declined by a quarter during that same period. Similarly, Agnew and Corbridge (1989) report that one-third of the U.S. trade deficit with Japan and the NICs can be accounted for by U.S. multinationals' exports *to the United States.*

Still others argue that the United States has fallen prey to unfair business, trade, and economic practices of foreign countries--especially Japan. A host of micro and macroeconomic differences exist between Japan and the United States, with the result that the United States is increasingly disadvantaged in competition. Unfair trade practices (dumping, subsidization, and barriers to trade) are certainly important factors in several industries, but it is more likely that larger differences in business practices and macroeconomic policies are responsible for the bilateral trade imbalance with Japan. Substantially different norms exist with respect to such issues as supplier networks, strategic management, innovation priorities, and profit time horizons; similarly, the much maligned Japanese industrial policy is—in many respects—a long term growth strategy. As the advanced industrialized nations have modernized and grown during the post war era, distinctly different national styles of business management and macroeconomic objectives have emerged. Quite simply, it would appear that some practices are more compatible with competitive success in an integrated global economy that others.

The Paradox of Commonality

Perhaps more troubling than the number of credible (but, unfortunately, competing) explanations of the competitiveness crisis is the relative absence of evidence indicating a "crisis" unique to the United States. Typical indicators of declining U.S. competitiveness include the net balance of trade, national R&D expenditures as a percentage GNP, international comparisons of productivity decreases/increases, and per capita GNP (as a measure of standard of living). In all of these instances except the trade balance, the U.S. performs as well as or better than its major industrialized competitors.

The archetypical "Competitiveness Index" of the Council on Competitiveness is a good example of this state of affairs (Council on Competitiveness, 1989a, 1989b). The Council's 4-factor index measures GNP per capita, export growth and share of world exports, manufacturing output per employee, and weighted investments in education, non-defense R&D, and plant & equipment. Although a dismal picture is frequently painted of U.S. competitive abilities by the Council and other organizations, an examination of its indices reveals that compared to the Summit 7 nations, the United States performs as well as or better than all of its competitors—except Japan—for the period 1972-88 and throughout the 1980s.

An evaluation of a more appropriate measure of competitiveness, import penetration ratios of domestic consumption of manufactured goods, again reflects the same phenomenon: with the exception of Japan, the United States enjoys the lowest import penetration ratio of all of the OECD countries—13.8 percent in 1986 (table 1.1). Unlike other nations, however, this ratio has doubled within a 10-year period and is accompanied by a large trade deficit; additionally, the U.S. has a higher import penetration ratio of Japanese goods than any of the other Summit 7 nations. Nevertheless, as table 1.1 also reveals, the Japanese share of U.S. consumption of manufactured products was only 3.5 percent in 1986—a penetration ratio much

Table 1.1--Comparative import penetration levels, all manufacturing industries (in percent)

Year and region of origin of imports	Import penetration levels for:						
	U.S.	Japan	Canada	France	Germany	U.K.	Italy
1970							
Total	5.5	4.7	23.5	16.2	19.5	14.2	16.3
Non-OECD	1.3	1.6	1.2	2.0	2.9	3.2	2.5
OECD	4.3	3.2	22.3	14.2	16.6	11.0	13.8
Japan	1.0	--	1.1	0.2	0.5	0.3	0.3
U.S.	--	1.7	17.3	1.8	2.0	2.0	1.9
Europe	1.7	0.9	3.6	12.0	13.6	6.8	11.0
All other	1.6	0.6	0.3	0.2	0.5	1.9	0.6
1975							
Total	7.0	4.9	25.8	17.9	24.3	19.4	22.0
Non-OECD	2.2	2.0	1.5	2.0	3.7	3.9	3.3
OECD	4.9	2.9	24.2	15.9	20.5	15.5	18.8
Japan	1.2	--	1.1	0.5	0.8	0.8	0.4
U.S.	--	1.4	19.3	1.6	1.7	2.1	2.0
Europe	2.0	0.9	3.6	13.6	17.3	11.4	15.9
All other	1.7	0.6	0.2	0.2	0.7	1.2	0.5
1980							
Total	9.3	5.8	27.7	22.8	30.6	25.3	29.4
Non-OECD	3.2	2.5	2.0	3.5	5.6	5.9	5.3
OECD	6.1	3.3	25.7	19.4	25.0	19.4	24.1
Japan	1.9	--	1.4	0.7	1.3	1.1	0.6
U.S.	--	1.7	20.8	2.2	2.3	2.7	2.3
Europe	2.4	1.0	3.2	16.1	20.6	14.6	20.4
All other	1.8	0.6	0.3	0.4	0.8	1.0	0.8
1985							
Total	12.9	5.2	31.7	27.5	39.1	33.3	31.3
Non-OECD	4.1	2.1	2.7	4.2	6.9	5.5	6.5
OECD	8.8	3.1	29.1	23.3	32.2	27.9	24.7
Japan	3.1	--	2.1	1.0	2.3	1.9	0.7
U.S.	--	1.7	23.2	2.5	2.8	3.9	2.1
Europe	3.2	0.9	3.7	19.3	26.1	21.0	20.8
All other	2.5	0.5	0.1	0.5	1.0	1.1	1.1

Source: Calculated by the author from OECD (1988b).

lower than one would expect given the concern surrounding the trade deficit, half of which is accounted for by the deficit with Japan.

There is a clear trend among the Summit 7 countries of increased import penetration of foreign manufactured goods. All of the regions and countries identified in table 1.1 have increased their market share *in absolute terms* in each of the Summit 7 countries since 1970, and a disproportionate amount of this increase occurred during 1980-85. However, this development does not imply that the competitiveness of all nations is declining; rather, it suggests a growing differentiation and specialization in world production and trade created in part by shifting comparative advantage. For reasons that are not clear, such differentiation and specialization intensified during the first half of the 1980s. Additionally, although the United States (together with the United Kingdom) experienced the fastest increase in import penetration over the 1970-85 period, there does not appear to be anything in the total magnitude of foreign goods in the U.S. domestic market which singles out the U.S. as terribly distinctive from the other countries.

The Paradox of Japan

Japan is somewhat unique among the industrialized countries for a variety of reasons. First, on most measures of aggregate macroeconomic performance (per capita GNP, productivity growth, expansion of world market export shares) Japan has--on average--outperformed most of the advanced industrialized nations in the postwar era. Additionally, Japan is peculiar in one very important regard, and that is its overall low level of import penetration: as table 1.1 makes very clear, Japan enjoys the lowest import penetration of all of the industrialized countries by several orders of magnitude. Balassa and Noland (1988) find that the low presence of foreign goods in Japan is far less than one would expect given its size and economic stature, and suggest that because it is so anomalous, the structure of the Japanese economy must be significantly different than others within the OECD.

It is amazing that, after all these years, Japanese economic performance remains an enigma. Scholars continue to debate whether or not the Japanese "miracle" is properly understood, and we are still struggling to understand both the complexity of Japanese political economy and how its system components interrelate with one another. In general, there have been two competing sets of explanations of post-war Japanese economic growth. The state-centered approach is far more of a political economy orientation, and argues that structures of the Japanese state--in particular government-business relations and an acute ability in national planning--are responsible for its extraordinary recovery and ascendance in the world economy. State centric theories present Japan as a highly coordinate political system, one which is oriented to long term economic development. Japan's industrial policy is usually a key feature of such political economy explanations. On the other hand, others argue that Japan has benefited from a number of key macroeconomic market conditions which stimulated its rapid growth. High rates of savings (which generate low costs of capital), intensive plant and equipment investments, a relaxed regulatory environment, and a highly skilled laborforce are all attributed as major determinants of growth.

As is usually the case with competing academic theories, "reality" usually lies somewhere in between. Analysts are now trying to understand not just the direct influence of government policies on individual industrial sectors, but how industrial and macroeconomic policies also manipulated the market environment to induce the sorts of competitive responses that were desired by the state. A new wave of Japanology thus tries to examine a little more closely the interplay between the private sector and government *as mediated* through market structure and competition policies. Another emergent theme in Japanese political economy, one that is more closely related to understanding how Japanese industrial innovation has led to its competitive success, also challenges the prevailing dichotomous approaches to Japanese performance. Authors such as Friedman (1989), Kenney and Florida (1990) and Stowsky (1989) blend both industrial organization and organization theory to explore how "the social organization of production and innovation in Japanese industry" (Stowsky, 1989, p. 2) acts as the nexus where state and market forces are worked out. In this respect, firm- and sector-specific conditions interact with the external environment to amplify Japan's competitive advantage.

Science and technology fit somewhat uneasily into these various explanations of Japanese performance. The role innovation has played in Japanese competitive strength is uncertain because the explanations themselves are contradictory and have not been fully explored. One set of views offers a version of "Japan Inc.", namely that Japanese industry has benefited from concerted governmental assistance in R&D. Yet R&D transfers to Japanese industry from the national and local governments is quite small both absolutely and relatively, and only the computer-related technologies were significantly boosted by government R&D programs. Similarly, there are claims that Japan has no indigenous innovation capabilities, choosing instead to imitate and borrow from Western technology. This line of argumentation raises an unusual sort of paradox, for how is it that Japan can do so much better on borrowed technology than its originators?

Since many see Japan as a significant technological leader while others refer to it as an unbridled copycat, it is reasonable to say that Americans hold divergent and contradictory views of Japanese scientific and technological strength. There are those policymakers, scholars, and industrialists who maintain that Japanese successes are owed to the technology of the West, and that Japan still does not create science or technology worth exploiting. Others see Japan as the emerging world leader in commerce and technology, principally because of its innovation prowess.

Japan's economic vitality is, from the viewpoint of science and technology, fundamentally paradoxical. It simply should not be possible to achieve such levels of performance solely on imported science and technology. It goes beyond what may be concluded from the historical record and our admittedly rudimentary understanding of the role science and technology play in an economy: there must be a reasonably sophisticated indigenous innovation base to successfully introduce foreign science and technology. Similarly, arguments that Japanese strength emanates from technological--but not scientific--innovation (e.g., Gamota and Frieman, 1988) attacks the very core of the science policy paradigm. Since science is presumed to be the precursor of technology, its is impossible to have significant technological innovation without a strong science base. If this assumption is valid, then the logical conclusion must be that Japan is getting its science from "someplace else," and indeed this is the prevalent attitude in the policy arena. The new U.S.-Japan bilateral science agreement was based on the assumption that Japan had been a free-rider on Western science, and is now obligated to contribute in-kind to the world's stock of scientific knowledge.

It is also nonetheless reasonable to conclude that there are different ways of exploiting science and technology, and that Japan may simply be pursuing a different model. The very problem with paradigms is that they generate cognitive stereotypes. We don't look for--or see--what we don't expect to find. Japan's scientific capabilities have been so denigrated that we don't really look for strength in basic science or research. Additionally, our copycat mentality about Japan has essentially prevented us from exploring how this nation has managed to successfully use science and technology for economic advantage. Only recently has the Japanese science and technology system become a subject of study in and of itself.

Conclusions

It seems reasonable to conclude at this point that there is a grossly inadequate state of understanding of the 1980s competitiveness crisis. The variety--and plausibility--of explanations suggests that these accounts are speaking to different sets of problems, or else that there was an extreme convergence of competitiveness debilitators in the early 1980s. Any one problem alone may not have been critical (e.g., exchange rates), but the coincidence of several "causes" of noncompetitiveness (exchange rates, the cumulative effects of recession, instrinsic disabilities, etc.) may have overwhelmed the capacity of the manufacturing sector to compete in international trade.

In light of the ambiguity surrounding the crisis, it is somewhat extraordinary that the U.S. policy response is overwhelmingly focused on science and technology. Not only are there a number of credible, alternative explanations, but the presence and nature of a crisis unique to the United States is uncertain beyond the existence of the severe trade deficit. Since many macroeconomic factors account for trading patterns, it is not clear that intrinsic competitive disabilities in the manufacturing sector had anything to do with the trade crisis. Even if intrinsic conditions were a factor, not all of them relate to innovation but rather to long-standing American business traditions. Moreover, there is considerable concern over what appear to be innovation "through put" problems on the part of firms; that is, they do not seem able to commercialize or profit from new science and technology at a rate commensurate with that of discovery and technological change.

How science and technology solutions became singled-out in this state of affairs, and with what consequence, is of considerable interest. From all appearances, science and technology may be completely irrelevant to the crisis; even if they are, the supply of new knowledge pales in comparison to the host of intrinsic business factors that can disrupt bringing science to market. In short, the policy focus on supplying science and technology seems shockingly primitive and ineffectual in light of all the other possibilities.

But such a conclusion results from the basic nature of the paradox of macro crisis. The level of aggregation of data typically used--national measures productivity, growth, trade, employment--is too large to find systematic patterns across all indicators. Since most indicators of competitiveness are not direct measures of market success, the presence of a competitiveness crisis and its causes is largely a *prima facie* data interpretation subject to the initial analytical assumptions being brought to bear by the analysts. In essence, everyone may be right because the appropriate data are lacking to show otherwise.

Indeed, since by business standards *competitiveness* is the ability to prevail in product markets, the United States seems to be in surprisingly good health: the import penetration ratios reported earlier for the Summit 7 show the United States to be better off than average. Where the United States does not seem to be relatively healthy is in its competition with Japan. Half of the U.S. trade deficit is accounted for by imbalances with Japan, and in spite of the seemingly low level of import penetration by Japanese goods, a number of key sectors have been seriously weakened by Japanese competition. The experiences of autos, consumer electronics, semiconductors, NC machine tools, tires, and a number of other industries are familiar to a large majority of Americans, not in small part because of the loss of employment that has resulted. Yet it seems that we cannot definitively account for Japanese competitive excellence anymore than we can America's seeming lack of it, and as with the United States, we have contradictory explanations of the role of science and technology in Japanese competitive performance.

Are policymakers foolishly ignoring these paradox, or just bringing their own set of assumptions to bear on ambiguous information? Why is science and technology the privileged arena, and more to the point, what is the possibility that these solutions might actually be the best/most appropriate/right ones? As will be seen in the next two chapters, competitiveness policymaking is driven by compelling assumptions on the role of science and technology in the economy. The assumptions that are applied act as a unifying policy paradigm, and have structured the overall response to the crisis.

There is a good deal of theory and evidence (reviewed in chapter 4) that suggests these assumptions are not misplaced. Where they are misguided, though, is in presuming that the supply of new knowledge alone is a sufficient condition, or even a necessary precondition, for competitiveness. To the extent that the exact nature of the crisis is unknown, and hence the relationship between competitiveness and scientific and technological innovation has not been directly "put to the test," there is still the possibility that a supply orientation may help to substantially remedy the crisis. Chapters 5-7 therefore explore the relationship between U.S. and Japanese scientific and technological innovation and competitiveness in an effort to understand how these nations use science and technology for economic advantage.

CHAPTER 2

The Paradigm

Science policy in the United States has developed on a presumption that the scientific community, if given a relatively high degree of autonomy in the conduct of its research, will in exchange provide the fountainhead for economic and social well-being. This presumption, linked as it is to expectations about the social and economic payoffs of science, developed from the evolution of both the philosophy of science and American popular attitudes about the role of science in society. During and immediately after World War II, presumption and sentiment were elevated to a funding paradigm designed to mandate federal funding of science, but not its management. As Averch summarizes of the paradigm and its evolution:

> At the end of World War II, the scientific community developed and proposed a set of connected arguments, concepts, and beliefs--a strategy or model--that would provide a basis for permanent federal suppport of the nation's research activities, and, specifically, of basic research. The strategy was initially predicated on meeting national needs through assured, but unpredictable, contributions to economic growth and social progress. (Averch, 1985, p. 7)

This "strategy" is the science policy paradigm, a model which asserts that "new knowledge is a necessary condition for economic growth and social progress" and that "new knowledge can only be derived from basic research" (Averch, 1985, p. 10). As Vannevar Bush, architect of the paradigm avowed, "A nation which depends upon others for its new basic scientific knowledge will be slow in its industrial progress and weak in its competitive position in world trade, regardless of its mechanical skill." Science has consequently been left to largely follow its own course, for if one accepts the power of science one must, by definition, accept the principle of research autonomy.

Understanding current science and competitiveness policies requires an appreciation of these intellectual underpinnings, for such underpinnings establish the boundaries of the policy design process. The historical overview to follow shows how rather long held ideas about the role of science in society, when combined with the political interests of science, gave rise to a policy framework which enables the public funding of science but which prevents government from using science as a policy tool. The framework's logical construct--axiomatic as it is--precludes diagnostic policymaking concerning technical change and economic progress.

Moving science toward specific economic outcomes--that is, using science as a *tool*--is simply not possible with a model that does not carry any cause and effect provisions.

But why bother with policy paradigms at all? When considering the effectiveness of public policy, it is frequently best to start with the enterprise of policy design, "the course of events through which problems are framed and defined, goals or purposes are set, and ideas for action are fully crafted into fully developed policy alternatives" (Ingraham and White, 1988, p. 316). Policy paradigms are key to the design process, since they are the models and frameworks that predetermine how we see the world around us. Paradigms are cognitive axioms, the fundamental notions that we hold to be true and enable us to pattern events, to relate cause and effect, to open our minds or hopelessly close them. It is in this realm of ideas, beliefs, and premises that the effectiveness of public policy may ultimately be decided. Paradigms establish the boundaries of what is and is not possible in the policy design process simply by creating our first impressions of problems, causes, and solutions. Once the parameters of any given policy issue are so defined, it becomes difficult, if not impossible, to change the debate.

As will be seen later in Chapter 3, competitiveness policy is largely derivative of American science and technology policy, not quite by accident but then again not quite by explicit design. If there is one hallmark characteristic of U.S. competitiveness policies, it is the degree to which it is *taken for granted* that science and technology--in some fashion--are the key solutions to our competitiveness problems. This presumption imparts extraordinary consequences for the shape, direction, and success of the nation's competitiveness efforts, and the curious thing is just how and why such a presumption came about. Perhaps more than any other policy arena, science/competitiveness policy appears to rest on an article of faith. While caution must be advised in overstressing the role of ideas (as opposed to interests) in politics, the science policy arena is nonetheless striking for its high degree of consensus on the role of science in society. It may very well be the one arena where the belief system has been thoroughly inculcated into the political system, where the policy debates virtually never revolve around the clash of paradigms.[1]

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[1]In contrast, we can look to both the foreign policy and social welfare policy arenas as examples of how radically different ways of seeing collide in politics. The Soviets are a monolithic Red horde out to dominate the world, or they are not; welfare recipients *want* to live off the dole, or they do not. All policy analyses and prescriptions logically follow from these initial premises, premises based on paradigms about Communism and human nature. In these arenas the paradigms are sufficiently cohesive that we can label their advocates--hawks (continued...)

Prehistory

Many treatments of U.S. science and technology policy approach the level of myth: if the atomic bomb were Zeus, then modern science policy would spring Athena-like out of its head--adult and fully formed. As the legend goes, when confronted with the extraordinary "success" of the Manhattan Project, the federal government spontaneously gave birth to science policy as the country anticipated its demobilization back into a peacetime society. Nearly euphoric with the brilliant management of science for war, government leaders and scientists alike saw endless possibilities for science in peace.

Although not entirely incorrect--World War II *was* a watershed for U.S. science and technology policy--such analyses of the emergence of science policy overplay the novelty of the war-time experience with science. The U.S. government, and for that matter, American society, did not first recognize the potentials of "managed" science during 1939-45. The "uniqueness" of the war, what gave it its watershed character, was not a transformation in our attitudes about science, a change in the nature of science itself, or even a major structural change in the system of scientific research. Rather, it was the scope and intensity of federal control over the scientific enterprise. Science was mobilized for the war effort, and the country liked what it saw. For the first time, the federal government thus gave itself a mandate to systematically promote general scientific research for the advancement of public welfare.

As mentioned earlier, this mandate did not however advance new ways of thinking about science and society or substantially restructure the U.S. research system. Reinforcing popular attitudes toward science that emerged during the early part of the century and supported by the existant structure of the U.S. research system, the war served as a catalyst between common beliefs about the relationship between science and society and the needs of a maturing scientific research system. Piggy-backed as it was on the New Deal, World War II simply gave the federal government license to expand its authority into yet another arena, as progressivism was wont to do.

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[1](...continued)
and doves, liberals and conservatives--and predict their likely responses to any given policy issue. Notably, the one area of rather chronic conflict in the science policy arena is over the degree of accountability recipients of public research funds are to be held to.

However, in a society which prides itself on limited government (or at least the illusion of it), new incursions on social activity require paradigms justifying government interference. In this regard the liberal tradition in America is relentless in its demands for warrants to state behavior. The science policy arena is no exception, and governmental and scientific interests converted popular beliefs into an immutable paradigm of science and progress. Thus justifying (and carefully limiting) state promotion of science, the U.S. created a policy regime which was explicitly understood to enhance national power. The dominant paradigm initially represented not just a pretext for government activity, but also constituted the *substance* of the policy itself. Even today this paradigm does not just serve as a warrant for policymaking, but seemingly acts as the very framework upon which all science policy is built.

The Foundation

The roots of contemporary U.S. science policy may be found in the period 1914-1939. Not only were these the formative years for American attitudes about science and society, but the underlying structure of the modern research system emerged as the nation responded to its military, economic, and social needs. While there actually was federal "science policy" both during and prior to the early part of the 20th century, these policies were principally discrete, needs-oriented measures directed toward the accomplishment of specific goals. The government addressed such matters as industrial standardization, patent rights and procedures, natural resource conservation, naval weapons and technology, and the national census. By and large, however, an identifiable body of actors and policies which systematically attempted to use science and technology as tools to advance national well-being was absent, with the rather singular exception of the extension services and experimental farms of the Department of Agriculture.[2] As Dupree concludes of this era:[3]

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[2]Even though the creation of the Department of Agriculture (by the Hatch Act in 1862) is more notable for beginning the era of federal bureau-building, it nevertheless established a precedent for federal involvement in scientific research. In setting up research as a responsibility of the Department, Congress "proceeded on the uspoken but definite assumption that its power to 'lay and collect taxes...for the common defense and general welfare of the United States' obviously warranted federal sponsorship of scientific research" (Dupree, 1957, p. 151). As there were no other government departments or agencies with a mission comparable to that of Agriculture--that is, one which required some degree of scientific research to meet the mandate of the bureau--agricultural expenses virtually dominated the federal research and development budget from about 1900-1939 (for the specific figures, see Dupree, p. 332).

> A look backward over the Republic's first 150 years of experience with science shows a coherent pattern on two distinct levels. On the pragmatic plane of science responding to the needs of society, the story is one of accomplishment. On the higher plane of the attempt to create a comprehensive organization of science as a fundamental institution within the state, the record is fraught with yearning. (Dupree, 1957, p. 375)

The transition to the modern era began with World War I and is most strongly tied to the political and economic events of the interwar years. Several key developments in the structure of U.S. scientific research and in public attitudes toward science and technology emerged during this period; not only was the research system assuming its mature form, but there was a widespread popularization of science.

With regard to the research system, World War I established the private sector as the final of three major performers of R&D in the United States. Such an extensive amount of commercial research funding was injected into the American economy that "industrial research as a branch of the country's scientific establishment dates its rise to eminence almost entirely from the war period" (Dupree, 1957, p. 323). For the first time, industry began using research on a widespread and systematic basis as a means of rationalizing economic production and developing entirely new products. U.S. private sector research, which now accounts for nearly three-quarters of the nation's R&D, thus emerged from war-time demands for more efficient mass production of war materiel. World War I in effect cemented the tripartite structure which characterizes the modern U.S. research system, that of the industrial, government, and university research sectors.

Additionally and perhaps most importantly, World War I made clear the power of scientific research when effectively mobilized and directed. Although much of this research simply adapted civilian technology to wartime needs, the list of applications is impressive and

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[3](...continued)

[3] Dupree is widely regarded as having authored the seminal work on the "pre-history" of U.S. science and technology policy. His book *Science in the Federal Government; A History of Policies and Activities to 1940* chronicles federal involvement in science and technology from the founding of the United States through the passage of the National Science Foundation Act in 1950. (The title is somewhat misleading since Dupree also carefully reviews the activities of World War II as well as the post-war debates on the establishment of a permanent federal role for the promotion of science.)

nearly rivals that of World War II.[4] There were, however, also major innovations--the airplane, the tank, the ability to synthesize ammonia, poison gas, and particularly the submarine.[5] Last but not least were innovations resulting from the demands of standardization and the organization of large scale mass production.[6]

Although the wartime military research apparatus was dismantled after 1918, the institutional developments stimulated by the war continued throughout the 1920s. Industry expanded its laboratory facilities and advanced its research on the technology of mass production and the creation of new and better consumer goods.[7] Philanthropic contributions to university research increased in recognition of the promise of science revealed by both "wartime" efforts and the economic expansion of the early 1920s. The government continued to fund mission-oriented work in agriculture, but now also increasingly in public health and defense. In short, the major structural characteristics of the contemporary research system were defined in the 25 years during and after World War I. There was, however, both an organizational and functional division of labor in this system as each of the three research-performing sectors specialized in particular brands of scientific research. Universities conducted nearly all of the nation's basic science, industrial labs worked on consumer-oriented R&D, and the government restricted its activities to research for the public welfare.

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[4] Adaptation of pre-existing technologies should not be interpreted as a lack of ingenuity. For example, precision optical instruments, when applied to weaponry, took the guesswork out of gunfire and enabled greater accuracy in virtually every weapon that required shooting or launching. And the tank, although "an invention relatively simple in conception, relying upon no new scientific ideas and no radically new technology but simply upon the proper assembling of technical devices already long in use" was the weapon that finally "revolutionized land warfare" and signalled the end of the war (Brodie and Brodie, 1973, p. 199).

[5] For a detailed discussion of the technological developments and use of research during World War I, See Bernard and Fawn M. Brodie, *From Crossbow to H-Bomb* (Bloomington, IN: Indiana University Press, 1973).

[6] Lest anyone underestimate the impact of stardardization, Brodie and Brodie observe that "In 1914 the supply of British [naval] destroyers was hopelessy inadequate, but by the end of the war the United States, using her tremendous facilities for mass production and prefabrication, was building destroyers in six weeks. When the war was over there were 400 to 500 available" (1973, p. 185).

[7]Kuznick reports that industrial research laboratories increased from about "300 in 1920, to 1,000 in 1927, to more than 1,400 in 1930" (Kuznik, 1987, p. 10).

As the research system was evolving, so were American attitudes about science.[8] Throughout the 1920s until the Great Depression, the country experienced nothing less than a lovefest between science and the public. Americans became obsessed with all things scientific--the scientific method, major discoveries, Einstein, microbes, the Scopes Trial, and improved toothpaste. As a church minister of the 1920s noted, "Science has become the arbiter of this generation's thought until to call even a prophet and a seer scientific is to cap the climax of praise" (Kuznick, 1987, p. 14).

Scientists did little to discourage the public's rapture with science and instilled the cult of science into households in the most fundamentally American way--through advertising. Scientists became so ubiquitous that the advertising industry's trade journal suggested a "Forget Scientists Week":

> Perhaps you have been so foolish as to think that scientists work at the business of science. Not so. They test cigarettes, tell frightened mothers about breakfast food, [and] warn young men against the dangers of something that usually ends with -osis. (Kuznick, 1987, p. 13)

Throughout the 1920s the scientific community enjoyed an unprecedented public good will, principally because the public associated science with the greater availability and array of consumer goods and with improved standards of living. As Kuznick observed, "Science's new prestige accrued largely from this close identification in the public mind [of science] with the prosperity of the 1920s, an identification scientists took pains to cultivate" (Kuznick, 1987, p. 10). In their own enthusiastic way, scientists "reinforced the facile equation of scientific progress with social progress" (Kuznick, 1987, p. 15).

When the Great Depression hit, the scientific community was ill prepared for the villification which ensued. For millions of unemployed, their condition was, as far as anyone could see, the natural result of the excesses of research. "Technological unemployment" became the popular explanation of the day--science had done nothing less than spawn the technology which had eliminated millions of jobs. Surplus manufacturing capacity and the displacement

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[8] Much of the above discussion on the history of American attitudes about science is drawn from Peter Kuznick, *Beyond the Laboratory, Scientists as Political Activists in 1930s America* (Chicago: University of Chicago Press, 1987). Interestingly, little historical research has been done on this topic for this era; Kuznick's documentation of events, personalities, and public "mood" is an invaluable resource on the politicization and popularization of science in the United States.

of labor were identified as the faults of scientific research and the clear cause of the Depression.

By 1934, leading scientists were initiating counterattacks against such criticisms. Typical of the responses was a symposium entitled "Science Makes More Jobs" at a joint meeting of the American Institute of Physics and the New York Electrical Society. Among the days events was "an exhibit at the Museum of Science and Industry that *strove to establish a direct connection between scientific discoveries, inventions, and increased employment through the creation of new industries*" (emphasis added; Kuznick, 1987, p. 21). Shortly thereafter General Motors organized a Jules Verne Symposium reinforcing the "science makes jobs" theme and the social rehabilitation of science was on.

In the years following 1934 there was, if not an orchestrated effort, at least a concerted action on the part of the scientific community to regain its esteem and position in the public eye and to definitively silence those who disparaged science's value to society and the economy. Unable to advance alternative explanations to "technological unemployment", scientists nevertheless looked to science as the cure. Symposia, meetings, conferences, newspaper articles, and trade fairs all reiterated the same themes: science creates new technologies, new industries, and new jobs. As with the pre-Depression years, science was again explicitly linked to prosperity via a chain of science, technology, and economic growth. More scientific research was advocated as the cure for the Depression; science stimulated economic expansion by creating new technologies and new science-based industries. In spite of radically different approaches to the "science is progress" arguments, there was a remarkable consensus within the scientific community on this vision.[9] Through persistent media coverage, political activism, and government lobbying, the scientific community succeeded in reestablishing the equation of scientific progress with social progress. By the end of the 1930s

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[9] The consensus was composed of two rather distinctive approaches to the impact of science on society. A large number of scientists, radicalized by the events of the 1930s, formed a brand of scientific progressivism. Seeing human problems as tractable but concerned over the lack of control over the applications of science in the marketplace, these scientists sought to exert greater political and scientific management of science. On the other side were those who maintained that science should not and could not be responsible for its applications within society; that on balance the positive effects of scientific progress were much greater than any negative. In fact, most of this second group disavowed any responsibility for negative consequences--science was always neutral. In spite of the lack of agreement over the issue of "scientific accountability", both groups did seem to agree that science was of inordinate economic and social value.

America seemed to be once again in agreement that science was a major determinant of social and economic advance; the capstone of the decade--the 1939 New York World's Fair-- was itself a popularized monument to the social munificence of the science and industry partnership.[10]

Over the course of 25 years a number of events thus transpired which primed the United States for its experiences with science during World War II. Perhaps most importantly for post-war science policy, there was the emergence, attack, and successful defense of the principle that scientific research creates jobs, science-based industries, economic prosperity, and higher standards of living. That this dogma could survive the severity of Depression-era hostility is evidence of both its appealing intellectual qualities and the prestige of scientists in America.

There were also the institutional developments. The U.S. had not only succeeded in creating a sophisticated and diverse scientific establishment, but one relatively rich in resources: during the latter 1930s, funding for scientific research quietly recovered from Depression troughs and steadily increased, largely as a result of growing federal funding. Although Roosevelt appears to have vacillated somewhat throughout the New Deal on both the social benefits of science and the role of government in scientific research, progressivism ultimately won out. By 1938 federal funding of R&D had reached a record high of $75 million (Dupree, 1957).

Distinctive changes were taking place within the federal research establishment as well. The Department of Agriculture, the Public Health Service's National Institutes of Health, and the newly established National Cancer Institute were all moving toward more fundamental scientific research in addition to their applications-oriented activities. Laboratory missions began to include not only research performed by civil servants, but the advanced training of specialists, research fellowships, and distribution of research grants to those outside of government. On the eve of World War II the scope of scientific activity was so significant that the government probably couldn't have ignored it for long. Dupree concludes that:

> The qualitative changes in...science during the later New Deal presaged an era even if war had not intervened. The research responsibilities of the government were now so large, so important to its major functions, and so interwoven with one another that important decisions of policy could not be postponed

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[10]For a revealing look at the extraordinary popular attraction and mystique of the 1939 World's Fair, see E.L. Doctorow's novel, *World's Fair* (NY: Ballantine Books, 1985).

> long...Some new move for a central scientific organization appeared called for which would not only coordinate the federal research establishment, but also adjust the total program of the nation in all the estates of science...The essentials of the New Deal rested on other bases than research and its results. Yet on a pragmatic level, the government in the New Deal years threw off the blight of the depression and raised the scientific establishment to unprecedented opulence. (Dupree, 1957, p. 368)

Significantly, when the war intervened as the catalytic event in this seemingly inevitable progression toward science policy, there was in fact a certain *status quo* to be maintained in the scientific estate. First, there was the popular philosophy that scientific progress drove human progress, a philosophy that allowed the scientific community a certain public prestige and a claim for private (philanthropic) resources. Second, a rather clear division of labor existed among industry, government, and academic research laboratories, with "pure" science most strongly associated with universities and their facilities. Finally, within the enterprise of science itself, a particular culture emphasizing scientific autonomy had become entrenched--that of the laissez-faire treatment of science.

The laissez-faire treatment of science emerged from a philosophy of science which stressed the notion that "autonomy is conducive to the advancement of knowledge and intervention obstructs advancement" (Bozeman, 1977, p. 56). Science, in other words, may deliver discovery and knowledge only when the direction and content of scientific research is left to scientists, both individually and as a collective community. While principles of autonomy may be traced to the rise of science in Europe, it was nevertheless on the minds of the American scientific community during the 1920s and 1930s. Scientific progressivism--attempts to make the scientific research agenda responsive to social problems--could not overcome the increasingly entrenched value system of the scientific community, a value orientation which argued that science (and society!) was best served by letting science follow its own natural courses (see Kuznick, 1987, passim). A "leave science to the experts" mentality was growing almost in direct proportion to the success of science during that era.

At the time World War II broke out, the U.S. scientific community was faced with a nearly untenable situation. The research system had matured rapidly during the previous decades, and was thought to be poised at a golden age of discovery and scientific progress. However, the system was seriously constrained by a lack of resources, and the magnitude of need was such that only industry or government could effectively provide the large-scale funding necessary to "unleash" science. Many in the community were adamantly opposed to assistance from either sector; more pragmatically inclined scientists realized that adequate and stable funding was likely to ensue only from the federal government. The dilemma was such that extramural research funding was likely to invite interference and intervention with the enterprise of science, a meddling which was firmly believed to weaken scientific standards, misdirect the focus of research, distort the priorities of universities, and generally disrupt the progress of science by virtue of the fact that laymen "do not possess sufficient knowledge to intervene wisely" (Bozeman, 1977, p. 56). As will be seen below, the U.S.'s experience with science during the war was key to diminishing the reluctance of the scientific community to accept government as a research sponsor, for it provided evidence that with a modicum of policy direction and an abundance of money, government and science could enter into a productive partnership.

The Transition

Although the atomic bomb is the signal scientific contribution to World War II, radically new innovations like radar, the proximity fuse, rockets, and antisubmarine devices determined much of the technological character and direction of the war. Extensive research also went into the perfection of such World War I weapons as machine guns, airplanes, tanks, torpedos, mines, and submarines. The involvement of major industrial research laboratories was again critical to war-time innovation in terms of both product development and the economics of mass production. Brodie and Brodie observe, "In World War II the scientist in the laboratory touched almost every aspect of war operations and profoundly influenced tactics and strategy" (1973, p. 200).

R&D funding by the federal government alone increased from $100 million in 1940 to a war-time peak of $1.6 billion (Dupree, 1957, p. 373). Overseeing the administration of these funds--expended principally in the form of research contracts to non-governmental organizations--was the Office of Scientific Research and Development (OSRD), the central management agency for all federally-sponsored, war-related research and development. Empowered to "serve as a center for mobilization of the scientific personnel and resources of the Nation in order to assure maximum utilization of such personnel and resources in developing and applying the results of scientific research to defense purposes," the OSRD was headed by Dr. Vannevar Bush. Bush, an MIT physicist and President of the Carnegie

Institution of Washington, D.C., was one of four prominent scientists who together comprised an unofficial scientific advisory committee to Roosevelt.[11]

Bush and the OSRD presided over a sensationally successful coordination of the university, government, and industrial research sectors. The technological achievements of the war and the relative ease with which they seemed to be translated from laboratory to battlefield heightened everyone's sense of and appreciation for the utility of science. The scope, intensity, and result of Government's mobilization of science raised national expectations about the ability of science to deliver national power in times of peace as well as war. This recognition of the potential of managed science coincided with another realization on the part of the federal government: that university-based scientific research needed stable sources of research funding. Although the scientific community had identified this need years earlier, few scientists were willing to endorse government-supported science as a reasonable alternative. As a consequence, industry become a major sponsor of academic research in the 1930s, a relationship that bothered many in the scientific community who thought that commercial interests distorted the research priorities of pure science.

Not only did it bother some members of the scientific community, it troubled an official of Congress as well--Senator Harley Kilgore, a New Deal Democrat from West Virginia. Kilgore may be credited with taking the first political initiative to establish a permanent federal role in the support of science; in 1941 he introduced a bill to the Senate establishing a federal science foundation to fund and direct scientific research.[12] Motivated by a dislike for industrially-funded scientific research and distressed by U.S. patent policies regarding government-sponsored industrial R&D, Kilgore hoped to provide a more secure financial environment for scientific research and to direct this research for the public good.

From 1941 to 1944 there was considerable debate over Kilgore's bill and it was revised and reintroduced several times in that period. Although many in the scientific community still resisted suggestions for any government involvement in peace-time science, the idea was

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[11] The other members of this de facto "science cabinet" were: James Conant (President of Harvard University), Frank Jewett (President of the National Academy of Sciences), and Karl Compton (President of MIT).

[12] For a comprehensive discussion of the political events of 1941-1950 regarding the creation of the National Science Foundation, see Daniel Kevles, "The National Science Foundation and the Debate Over Postwar Research Policy, 1942-1945,", *Isis* 68 (1977): 5-26.

obviously appealing to policymakers who recognized that federal sponsorship of science was critical if the nation's wartime experience was to be translated to post-war America. Moreover, there were those scientists who recognized that in order to release the advancement of science itself, predictable funding resources were necessary. Vannevar Bush was a leading proponent of this view, but with a major caveat: government should support, but not control, the scientific enterprise.

When Bush failed in his attempts to persuade Kilgore to change his bill accordingly, he seized the political initiative and ultimately became the primary influence on legislation creating a federal science agency. With the assistance of several Administration officials, Bush arranged to receive a letter from Roosevelt asking him to recommend how the "unique experiment" of the OSRD could be applied to times of peace. As Roosevelt wrote in his letter to Bush in November 1944:[13]

> There is...no reason why the lessons to be found in this experiment cannot be profitably employed in times of peace. The information, the techniques, and the research experience developed...should be used in the days of peace ahead for the improvement of the national health, the creation of new enterprises bringing new jobs, and the betterment of the national standard of living.
>
> New frontiers of the mind are before us, and if they are pioneered with the same vision, boldness, and drive with which we have waged this war we can create a fuller and more fruitful employment and a fuller and more fruitful life. (Bush, 1945, pp. 3-4)

In the spring of 1945 Bush responded to Roosevelt's request with *Science--The Endless Frontier*, a treatise on the virtues of basic scientific research and its contributions to national welfare. The report recommended the establishment of a federally-sponsored National Research Foundation, an organization which would provide stable research support for basic research in universities but which would not interfere politically with the science itself. The report was a "smash hit" with everyone but the Truman Administration (Roosevelt had died by the time Bush transmitted his report in 1945), since as one official remarked, the report did not "fulfill the broad, democratic purposes which a federal research agency should accomplish" (Kevles, 1977, p. 23).

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[13] Roosevelt did not actually write the letter--it was crafted by members of his staff who were trying to promote Bush's position.

From 1945 until President Truman signed the National Science Foundation Act into law in 1950, the government argued the proper form and role for government funding of scientific research. It was clear to all that the federal government should have some role in advancing scientific research during peacetime, the issue was always how and for what purpose. At the heart of the political conflict was the disagreement between those New Dealers, liberals, and progressives who wanted government to "manage" and direct science for specific societal goals and those conservatives, Republicans, and scientists who wanted government's money for science, but not its guidance; discussions consequently polarized around the positions of Kilgore and Bush. Both individuals wanted a federal science agency empowered to fund scientific research, but their differences boiled down to the fact that "Kilgore wanted a foundation responsive to lay control and prepared to support research for advancement of the general welfare; Bush and his colleagues wanted an agency run by scientists mainly for the purpose of advancing science" (Kevles, 1977, p. 16).

In spite of Kilgore's early initiatives, the proposals in *Science--The Endless Frontier* defined the parameters of the debate for the next five years. The arguments finally concluded in March 1950 with the passage of the National Science Foundation Act. Reflecting much of the Bush architecture, the Act created a national science agency which funded basic scientific research but did not, however, interfere with the actual conduct of this research or guide its direction. Although the Act did contain concessions on such concerns as the geographic distribution of research funds, balance of research mission, and Presidential control over the Agency, it more or less left the business of science to scientists. Bush had managed to get science the much needed federal funding for scientific research without compromising its autonomy. Kevles summarizes this legislative history by observing that:

> Bush's program, rooted in and justified by *Science--the Endless Frontier*, won its strongest adherents from conservative Republicans. At the time of its publication, analysts...recognized Bush's report for what in so many respects it was, essentially a conservative response to Kilgore's liberal initiative. Bush was willing to endorse an end to laissez-faire in American science insofar as he was willing to put the government into the business of funding academic research.
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> But while Kilgore's program aimed at organizing scientific research in the best interest of meeting the nation's social and economic needs, Bush essentially aimed at enlisting the nation's social and economic resources in the interest of advancing the best science. Bush had produced...a political document, a textual weapon for the political battles of 1945 to 1950 over the shape, purpose, and choice of federal policy for scientific research and development in the postwar era. (Kevles, 1977, p. 26)

In sum, whereas Kilgore and other liberals saw science as a policy *tool* which could be developed and manipulated for specific national needs, Bush's conceptualization portrayed science as a policy *outcome* beneficial to public welfare *only* when impartially supported and left to naturally follow its own dynamics. Rather than direct scientific research toward particular goals, government should generously support the "best" science in the expectation that this science would reward society with the means to resolve national problems and achieve national goals. The political dilemma was not trivial, since at issue was the very nature of federal involvement in science:

> The five year debate never questioned the support of science; rather it always swirled around the issue of how...the ethic of pure science, with its esoteric subject matter appealing only to a few, [was] to be supported in a nation that was traditionally most comfortable with practical goals that applied to the many. (NSF, 1988a)

The choice that prevailed did so because of Bush's "textual weapon", essentially a promise that in return for financial support and research autonomy, science would provide the keys for national well-being. *Science--The Endless Frontier* certainly decided the issue at hand, but what Bush ultimately accomplished was in fact an institutionalized, virtually unquestioning policy support of basic research, of the laissez-faire treatment of science under the guise of a science-as-social-good paradigm.

The Paradigm

While eloquent, Bush's writings on the practical consequences of science were not novel; they reflected a natural culmination to the American thought of the interwar years and the scientific achievements of World War II. The great accomplishment of *Science--The Endless Frontier* was its explicit linkage of *basic* scientific research to human health and betterment. For a nation seeking a reason to institutionalize the relationship between the estates of government and science, *Science--The Endless Frontier* satisfies as a manifesto on the ability of science to deliver prosperity and power.

The paradigm set forth by Bush is one of considerable intuitive appeal. Quite simply, it is a conceptualization of science as the root of human progress:

> Advances in science when put to practical use means more jobs, higher wages, shorter hours, more abundant crops, more leisure for recreation, for study, for

> learning how to live without the deadening drudgery which has been the burden of the common man for ages past. Advances in science will also bring higher standards of living, will lead to the prevention or cure of diseases, will promote conservation of our limited national resources, and will assure means of defense against aggression. (Bush, 1945, p. 10)

Confident in the social promise of science, Bush went on to warn that "without scientific progress, no amount of achievement in other directions can insure our health, prosperity, and security as a nation in the modern world" (Bush, 1945, p. 11).

This conviction in the association between scientific progress and human progress operates as the dominant paradigm in U.S. science and technology policymaking. The theme pervades most discussions in the postwar era about government support of science, and is consistent in its thesis: science--unpredicatable and abstract as it may seem--has social utility. In characteristic homage, Strasser concludes simply that "the considerable dependence of our welfare, progress, and even survival upon science and technology has been...repeatedly demonstrated" (Strasser, 1973, p. xi).

The paradigm reveals itself in a multitude of policy documents; typical are the assertions codified in the National Science and Technology Policy, Organization, and Priorities Act of 1976:

> The scientific and technological capabilities of the United States, when properly fostered, applied, and directed, can effectively assist in improving the quality of life [and] strengthening the Nation's international economic position. Federal funding for science and technology represents an investment in the future which is indispensable to sustained national progress and human betterment. The general welfare, the security, [and] the economic health and stability of the Nation...require vigorous, perceptive support and employment of science and technology in achieving national objectives.[14]

More than a decade later, the Office of Management and Budget (OMB) again affirmed that "The ability of the Nation to meet global competition, to provide for the national security, and to improve the quality of life for all citizens depends...on national investment in science and technology" (OMB, 1989, p. J-1).

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[14]National Science and Technology Policy, Organization, and Priorities Act of 1976, PL 94-282, §101(a)(3,4); §202.1.

Clearly such expressions of our dependence on science and technology are based upon an understanding that scientific knowledge has practical consequences. Indeed, the more science is perceived to deliver useful benefits, the greater are our demands on it. Such presumptions are not confined to the U.S. alone; as the OECD has observed of its members, "Growing expectations of economic and social benefits from science and technology are elevating associated policy issues to the highest levels of government" (OECD, 1988e, p. 9). In a nutshell, government funding of science depends upon a paradigm which maintains that science is, ultimately, utilitarian.

At this level of operation the paradigm is hardly problematic and its origins are easy to identify. There can be no doubt of the total conviction of most scientists in the social utility of their work; Kuznick (1987) provides an almost exhaustive account of how this self importance developed and how its concommitant self-promotion shaped popular attitudes during the 1920s and 1930s. From all appearances, with the exception of the "technological unemployment" episode of the Depression, the American public seems to have had an instinctual affinity to the notion that science "pays off". The economic expansion of the 1920s, the equation of science with industrial glamour in the 1930s (à la the high tech futurism of the New York World's Fair), and the unequivocal "success" of the atomic bomb program provided a 25-year legacy of salient, science-as-progress history.

For all practical purposes, in 1945 science *was* a social good--utilitarian and progress-oriented. A science-as-social-good paradigm thus served the government's (and science's) need for a funding rationale more than adequately. This theme in *Science--The Endless Frontier* was simply another variation of the "science makes jobs" refrain heard throughout the previous decades. At this level of abstraction and in its "thesis" form, the science policy paradigm is essentially a funding paradigm, a supply-sided mandate designed to enable government expenditures for science, and hence for its supply. Granted the supply is unpredictable--such is the nature of discovery--but it will be useful:

> The fundamental justification for expending large sums from the Federal budget to support [science] is that these expenditures are capital investments in the stock of knowledge which pay off in increased outputs of goods and services that our society strongly desires. (Kaysen, 1965, p. 148)

On this point there was no dissent during the debates over a national science foundation. Liberals, conservatives, progressives, and scientists all viewed science through the same pair of rose-colored glasses; in many respects there was a single national vision--a non-partisan paradigm--about science and progress. It was a vision with which all but the most committed cynics would agree; Americans seem to have an intuitive understanding that the history of civilization and scientific and technological progress go hand in hand.

The critical political and scientific issue was not the *support* of science, however, but its *management*. How extensively should government get involved in a scientific estate that, heretofore, was largely independent of government influence? On this point the dissent was great and the self-interest of science unequivocal: not at all. It was to *this* issue that Bush speaks in *Science--The Endless Frontier*, and does so by crafting a careful extrapolation of the paradigm.

The Operationalization of Paradigm

For the Government to do any more than simply fund scientific research it would have to address issues of research agenda-setting and the utilization of science and technology, an involvement that would not only threaten the autonomy of science but take the government dangerously close to the activities of the private sector. Government could not be in the business of deciding society's scientific needs or determining its usage of existing knowledge for fear of diminishing the present quality and future potential of science as well as distorting free enterprise. An argument had to be advanced that would dissuade the government from interfering with science while simultaneously ensuring that funds would be forthcoming. In other words, how to discourage public management (and in many respects, accountability) of science without jading the enthusiastic support which science enjoyed?

Bush fashioned such an argument by operationalizing the science-as-progress paradigm into a model of innovation, the process of commercializing science and technology. While the model itself is implicit in *Science--the Endless Frontier*, it is revealed by Bush's explicit reduction of human progress to basic research:

> Progress in the war against disease depends upon a flow of new scientific knowledge. New products, new industries, and more jobs require continuous additions to the knowledge of the laws of nature, and the application of that knowledge to practical purposes...This essential, new knowledge can be obtained only through basic scientific research. (Bush, 1945, p. 5)

Such compelling reductionism--iterated throughout *Science--The Endless Frontier*--is the truly significant accomplishment of Vannevar Bush. That scientific and human progress were intimately related was a commonplace by 1945, but now there was an operational connection between science and social advance:

> Basic research leads to new knowledge. It provides scientific capital. *It creates the fund from which the practical applications of knowledge must be drawn.* New products and processes are not born full-grown. They are founded on new principles and new conceptions which in turn are painstakingly developed by research in the purest realms of science. (Bush, 1945, p. 19; emphasis added)

In a simple expression of linkage between basic science and new products and processes, Bush was able to to convey the sequential transformation of knowledge developed "in the purest realms of science" to commercial goods and manufacturing processes.[15] As Ronayne explains of this passage, "In giving pure research a key role in the innovation process, Bush was propounding what we now call the linear model of innovation. In this model, technological innovation...is represented as a multi-stage process in which pure research is the first essential step" (Ronayne, 1984, p. 33).

The innovation model in Bush's discussion is a relatively simple one, with the stages flowing unidirectionally from science, to technology, to commercial development, to the marketplace. In practice, these stages become basic research, applied research, experimental development, and commercial sales; knowledge becomes technique, and technique results in new products and manufacturing processes.

Essentially the operational form of the "scientific progress is social progress" paradigm, the linear model of innovation (also known as the "science push" model) portrays science as both the precondition to and impulse for the innovative process. Because of its linearity, the

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[15]The reader may wonder how the Bush formulation of science-technology linkages differed from that during the 1920s and 1930s: Bush was unrelenting in his insistence that all technological advance drew exclusively from the knew knowledge uncovered through basic research. In comparison, arguments during the previous era focused rather fuzzily on the contributions of "science" more generally, without drawing any hard and fast distinction between new and old science or insisting that all technological change stemmed from scientific discovery. For a nice overview of the role of "old" science in the second industrial revolution and the economic growth of the early 20th century, see David Mowery and Nathan Rosenberg, "The Beginnings of the Commercial Exploitation of Science by U.S. Industry," in *Technology and the Pursuit of Economic Growth* (Cambridge: Cambridge University Press, 1989).

model suggests a certain inevitability to the process of commercializing science; once research provides a new discovery, industry reacts by turning it first into technology, and then into discrete products. Such a process appeals to scientists' sensibilities about the relationship between science and technology, but it is also reinforced by the structure of the country's research system, which divides responsibilities for basic and applied research and development between universities and industry.

In *Science--The Endless Frontier* Vannevar Bush capitalized on the evolution of American public sentiment about the social and economic significance of science and technology. Indeed, Bush himself was likely a product of the era's acculturation; this made it all the more natural to advance a portrait of science and technology in which they were sequentially related. To most reasonable people, science and technology did seem to have such a relationship, especially since it had been a carefully cultivated theme in the public's rapture with science during the boom of the 1920s and the rehabilitation of science during the economic recovery of the late 1930s. It was also stunningly verified by the research-to-battlefield experiences of World War II.

In using the linear model to reduce social and economic progress to basic research, Bush was speaking from scientists' own perceptions of their utility, a perception willingly accepted by a public who enjoyed the "fruits" of scientific research and by a government which reaped the national power that science had sowed. Yet by doing so, Bush cleverly set the parameters for federal involvement in science. First, he established the primacy of science in the science-technology-society linkage, delivering an ongoing policy rationale and (as a consequence) the much needed funding itself. Second and perhaps more importantly, by arguing the primacy of basic science he was able to invoke the principles of scientific autonomy: government management of science was hence proscribed at virtually every level of the scientific enterprise. In one document Vannevar Bush assured science both its resources and its independence; the political interests of the scientific community thus fashioned the ideas and the policy paradigm in their own image.

The Paradigm and Science Policy

The linear model of innovation (with some modification) continues to be a critical influence in the development and execution of U.S. science policy, principally because of its core assumptions about the relationship between science and technology. It is a persistent understanding that has been explicitly stated by policymakers and science policy analysts over the past 30 years (emphasis added in all quotes):

> Basic research [is] an expression of man's desire, his need to learn and explore--and, quite incidentally from one standpoint, *the source of all technological progress.* (NSF, 1957, p. 1)

> If industry succeeds in producing these goods [adequate food supply, new sourcs of energy, raw materials], it will be because technology has solved the many complex problems involved. *And if technology solves these problems, it will be because basic scientific research has provided the fundamental knowledge upon which technology grows.* Society will determine the rate of progress of this whole industrial-technological-scientific complex by the policies it adopts and follows in support of basic scientific research. (Wolfle, 1959, p. 26)

> History has proven to be valid...the assumption that *development of technological innovations is dependent on basic research.* (Willard, 1965, p. 289)

> As to the recent past, we have overwhelming evidence that *scientific research, translated into technological innovations through...organized applied research and engineering development,* has had a dominant and beneficial effect on the welfare of advanced nations. (Kistiakowsky, 1965, p. 169)

> When one points to the usefulness of science, one includes science with technology...*Clearly technology is only somehow the application of science, and that is what science is for.* (de Solla Price, 1973)[16]

> The function of applied research and development is...*to discover radically new technology based on new technical possibilities derived from scientific research* (Hollomon, 1973, p. 29).

> We must devote increasing support to the science and technology necessary to meet growing civil needs; [this] requires striking the right balance between support of basic and applied research to assure a dynamic flow of knowledge and technology...It is clear that a fundamental bedrock of knowledge provided by basic research is essential to applied research oriented toward the solution of problems. *Yesterday's basic research is the foundation on which today's applied research is built.* (Stever, 1973, p. xx)

> The development of new technology, *mostly as a result of scientific efforts,* and its use has been a powerful factor in raising human welfare. New technology has contributed greatly to economic growth by raising GDP and has enabled the population to live at a higher standard of living than otherwise possible. (Tisdell, 1981, p. 13)

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[16]In all fairness it should be pointed out that de Solla Price is not a proponent of scientific reductionism. This quote is his presentation of the prevailing received wisdom, a wisdom he took great pains to critique.

Technology depends on basic research--the source of insights that lead to really new products and processes. (Bloch, 1987, p. 8)

Clearly beliefs about the primacy of basic research as a precursor to social and economic progress rely upon fundamental assumptions about the relationship between science and technology: social and economic change cannot occur without new technology, and technology cannot advance without science.

This operational form of paradigm persists even though the linear model of innovation has been discredited by a number of economic historians who have shown that, not infrequently, major technological innovations are not at all connected to the realm of science.[17] In spite of evidence presented in these critiques, the science push model and its accompanying assumptions about the relationship between science and technology continue to prevail in government policymaking; as Brooks observes, "this simple and appealing model of the genesis of technological innovation...still has political potency" (Brooks, 1988, p. 50). De Solla Price concluded over a decade ago that the model is so persuasive because the world around us seems to continually reinforce its validity:

> It seem(s) so very simple and logical to suppose that there (i)s a great chain of action in which basic scientific research bec(omes) the foundation for applied research on practical problems, and that the solution of practical problems leads to the process of development whereby an invention would become an innovation that produced new goods or helped increase the effectiveness of producing established goods. Such an instinctively correct view is hallowed by the anecdotal evidence of history. (De Solla Price, 1977, p. 25)

Explaining the ongoing potency of this model is therefore not difficult, given its apparent validation by at least some economic history. In the contemporary period, the model has taken on a new urgency by the seeming conflation of science and technology themselves; the growing science intensity of technology, when combined with the role of advanced technology in scientific discovery, has rendered the science/technology distinction irrelevant for many high technologies and industries. Erich Bloch, Director of the National Science Foundation, asserts that "The lines between science and engineering, between basic and

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[17]This literature will be reviewed in Chapter 4.

applied research, have blurred considerably" (Bloch: 1987: p. 7)[18]; the National Governors Association found in a survey of industrial R&D managers that they had an explicit perception that "the line between basic and applied research is blurring and that there is a need for greater interaction between basic research and technology development" (NGA, 1987, p. 23). As one survey respondent noted, "We have come to realize that the innovation process is not a sequential process (pure science leading to technology and to economic opportunity) but involves strong coupling--both ways--between technology and basic science. Each is stimulated by and dependent on the other" (NGA, 1987, p. 23).[19]

This recognition that the relationship between science and technology is not sequential, that the two are in fact mutually interdependent and increasingly "indistinguishable", weakens the linearity of Bush's model of innovation but does not really jeopardize the primacy of science in the equation. If anything, it heightens the role of science in the science-technology-economy formula by requiring a stronger coupling between science and technology than that which is conventionally assumed to exist. Instead of being a precursor to technology, science is now a partner, with all the coincident demands upon it.

More specifically, as technological change is now perceived to be critical to economic competitiveness, and with technology mutually dependent on science, science itself is now critical to economic competitiveness. The growing synergism between science and technology amplifies the logic of the paradigm and heightens our sense of temporal economic urgency: as Robert Mosbacher has commented, "We could be losing the most important race for the future--that of moving discovery from the laboratory to the marketplace." Far from limiting the role of science in economic performance, technology-based competition and the new science-technology interdependence make it that much more critical that scientific discovery and research proceed apace with economic demands for technological change.

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[18]Bill Broad, the senior science reporter for the *New York Times*, confirms that "The [apparent] fusion of science and technology is viewed as crucial by Federal officials who help shape the Nation's R&D effort" (1988, p. C-1).

[19]In addition to these qualitative evaluations, Narin and Noma have also found empirical evidence suggesting a conflation of science and technology. Analyzing the science content of U.S. biotechnology patents, the authors conclude "the division between leading edge bio-technology and modern bioscience has almost completely disappeared" (Narin and Noma, 1985; p. 369). More commonly, however, analysts simply reflect on the case histories of biotechnology, semiconductors, new materials, pharmaceuticals, superconductors, and microelectronics and conclude that the science and technology are nearly indistinguishable.

The Constraints of Paradigm

What, then, is the problem? Why is it a concern that policymakers find appealing an economic view of science that is hallowed by the anecdotal evidence of the past and reinforced by the anecdotal evidence of the present?

As science policy attempts to become more proactive in its influence on economic performance, the paradigm and the linear model of innovation (however revised) utterly fail as heuristic devices. Not only have they never been able to inform the ongoing dilemma in science policymaking--what level of research funding is required to ensure a dynamic research base and the resultant economic vitality--but they certainly lack the conceptual and analytical tools to diagnose the contemporary economic malaise. What seems to have been lost on policymakers and many science policy analysts is that the process of bringing science to market involves complex dynamics of supply, demand, and the interrelationship between these forces. To the extent that the paradigm and the linear model of innovation were created to justify government funding of science, they have performed admirably. The paradigm is a funding mandate, a call for government support of science because science is thought to be the primary input into technological change. Such change is in turn crucial to the long-term dynamics of an economy.

The linear model is thus a supply-sided accounting of the translation of science into product; it is not a framework for the complicated process of bringing science to market because it is mute on the process of commercialization--both innovation and diffusion. While it is accurate that science/technology must be transformed through a process of product development and marketing to ultimately find their way into society, *not all science/technology is so transformed*. Quite simply, we cannot work backward through the model to diagnose economic ills; we inevitably wind up with the conclusion that the supply of science is inadequate. There is clearly a utilization dynamic taking place independently of the supply of science dynamic; more complex still, there is the interface between supply and demand.

Any attempt to analyze economic problems through the paradigm itself (including its operational form as the linear model of innovation) will not reveal that there are in fact alternative sources of change or that science and technology alone are not sufficient conditions for innovation or the diffusion of innovations throughout an economy. Because of their logical structure, the paradigm/linear model fail as heuristic devices since they cannot be used in either a diagnostic or prescriptive capacity. Not only can they not help us decide "how much basic research is enough," but they cannot analyze bottlenecks or breakdowns in the linkages between technical progress and economic performance. Among other equally important questions, this supply-sided framework cannot answer "when does science not turn into a practical good?"

In its supply-sidedness, the paradigm can say nothing about those scientific discoveries which have not had (and may never have) practical social or economic benefit. Silent on the non-event, the paradigm may thus be readily validated by historical anecdotes of scientific discovery leading to major social change. We do not look for--and in fact cannot find--the state of non-change because the paradigm makes science infinitely useful. As the National Goals Research Staff stated, "there is no serious research, no matter how theoretical or basic in intention, which does not have some potential for generating knowledge which can lead ultimately to some socially valuable application" (NGRS, 1970, p. 104). Impressively enough, Jean de Rond d'Alembert, the 18th century mathematician and philosopher, realized the same over 200 years ago:

> Another motive serves to keep [scientists] at work: utility, which though it may not be the true aim, *can at least serve as a pretext*. The mere fact that we have occasionally found concrete advantages in certain fragments of knowledge, when they were hitherto unsuspected, authorizes us to regard all investigations begun out of pure curiosity as being potentially useful. (quoted in Kennedy, 1986, p. 265; emphasis added)

As Kennedy wryly observes about d'Alembert's remarks, "He understood grantsmanship before there were grants" (1986, p. 265).

The problem is not that the paradigm is not valid, but that it is--perfectly so. The principle that scientific progress drives human progress is axiomatic: it is a logical truth statement that can never be falsified. Either we immediately recognize the utility of science--which "proves" the theory--or we are intellectually incapable of invalidating it.[20] Since perceptions of utility depend upon our cognitive abilities to recognize it, science is always

[20] The recognition factor is an important one, since it is one way of arguing that even though we may not recognize it at the time, some item of knowledge may be useful in the future (reinforcing the unlimited utility of science).

waiting upon society's enlightenment to finally put it to good use. To wit we have d'Alembert's recognition that the occasional utility of science authorizes us to regard all investigations as potentially useful; this is the pretext that scientists developed, advanced, and cultivated in order to assure ongoing funding of basic research. Validation of the paradigm requires showing only that science does--at least periodically--yield socially significant results. We can never invalidate the paradigm by showing that science does not lead to social utility because there is always the potential that it eventually will.

The logical structure of Bush's paradigm forces us to view the supply of science as a necessary and sufficient condition for social and economic progress. When we say "look at penicillin, the atomic bomb, the Watson-Crick model of DNA, the transistor, nylon", what we are in effect asserting is that such breakthroughs lead inexorably to social product: if x, then y. Such a statement represents the damnable nature of the paradigm and the linear model of innovation. It really isn't the direction of the process that's so troubling--we would be hard pressed to find instances in which science "paid off" yet did not follow the science-technology-marketplace trajectory--but its implicit determinism (science will always be profitable) and exclusivity (there are no other significant sources of technological change). The caveat usually put forward is that basic research/science is unpredictable only in the rate and timing of a discovery; science can make no promises as to when or how a breakthrough will occur. However, there is the implication that once a discovery is made, its commercial application will proceed apace. Within the logical framework of the dominant paradigm, if economic progress is not taking place, then it must be because there isn't enough science supplying it.[21] As was

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[21]Note that these diagnostics are largely confined to science policymakers and analysts. Industrialists typically do not see the science-technology-progress linkage this way, since they operate far more within the realm of demand forces. However, it does depend to some extent on the industry; high-tech and science-based industries do tend to regard science as the precursor to their own technological advance. For example, William Norris, founder and chairman emeritus of Control Data Corp., has said:

> The linear model in every form has demonstrated its validity to the extent that it underscores the inevitable science underpinnings of technological innovation. Where the narrowly-drawn linear model...goes wrong is in not recognizing that the most relevant forms of the model have feedback loops...[This] illustrates that sometimes even science responds directly to [market] forces. In all scenarios, however, technology rests on science...Every technological innovation is bottomed upon one or more achievements in science. But for the generation of specific science outcomes, the technological innovation could not have become a reality. (Norris, 1988)

mentioned in the previous chapter, when competitiveness is evaluated through the science policy paradigm, simply no other explanation may be forthcoming.

While we may certainly argue that it is unfair to hold policymaking to the rather strict philosophy of science requirements about construct validity and falsification, it is nevertheless reasonable to identify how--because of these weaknesses--policymaking is constrained in its prescriptive capacity. As a first-order cut at competitiveness policy analysis, we find that the paradigm which guides current policymaking may not be up to the task at hand. In coloring our first impressions of problems, causes, and solutions, the paradigm directs our conclusions toward a supply-of-science orientation, an orientation that is only one facet of a problem which, to be cliché about it, is terribly complex and multidimensional. As will be seen in the next chapter, U.S. competitiveness policies do indeed rely heavily upon supply-sided science and technology approaches. What becomes clear, though, is that the politics of budgets and crisis figured in the equation to firmly establish science policy as the lead arena in dealing with the crisis.

CHAPTER 3

Paradigm, Politics and Supply-Sided Competitiveness Policy

While the paradigm and its accompanying model of innovation *predispose* policy expectations about the capacity of science and technology to deliver economic welfare, it took an unusual constellation of events to turn the gaze of government fully upon the science and technology arena. A constrained budget environment, the emergence of the competitiveness crisis itself, and--for the first time since sputnik--the identification of science and technology as the primary tools for resolving a national crisis all configured to concentrate policymaking activity in the science policy arena. Key to this concentration was the political exploitation of the paradigm by the technoscience agencies, the Congress, and the executive branch, albeit all for different reasons.

The net effect of events and the political reaction that they provoked is a cumulation of policies which are understood to be our country's response to the competitiveness crisis. As will be seen, the influence of paradigm, the nature of the political needs, and the long-standing *laissez-faire*[1] treatment of both science and industry resulted in a U.S. competitiveness policy[2] concerned largely with the stock and flow of scientific research--that is, it is a supply-of-science solution to the perceived decline of U.S. strength in world markets.

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[1] Note that science policy is probably far more *laissez-faire* (to the extent that any public policy may truly be so) than economic policy. Since scientific knowledge is thought to result from a "supply" of qualified researchers and various scientific "demands" for research on particular subjects, the best and most useful knowledge will logically result only if this market is left to function principally on its own, unbiased by political or commercial interference. The principles of scientific autonomy are in effect the principles of this knowledge supply and demand. Like economic policy, science policy can be regulatory in the sense that it attempts to correct imperfections in the supply/demand dynamics of the production of scientific knowledge, hence concerns over distortions in peer review and the slowness of some disciplines to respond to important research questions.

[2] It may be reasonably argued that the discrete competitiveness policies produced throughout the decade are sufficiently cohesive around this supply-of-science orientation that we can think of them as a single national policy.

The analysis that follows is not a detailed accounting of competitiveness policy design—that is, how the specific policies were derived—but an overview of how the commingling of politics and paradigm established the boundaries of what was (and was not) possible in addressing the crisis. The policy design process is probably rarely as rational as Ingraham and White imply it to be ("the course of events through which problems are framed and defined, goals or purposes are set, and ideas for action are fully crafted into fully developed policy alternatives"; Ingraham and White, 1988, p. 316); the reality may be less an objective assessment of problems and solutions than a process of eliminating what is not possible in a given political environment. Such elimination may be the result of explicit appraisal or the subtle cognitive influence of paradigms, but the appearance of rational policy design may nonetheless be evoked.

The Parameters of Policy Design

On the eve of the competitiveness crisis the federal technoscience agencies (and by extension, the scientific community) were faced with what seemed to be a new reality in science policy-making. The rhetoric and the budgets of the early Reagan years made it quite clear that the R&D and science and technology budget was to increasingly become a zero-sum competition, with the agencies subjected to stringent relevance tests to prevent declines in their budgets, let alone garner increases. Whereas earlier federal objectives in space, energy, and the environment were pursued as supplements to government's responsibility for the advancement of science, these objectives were now competing for scarce federal funds against one another as well as with basic scientific research. Thanks to the peculiarity of the Congressional budget process, some of the technoscience agencies were also in direct competition with welfare agencies such as HUD and the VA[3]; science and technology programs had to be prioritized not only against each another, but also against domestic welfare objectives in public housing and veterans' care.

Because the competitiveness crisis created the "relevance test" against which the science and technology agencies qualified for funds, they were naturally encouraged to make exaggerated claims about promoting economic welfare in order to prevail in their budget requests.

[3]NSF, NASA, and the Department of Energy R&D programs are in the same Congressional authorization committee as HUD and the VA.

Science and technology budget justifications, once couched in terms of scientific merit and mission relevance, relied upon arguments which linked agency programs to competitiveness. *That they could do this at all* was the consequence of both the paradigm and the precedents set during the Carter Administration. Barely a few years before, the government had already explicitly identified science and technology as key to the nation's industrial competitiveness; the international competitiveness crisis of the 1980s seemed a natural culmination to the earlier decline in the manufacturing base.

As will be seen later in this chapter, none of the agencies fared quite so well as the NSF in this budget game.[4] The NSF and its director, Erich Bloch, excelled in establishing a linkage between the agency's mission (funding scientific research) and international competitiveness. The other agencies might have miscalculated in their strategies, which appeared to rely on selling multi-billion dollar science projects (DOE's Super-conducting Super Collider, NIH's Human Genome project, NASA's Space Station). Such "big-ticket" approaches were probably disabled by several key factors. Links between mission agencies and broader economic welfare have never been as strongly established as that for basic research, since by definition they are mission-oriented--geared to narrow responsibilities in health, space, defense, energy, and the environment. It was probably much harder for OMB and Congress to swallow the alleged competitiveness relevance of mission research than that for basic science, for which they had a 35-year legacy of rhetoric. Additionally, the Congress has been reluctant to fund all three projects in their entirety, and seems unable to prioritize the relative social and economic contributions of atom smashing, identifying all humanly possible genome pairs, and constructing a manned platform in space.

Finally and maybe more importantly, rising expectations about the economic payoff of science and technology created a new avenue for pork-barrel politics right about the time other pork taps (water, construction, airports, etc.) were being shut off.[5] As the perceived stakes in the "ownership" of science and technology rose, research projects became earmarked for home

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[4]Note that the Department of Defense was actually the big winner of the Reagan Administration's new R&D policy. From 1980 to 1986, federally-funded defense-related R&D increased from 50% of the total federal R&D budget to 70%.

[5]For a more detailed discussion of the rise and nature of pork barrel science, see Bozeman and Crow (1990), "Pork Barrel, Peer Review, and Congressional Science Policy".

districts is the best pork barrel fashion.[6] Big-ticket science projects have became derailed partially because of the politics of location associated with the lucrative payoffs of their research, construction, and manufacturing contracts.

Vying with the vested and parochial interests of the Congress itself, with domestic welfare programs, and with each other, it is no wonder technoscience agencies actively promoted the science-technology-competitiveness relationship. The Reagan mandate for greater utility and the salience of the crisis itself inspired the new budget rhetoric linking mission technoscience to competitiveness, a linkage enabled in large part by the paradigm and the linear model of innovation. While most of the agencies have had only limited success in their exploitation of the crisis, this new budget competition did help center the competitiveness debate on science and technology. No other domestic policy arena--with the exception of trade policy--could make quite as compelling claims about its relationship to U.S. international competitiveness. At the very least, the budgets of the science agencies have certainly become less discretionary and *pro forma* in the face of greater political scrutiny.

Not only have budgetary politics changed, but there are indications that the nature of science and technology policymaking may be changing as well. Throughout most of the post-war era, U.S. policies regarding science and technology have constituted little more than a pluralistic sum of the parochial interests of the Departments of Defense, Agriculture, and Commerce as well as the National Science Foundation and NASA. Lambright observes of science and technology policymaking in the United States:

> There is certainly no general, overarching, long-range course-setting for the federal government as a whole in R&D affairs. That kind of policy does not exist. What constitutes the reality of policy is more a combination of initiatives, mostly from the agencies, but occasionally from central political authority. This sum-of-the-parts policy may be called *de facto* to distinguish it from more *strategic* approaches. (Lambright, 1976, p. 183)

He adds:

> Technoscience agencies decide which science and technology programs to support and their relative priorities...Higher authority may reject, delay,

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[6]With more than 500 state and local science and technology-based development initiatives, it is clear that these governments see science and technology as a way of stimulating their economies. The delivery of science and technology pork to home districts is certainly not inconsistent with, and may be partly driven by, the new economic development strategies that are emerging in local governments.

question, or even change administrative policy, but it usually begins where the agencies leave off. Technical, programmatic judgements and advocacy start at the administrative levels. These technical, programmatic judgements, however, are the crux of policy in R&D. These "small" decisions aggregate into the big decisions that set the course of overall government. (Lambright, 1976, p. 202)

The *de facto*, ground-up pluralism of science policy appears to be giving way to the immediacies of presidential and congressional leadership. With the growing salience of the competitiveness crisis came the need for more "visible" policymaking--crisis politics typically requires reaction by the highest levels of government. As a result, priorities of the Congress and the President have been imposed in top-down fashion on the federal science community; an uncharacteristic amount of science and technology-related legislation, executive orders, presidential initiatives, and task forces have all served to remove agenda-setting power from the hands of the technoscience agencies. Not only has the agenda been set for the agencies by the circumstances of economic events and the President's budget relevance tests, but nascent "strategic" management the federal science and technology establishment continues to place the technoscience agencies in a reactive mode.[7]

The Confluence of Paradigm, Politics, and *Laissez-faire*

Needless to say, the capacity of the federal government to effect change in many public policy arenas critical to the nation's competitive position has been severely constrained the past decade. The ability to enact change in human and intellectual capital through national education policy and workforce training programs confronts long-standing political conflicts and traditions in both education and labor policy. Our national decision-makers seem incapable of addressing both the competitiveness crisis and the looming budget crisis through fiscal policy; reducing the federal budget deficit appears impossible in spite of the long term financial and banking implications of the sustained debt burden. Similarly (and an issue that will be discussed in the next chapter), U.S. macroeconomic policy has never been designed to stimulate long-term economic growth and productivity, and there is ongoing dispute over its

[7]Strategic science and technology policymaking is undoubtedly too strong a word for the congressional and executive activities of the 1980s since it implies interrelated and purposive planning items. However, it does convey the weakening grip on agenda-setting that the agencies have experienced because of greater policy interference and initiative by the Congress and the executive branch.

role in the crisis itself.[8] Finally and more to the point, the government's financial situation prohibits solutions that involve "throwing money" at a problem.

The combined necessity for relatively costless and politically expedient policy options virtually dictates that the government's attention be directed towards policy arenas that are one or the other, and ideally both. The burden of restoring national competitiveness was consequently left to U.S. science, regulatory, and trade policies, arenas where policy activity does not require too much in the way of federal expenditures, but also ones which claim to speak to the crisis itself. Since both public and private sector leadership seem to hold a rather genuine conviction that U.S. innovative capacities are seriously wanting, there was a further concentration of attention and policy effort on both the science and technology arena and science and technology-related components of trade and regulatory policies. Smoothed by the precedent set by the Carter Administration, science and technology in effect represented the path of least resistance for crisis policymaking because of the (not unfounded) predisposition to regard innovation as the root of economic progress, and the fact that science and technology issues are the least politically fractious of science, trade, and regulatory policies.

In sum, the arena location and science and technology orientation of U.S. competitiveness policies was initially determined by the need to respond "quickly" to the crisis; fast, at least, in the world of government. Many seemingly appropriate arenas (education, labor, economic policy) were closed off because of requisite costs and/or their entrenched politicization--no timely response could reasonably be considered forthcoming. Other policy choices--especially fiscal, most trade, and some monetary--were not viable because of congressional and presidential paralysis or idealogy. Science and technology became the object of government policy energies because they possessed the virtues of the policymaking holy trinity: initiatives were practically costless in budgetary terms, the arena was void of intractable political conflict, and they seemed to be *a truly appropriate* solution to the problem at hand.

This is not to impart a hyper-rationality to the policymaking process, but to illustrate how policy arena and policy substance can be somewhat epiphenomenal to the politics of choice. Nor can the homing in on science and technology that resulted be divorced from what

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[8]Unlike other nations, particularly Japan, U.S. macroeconomic policies have evolved to manage short-term fluctuations in the business cycle, inflation, and unemployment. Alternative goals for macroeconomic policy include, for example, long term growth, productivity, and structural adjustment.

was happening within the science and technology arena itself; the technoscience agencies' budgetary exploitation of the competitiveness crisis undoubtedly served to further attract policymaking attention to science and technology and to validate assumptions about the role of innovation in the economy. Crisis policymaking and bureaucratic budget wars were thus mutually reinforcing, creating a sort of centripetal force of competitiveness policies centered around science and technology solutions.

But why the supply orientation once within the science and technology arena? Why not science, technology, and innovation policies that are directed toward the utilization of science and technology, toward making private sector innovation more economically effective? Although science and technology are key elements of technical change, they are by no means exclusive requirements, and as will be explored in the next chapter, the competitiveness crisis could just as easily be caused by innovation bottlenecks and market structures. So why the preoccupation with the supply and flow of scientific research? For this dimension of competitiveness policies we have to look back to the influence of the science policy paradigm and the *laissez-faire* tradition in American science and economic policies, since both act to preclude "demand" (or more properly, market) factors from policy consideration.

As discussed at length in the previous chapter, the science policy paradigm distorts our analysis of economic problems in two ways. First, while accurately noting the role of innovation in the long-term social and economic welfare of a nation, the paradigm privileges the role of basic research in this process by reducing innovation to changes in the stock of scientific knowledge. Second, the linear model of innovation, by virtue of its thesis and logical construct, effectively proscribes us from seeking (or seeing) alternative "sources" of innovation. Paradigmatic reductionism and linear determinism constrain problem-solving by essentially predetermining the root cause of economic performance. Decision-makers who work from within this construct could scarcely come up with alternative explanations of economic well-being.

The *laissez-faire* tradition intensifies this scientific and technological supply-sidedness by making it improper for government to involve itself in utilization issues, scientific or economic. For all three of the main constituencies of federal science policy--the technoscience agencies, the private sector, and the scientific community--there is a committment to obtaining certain services from the federal government, whether it be budgets, a less restrictive set of economic policies, or research funding. In each case there is a premium on *laissez-fairism;* all carefully guard their ability to conduct business relatively independent of direction by the state (or in the case of the bureaucracy, from Congress and the White House).

The technoscience agencies (especially those with substantial basic research programs) and the scientific community protect their autonomy by advancing a paradigm in which *basic* research--research not capable of lay control--is conceived as the essential precursor to technological change, and hence, economic progress. It is no coincidence that the National Science Foundation has only 5 line items in its authorization budget. The private sector, in comparison, achieves greater independence by arguing that 1) technological innovation is the solution to the competitiveness crisis, and 2) its ability to innovate is hampered by government regulations which obstruct R&D and innovation. The net result of the natural attraction to science and technology, paradigmatic reductionism, and the *laissez-faire* tradition is *an overstatement of the impact of technological change on competitiveness and the role of scientific research (whether publicly or privately generated) in creating that change.*

Policy solutions to the competitiveness crisis were thus bounded and defined by the interaction of political events, vested interests, and the science policy paradigm. Parameters on the scope of policy alternatives were quickly set by the demands of crisis policymaking and the ascendance of higher order politics. Solutions--of necessity--had to be relatively quick, costless, and politically expedient. This ruled out many appropriate policy arenas; by establishing the science-technology-competitiveness linkage in the late 1970s, the Carter Administration created the path of least resistance to the science and technology arena, a direction reinforced by the American predisposition to view science and technology as the precursor to social and economic well-being.

Policymaking attraction to science and technology was further intensified by the budget rhetoric of the technoscience agencies, especially the NSF. Forced to provide competitiveness rationales for their activities, the agencies responded with rather classic (and elegant) arguments on the role of science and technology in the economy. Once fully captured by the science and technology arena, policymaking energies were confined to fostering the supply of science and technology, with a particular emphasis on basic research. Vested interests in *laissez-faire* treatments curbed government encroachments on industry and science, but also complemented government's own self-restraint and aversion to "industrial policy" and "picking the winners". The supply-oriented policy prescriptions to the competitiveness crisis are consequently well-suited not just to the constituencies involved, but also to to the state's own needs; that is, government can show decisive (and claim effective) policy action in policy arenas where it has politically acceptable and well-defined responsibilities.

In short, the U.S. government gives the appearance of a rational response to the competeiveness crisis because its solutions are coherently framed by a supply-sided science and technology orientation. Since the language and rhetoric of competitiveness policymaking *consistently* reflects the language of the science policy paradigm and the linear model of innovation, policymaking seems to be informed by and responsive to these approaches to science, technology, and the economy. While such policymaking "rationality" may indeed be predisposed by the dominant paradigm in science policy, there does appear to be an extraordinary social and governmental empathy with this perspective. More likely than not, though, this rationality is epiphenomenal to the interplay of ideas, interests, and constraints in the federal decision-making environment.

The Policy Response to Competitiveness

The U.S. policy response to the competitiveness crisis may be characterized by either its substance or its objectives. On the one hand, policy efforts have concentrated on basic research, technology transfer, and fostering industrial R&D; on the other, these substantive concerns also reflect implicit goals regarding the stock and flow of scientific and technological knowledge, especially for the purpose of stimulating industrial innovation. It is probably reasonable to argue that competitiveness policy contents and objectives are remarkably substitutable, largely because the language of each has historically been synonymous–knowledge stocks with basic research, flows with technology transfer, innovation with industrial R&D.

As will be illustrated below, the government's competitiveness policies represent a rather unified set of initiative that try to foster the supply and flow of public and private sector research. The policies themselves cluster into three main groups regarding basic research, technology transfer, and incentives for private sector innovation. There is also a complementary set of "techno-nationalist" activities; these are essentially protectionist measures to curtail the flow and accessibility of U.S. science and technology to foreign economic competitors. Techno-nationalism also reveals the primacy of the "supply orientation" in the official policy responses to competitiveness; that is, the assumption that the supply of scientific and technical information is a primary determinant of U.S. competitiveness. U.S. efforts to transcend the limitations of this supply orientation--namely through technology policy--are the least well-defined, most limited in scope, and most politically fractious of the competitiveness policy initiatives.

Basic Research

The principal budgetary response of the federal government to the competitiveness crisis has been increased funding for basic research--57% in real terms from FY81-89, and 28% in real terms during FY84-89. These funding boosts have been accompanied by considerable rhetoric regarding the association between science and technology (or basic research) and competitiveness:

> The health of American basic research is critical in an era when international competition increases industry's need for scientific advances. Basic research must be made a high national priority....The government must maintain a continuing commitment to basic research in order to provide the necessary underpinnings for innovative technologies. (Business Higher Education Forum, 1983, 9-10)

> Any society that wishes to remain competitive in the modern world must...support basic research. (Bloch, 1986, p. 4)

> Coretech was established in 1987 to develop and implement a public policy agenda that fosters basic and applied research, and hence, U.S. competitiveness. (Coretech, 1987, p. 12)

> The ability of U.S. firms to compete in world markets depends critically on their ability to continually generate new ideas and use new technologies. To remain competitive, the United States must remain at the cutting edge of science and technology and adopt and implement the new technology developed. (NGA, 1987, p. 6)

> Our science and technology base has been and currently remains a source of special U.S. strength and leadership in economic performance and international competition. (National Science Board, 1988b: ii).

> Basic research provides new knowledge which has the potential to improve our quality of life and to increase the contribution of science and technology to the national goals of improved economic competitiveness and a strong national defense. (White House Office of Public Affairs, 1988, p. 5)

> President Reagan believes basic research is the passkey to the future. (White House Office of Public Affairs, 1988, p. 4)

> Basic research performed at universities serves the dual role of providing new knowledge and helping to ensure the future availability of high caliber scientists and engineers. Both of these are key elements in the long-term ability of the nation to compete in global markets. (Office of Management and Budget, 1989, J-9)

While rhetoric may be in part self-serving, there does seem to be some underlying conviction to these beliefs. In a national survey of R&D officials, the National Governor's Association found that nearly 60% of the industrial respondents and 72% of the university respondents believed increased support for university-performed basic research was critical to the competitiveness of the U.S. economy (NGA, 1987, p. 21). Not only is university-performed basic research thought to be significant, but industrial basic research is as well:

> Increased basic research in the industrial sector is crucial to the long-term well-being of our industries, and combined with improved manufacturing technology, it will provide the foundation for a healthy and competitive American commercial enterprise.[9]

Such assumptions in turn lead to strong reactions to business phenomena; the spate of leveraged buyouts (LBOs) and mergers that have taken place in corporate America are being questioned not only for their financial soundness, but for their impact on R&D. As Skrzycki concluded, "the ultimate fear [about LBOs] is that a decline in long-term basic research will further erode America's competitiveness" (1988, H1).

The perceived criticalness of basic research to U.S. competitiveness promoted the funding thrust in federally-funded basic research, with support of the NSF acting as hallmark of government basic research policy.[10] This focus on basic research did not begin early in the Reagan Administration, but rather in FY1984 when "basic research...came to be viewed as essential to economic competitiveness" (Teich and Gramp, 1988, p. 19). The Administration consequently made a verbal commitment to increased federal funding of basic research, which rose 28% in real terms from FY1984-89, slightly more than the 24% growth in the R&D budget

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[9]National Science Foundation (1988c), "NSF/OMB Workshop on Basic Research in Industry," Final Report, p. iv. Note that the above statement is a summary of industrial leaders' opinions, not of NSF or OMB.

[10]For example, Teich and Gramp (1988) observe: "In subsequent years, favored treatment...for basic research...developed into an important policy focus for the Reagan Administration, undergirding its efforts to bolster the nation's international competitiveness NSF [is] regarded as the centerpiece of the Administration's basic research program" (pp. 4, 8).

as a whole. However, as table 3.1 shows, the Reagan Administration does not appear to be substantially different in its treatment of basic research than previous administrations: basic research as a percentage of total federal R&D obligations has been increasing steadily since 1965. Nevertheless, real increases in federal obligations for basic research have grown more rapidly during the Reagan era than in previous years.[11]

Part of the Administration's pledge to support basic research was also a promise to double the budget of NSF between FY1988-92. Barfield notes about this focus on NSF that, "the Agency is the beneficiary of politicians' concerns about the nation's other deficit--in its international trade accounts--and about the ability of American companies to compete in world trade....Improved science, technology, and innovation in commercial products and processes are the keys to improved competitiveness, in the view of the White House and Congress, and they are looking to NSF to lead the way" (1988, p. 22). However, in a telling comment about NSF's ascendance in the 1980s, one congressional science and technology staff offical noted "NSF's budget got on the fast track on Capitol Hill because Bloch tied it to the competitiveness issue. It was a brilliant maneuver" (Lepkowski, 1989, p. 22). In an even more jaded observation of NSF's budget windfalls, one NSF official commented "when you're asking for the kind of increase we want, you've got to be able to show Congress and the American people that there will be an economic payoff somewhere down the line" (Barfield, 1988, p. 26).

NSF's selling of basic research obviously worked, since the agency is now in its "second of only two periods of extended real growth", the first being the post-Sputnik era of 1958-68 (NSF, 1988b, p. 5). The second period began in 1983, and research funding for NSF increased 38% in real terms from FY1983-88 (NSF, 1988b, p. 19). Although NSF's annual budget increases were not enough to double the budget by FY1992, the Bush Administration has reaffirmed the commitment of President Reagan and the OMB and will try to achieve this goal by FY1993.[12] The Bush budget for NSF is one-third larger than Reagan's for FY1990.

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[11]Obviously, some credit for these funding increases must be given to the Congress as well. Note, however, that Congress has systematically cut the R&D provisions of OMB's budgets and in recent years has subjected the technoscience agencies to far greater budget scrutiny and interrogation that has traditionally been the case.

[12]The NSF budget has not doubled--in spite of the proposed OMB budgets--because Congress will not provide the requisite increases.

Table 3.1-Trends in Federal Obligations for Basic Research
(constant 1982 billion dollars)

YEAR	BASIC RESEARCH OBLIGATIONS	BASIC RESEARCH AS A PERCENT OF TOTAL R&D OBLIGATIONS
1960	$1.93	7.9%
1961	$2.54	8.8%
1962	$3.13	9.7%
1963	$3.68	9.6%
1964	$3.93	9.2%
1965	$4.15	9.6%
1966	$4.61	10.5%
1967	$5.01	10.9%
1968	$4.84	11.3%
1969	$4.85	12.2%
1970	$4.58	12.4%
1971	$4.58	12.9%
1972	$4.78	13.3%
1973	$4.55	13.1%
1974	$4.60	13.8%
1975	$4.52	13.7%
1976	$4.51	13.5%
1977	$4.92	14.0%
1978	$5.16	14.3%
1979	$5.39	14.9%
1980	$5.55	15.8%
1981	$5.36	15.1%
1982	$5.50	15.1%
1983	$6.14	16.7%
1984	$6.47	16.2%
1985	$6.99	15.8%
1986	$7.07	15.4%
1987	$7.63	16.0%
1988	$7.81	16.2%
1989	$8.28	16.7%
1990	$8.47	16.6%

Source:Office of Management and Budget,1989,p.J-16

In spite of this growing financial support for basic research, there is an understanding on the part of policymakers that increasing the volume of basic research will not be entirely sufficient for greater economic competitiveness and innovation. Concommitant with the emphasis on basic research has therefore been an assumption that the flow of knowledge from the providers of basic research (government and universities) to the practical users of this knowledge (industry) must increase. As the perceived "acceleration" of technological innovation continues, then greater technology transfer and research cooperation between industry, government, and academia must occur:

> The relationship between academia and industry is different. No longer is research at arms length from application in many fields--biotechnology, computers, materials science, and many others.[13]
>
> The pace of development is accelerating very rapidly. We need to transfer knowledge between universities and industries much faster and better than we usually do. (Bloch, as quoted in Broad, 1988, C1)
>
> One response to the [blurring of basic and applied research] has been the creation of new institutional relationships between businesses--the primary users of research--and universities, where most basic research occurs. (NGA, 1987, p. 23)

Government's attention to fostering the stock of basic scientific knowledge is consequently coupled with a concern over encouraging an adequate flow of this knowledge from the providers to its users. This process, known as technology transfer, relates to the movement of scientific and technical information from one organization to another.[14]

Technology Transfer and Cooperative R&D

The technology transfer policies of the federal government have largely centered on moving the knowledge generated by the federal laboratory system to the private sector. This emphasis has resulted in requiring the labs to improve their information dissemination activities--getting the information "out the door"--and on altering intellectual property laws in

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[13] Erich Bloch, Director of NSF, as quoted in "Erich Bloch: On Changing Times and Angry Scientists at NSF," *Physics Today*, August, 1988: 48.

[14] More specifically, technology transfer is defined as "the process by which technology, knowledge, and/or information is developed in one organization, in one area, or for one purpose is applied and utilized in another organization, in another area, or for another purpose" (Congressional Research Service, 1988, p. 7).

order to overcome private sector inhibitions about using publicly-generated knowledge and technology.[15] To a lesser extent, the policies have also tried to promote more extensive collaborative R&D among the government, industry, and university research sectors. The government's focus on federal laboratories is based on the presumption that:

> The federal laboratory system has extensive science and technology resources developed as a consequence of meeting the mission requirements of the Federal departments and agencies. It is a potential source of technology, technical expertise, information, and state of the art facilities which can be utilized in the business community and other government entities. In particular, a portion of the knowledge, technologies, and techniques may have commercial application....The ongoing pursuit of science and technology [in the federal labs] has created technologies which may have applications beyond their original use in meeting the mission requirements of the Federal departments and agencies. (Congressional Research Service, 1988, pp. 7, 9)

More simply put, "The federally funded laboratories are being ordered to the front in the trade wars with Japan and Western Europe. The current trade crisis has spawned a political campaign for 'technology transfer'--finding commercial uses for technology developed inside government laboratories" (Charles, 1988, p. 874).

Although technology transfer wasn't an explicit mission of the federal laboratories prior to the 1980s, they are nevertheless being severely criticized for failing to do so in significant amounts:

> The public is being ripped off; it isn't getting its money's worth from federal research because there aren't good mechanisms of technology transfer. (Roger Ditzel, Director of University of California Patent Office, as quoted in Charles, 1988, p. 874)

> The Department of Energy labs are a huge treasure and storehouse of knowledge and science...but their record of traceable new products spun off is so small that one would think they're not charged with doing it. (Senator Pete Domenici, as quoted in Charles, 1988, p. 874)

> We're talking about several hundred federal labs, doing basic and applied research on everything from cancer cures to the development of better building

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[15]For a discussion of the "out the door" model of technology transfer, as well as the other dominant conceptualizations of technology transfer for the federal laboratories, see Barry Bozeman and Maureen O'Neill Fellows, "Technology transfer at the U.S. National Laboratories: A Framework for Assessing Policy Change", undated working paper, Technology and Information Policy Program, Syracuse University.

materials. And yet the revenue stream to the government from commercialized patents last year was less than $4 million. Something is simply not working.[16]

The result of [barriers to technology transfer] has been frustrated government scientists who can't commercialize their inventions, discouraged businesses who can't get at valuable technologies and penalized taxpayers who have lost untold millions of dollars in unrealized licensing and royalty revenues.[17]

In response to such concerns and expectations, there has been an active legislative record during the 1980s regarding the transfer of new knowledge and technology from the federal laboratories to the private sector. Although technology transfer occurred prior to the passage of the relevant statutes, they did provide the first legislative mandate for laboratories to pursue technology transfer activities and charged the Federal Government as a whole with ensuring "full use of the results of the Nation's Federal investment in research and development".

Principal among the legislation are the Stevenson-Wydler Technology Innovation Act (P.L. 96-480, 1980) and the Federal Technology Transfer Act (P.L. 99-502, 1986) which create mechanisms through which the federal agencies and their laboratories can transfer technology.[18] The legislatively-mandated programs and activities involve establishing offices of research and technology applications in all federal labs meeting a certain budget threshold, the creation of the Federal Laboratory Consortium for Technology Transfer, the creation of a more (but note completely) conducive legal environment for joint public-private R&D ventures (cooperative R&D), the revision of intellectual property laws regarding research performed in and funded by the federal government (see below), and provisions regarding federal employees and their private business activities. Additionally, Executive Order 12591 (1987), "Facilitating Access to Science and Technology," reiterates many of the provisions of the Federal Technology

[16]Stated by Congressman Ron Wyden (as quoted in "Staff Paper Criticizes Federal Laboratories' Tech Transfer," *The Wilson Report on Material Policy*, vol. 2, #9 (October 13, 1989).

[17]Internal staff report of the U.S. House of Representatives, Small Business Subcommittee on Regulation, Business Opportunities, and Energy (as quoted in "Staff Paper Criticizes Federal Laboratories' Tech Transfer," *The Wilson Report on Material Policy*, vol. 2, #9 (October 13, 1989): 1).

[18]For a good summary of the scope and details of federal technology transfer legislation and executive orders, see Congressional Research Service, *Commercialization of Federally Funded R&D: A Guide to Technology Transfer from Federal Laboratories* (Washington, DC: U.S. GPO, 1988).

Transfer Act and related patent laws, but also directs each agency and department to promote cooperative R&D efforts for the purpose of "transfer[ring] technology to the marketplace".

As implied by Executive Order 12591, there has been a secondary technology transfer emphasis on greater university-industry-government research collaboration, largely out of the conviction that one of the best mechanisms for technology transfer is people-to-people contact. Moreover, it is believed that promoting greater research collaboration between universities, government, and industry will make basic research more responsive to the strategic research needs of industry. In the world of scientific research, it is now assumed that some basic research may be *more practical* that others.

Executive Order 12591 directed all of the federal agencies to promote collaboration between federal laboratories, universities, the private sector, and state and local governments to the extent that such collaboration does not violate existing law. Patent laws and laboratory policies were revised to allow such cooperation with the federal labs; new research institutions such as NSF's university-based engineering research centers and science and technology centers have also been developed.[19] These centers are organizations in which researchers from academia and industry may conduct interdisciplinary "strategic" basic research and are a direct response to the competitiveness crisis:[20]

> The basic research 'targeted' toward competitiveness which the centers will sponsor is a necessary supplement to NSF's more traditional support of the individual researcher. (NSF official, as quoted in Barfield, 1988, p. 26)
>
> Centers can contribute to the nation's economic competitiveness by advancing the frontiers of knowledge; providing the opportunity for timely exploitation

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[19]Typical of new policy-oriented organizations responding to the call for greater university-industry-government cooperation is the Government-University-Industry Research Roundtable of the National Academy of Sciences, established in 1983 "to improve the productivity of the nation's research enterprise [by] foster[ing] strong American science through effective working relationships among government, universities, and industry" (Government-University-Industry Research Roundtable, 1989).

[20]NSF's new centers have been vigorously, vehemently, and angrily opposed by members of the scientific community. The belief is that the centers will jeopardize the funding base for individual (principal investigator) scientific research. NSF's official response has been consistent: the centers will not divert funds from the budget for individual research grants and are a neccessary development in scientific research in this country, from both a cost and disciplinary perpective.

of new discoveries; and accelerating the application of new knowledge to the resolution of economically important problems. (National Academy of Sciences, 1987, p. 1)

Within the policy framework for greater technology transfer and inter-sector research collaboration is a rather explicit recognition that the federal government is not in the business of commercialing technology. Government understands its proper role to be only in the supply of scientific knowledge and, to a lesser extent, technology. Exploitation of this knowledge is clearly the domain of the private sector:

> The federal goverment does not have the authority or capability to develop, refine, adapt, and market the results of...research and development beyond legitimate government mission objectives--thus the expanding interest in transferring technology to the private sector which has the resources to undertake commercialization activities....Commercialization is the responsibility of the private sector. (Congressional Research Service, 1988, pp. 7, 8).

The government has, however, taken only limited steps to aid the industrial sector in its commercialization efforts. Other than making some changes in U.S. intellectual property rights, government policy relating to industrial innovation/commercialization has been limited to measures which offer greater incentives for privately-conducted scientific research.

Incentives for Private Sector Innovation

Consistent with the government's preoccupation with the supply and flow of basic research from the public to private sector is its concern over the supply of basic (and to a lesser extent, applied) research emanating from the private sector itself. In an effort to stimulate the production of industrial and industrially-sponsored basic research, government policies have attempted to alter the private sector's incentive structure to encourage more R&D. Focusing largely on taxation, regulatory policies, and intellectual property rights, the government has tried to remove those barriers which act as disincentives to private research investment and technological innovation.[21]

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[21]Note that the policy prescriptions discussed in this section are bounded by those advocated by industry itself. See, for example, The Young Report (1985), NSF (1988c), and the testimony of participants at recent Congressional hearings on 1) "The Role of Science, Technology, and Education in the Creation of New National Wealth" (House Committee on Science, Space, and Technology, April 11 and 12, 1989), and 2) "Adequacy, Direction, and Priorities for the American Science and Technology Effort" (House Subcommittee on Science, (continued...)

Tax Credits.--In order to increase private sector R&D expenditures, the Economic Recovery Tax Act of 1981 introduced a 25% Research and Experimentation (R&E) tax credit for incremental increases in corporate R&D expenditures. This tax credit was later modified and extended by the 1986 Tax Reform Act; at the same time, the Act instituted a temporary basic research tax credit as part of the 1986 Tax Reform Act. The basic research tax credit is somewhat more generous than the R&E credit since it is not incremental and allows a fixed deduction for total expenditures as long as these expenditures exceed a defined base; however, the credit may only be taken for research funded--but not performed--by the firm itself. The basic research tax credit was designed to encourage industrial funding of university (and other non-profit) research.

The intent of the revisions in the tax code--by encouraging private sector R&D expenditures--is to increase the knowledge base from which commercial innovation may draw.[22] As the Council on Research and Technology (CORETECH) reported:

> By adopting the new [basic research] credit, Congress sought to encourage U.S. competitiveness through technological innovation and to speed the process by which new ideas are discovered by university researchers and translated by U.S. companies into new products or industrial processes. (CORETECH, 1987, p. 2)

Both the R&D tax Credit and the basic research tax credit expired at the end of calendar year 1990, although the Congress is still considering making these provisions permanent features of the tax code.

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[21](...continued)
Research, and Technology, February 28 and March 1, 1989). Summaries of the testimonies may be found in NSF, *Congressional Report*, March 1989 and May-June 1989. The two notable disjunctures between industry's recommendations and the government's policy response is in government's failure to respond to repeated calls for a reduction in the U.S. cost of capital, which is now estimated to be three times that of Japan, and to improve the quality of U.S. education and the workforce.

[22]While the incremental R&E tax credit may aid the commercial introduction of innovations (90% of all industrial R&D is development, not research), many dispute the impact of this credit. Some (like Lewis Branscomb of Harvard University) argue that companies think they are already spending about the right amount on R&D, and incremental increases are not likely to result from the credit. Others also argue that there is a perverse impact of the credit: it would cause firms--in the short run--to decrease their R&D expenditures in order to decrease the base against which incremental increases are assessed.

Antitrust Revisions.--One aspect of U.S. perceptions of unfair Japanese competition is that industrial firms in Japan can form research consortia and joint research projects to overcome the risk and cost disincentives associated with frontier, equipment-intensive basic research. Until recently such cooperative activity has been prohibited in the U.S. by antitrust laws. However, the National Cooperative R&D Act of 1984 (NCRDA) relaxed these restrictions and allows groups of companies to collaborate on R&D by giving them special dispensation from certain provisions of the antitrust laws. The NCRDA does not protect companies participating in a consortia or joint venture from antitrust law suits; rather, it limits legal claims to actual, instead of the normal treble, damages in a successful antitrust suit. It is hoped that the the resultant research activity--namely through consortia and joint ventures--will allow certain industrial sectors to gain a competitive edge over foreign rivals by enabling them to develop "industry-led" new technologies. At present, the semiconductor, machine tool, micro-electronics, and optoelectronics industries have research consortia and dozens of others have registered joint research ventures with the Department of Commerce.

A number of bills have been introduced to Congress which would expand the NCRDA to include not just R&D, but joint production, distribution, and marketing ventures as well. Other proposed legislation would further revise antitrust law so that with the joint approval of the Department of Justice and the Federal Trade Commission, approved joint research ventures would be exempted from all civil and criminal suits for activities performed under the scope of the agreement.[23]

Intellectual property rights.--Intellectual property rights are understood to be critical to U.S. competitiveness because they provide incentives to invention and technological innovation. One of the basic principles of industrial innovation is that firms and inventors must be able to appropriate the fruits of their intellectual property before they will attempt to commercialize it. Otherwise, because of the characteristics of public goods, the inability to exclude others from the economic use of knowledge will act as a disincentive to both research and commercialization. Through intellectual property laws, intangible ideas get translated into private goods by legally empowering the inventor or creator with their exclusive use. By "owning" such proprietary knowledge, the inventing firm/individual can recoup the research

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[23]For a discussion and listing of this pending antitrust legislation, see NSF, *Congressional Reports*, April-June 1989.

costs of the innovation and therefore has an incentive to commercialize it by virtue of being able to realize sufficient profits on the research investment.

Evaluations of the U.S. intellectual property system[24] have resulted from concerns about 1) the degree to which the existing system is capable of assuring exclusive use of intellectual property, 2) the ability of the existing system to even *grant* exclusive privileges to emerging technologies like biotechnology and new materials, and 3) the public good nature of intellectual property owned by the federal government. Substantial debate and discussion have centered on such issues as loopholes which limit protection for computer software, genetically engineered microorganisms, and semiconductor circuitry; the adequacy of punitive measures against foreign infringement and expropriation of legally protected intellectual property (leading to "counterfeit" or "pirated" goods); and the inability of private actors to appropriate technology generated by the public sector.[25] At the heart of these issues is concern over the ability of the intellectual property system to provide sufficient protection given the current nature and rapid pace of technological advance. For example, the product life cycle of semiconductors can be shorter than the length of time necessary to acquire a patent; similarly, many new fields of technology imitate science more than they do art, they are not traditionally protected by the system.[26]

The federal government's policymaking with regard to intellectual property rights has not come to terms with many of the more difficult issues underlying protection and competitiveness. Instead they have focused largely on the transfer of ownership of public domain property (e.g., patents owned by the federal government or discoveries made through public funding) to the private sector out of the belief that private ownership will act as an

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[24]The intellectual property "system" is composed of laws and legislation relating to patents, trade secrets, copyrights, trademarks, and any other measures (such as Congressional protection of semiconductor "mask works") which assign exclusive rights of ownership to ideas, writings, and discoveries.

[25]For a comprehensive and excellent discussion of most of the issues relating to intellectual property rights to advanced technologies, see the Young Report (1985), Appendix D, "A Special Report on the Protection of Intellectual Property Rights."

[26]In the language and structure of the U.S. intellectual property system, scientific knowledge is typically considered to be intangible and consequently not appropriable. "Art" on the other hand refers to the design of something that is physically possible to make--a tangible object--or the process of making such objects.

incentive to commercialization. These, as well as other major initiatives, are summarized below:

- The Bayh-Dole Act of 1980 gave universities, nonprofit institutions, and small businesses the option to retain title of ownership to inventions made using federal funds, and a 1983 Executive Order extended these provisions to other businesses to the extent that existing laws are not violated.

- Amendments to the Stevenson-Wydler Technology Innovation Act of 1980 allow all companies to retain title inventions resulting from research performed under cooperative agreement with federal labs.

- The Patent Term Restoration Act of 1984 restores 17-year property protection for new pharmaceuticals, medical devices, and food additives that "lost" years of protection due to federal premarketing regulatory procedures.

- Efforts are underway to improve the administrative efficiency of the U.S. Patent and Trademark Office by assuring it relatively stable funding and automating its activities; the processing time for nearly all patent applications is now down to 2 years.

- The U.S. is working with the EC and Japan to harmonize the various national patent systems so that maximum international patent protection is afforded to all inventors of all countries.

- The Omnibus Trade and Competitiveness Act of 1988 amended the authority of the International Trade Commission and the USTR to allow self-initiation of trade investigations for "denials of adequate and effective protection of intellectual property rights" which have an adverse impact on U.S. trade and/or deny the U.S. access to foreign markets.

While most of these efforts involve injecting more rigor into the existing system, there are problematic issues which continue to go unresolved. As the Young Report concludes:

> The continuing stream of new scientific advances calls for rethinking the very concepts derived from earlier centuries on which those intellectual property rules are based. New concepts of what intellectual property is and how it should be protected--beyond patents, trademarks, trade secrets, and copyrights--may well be needed, as may sweeping changes in intellectual property laws and the ways they are administered and enforced. (p. 305)

Techno-nationalism

Perceptions that the supply of scientific and technical knowledge drives American competitiveness and that foreign competitors have unduly profited (at American expense) from

U.S. science and technology have resulted in somewhat ominous activities relating to foreign access to U.S. scientific and technical information. The United States, in conjunction with its efforts to stimulate the supply of scientific and technical knowledge, has also directly and indirectly sought to stem foreign access to such knowledge. Techno-nationalism has revealed itself through policy studies, government action, and in the case of Japan, in U.S. efforts to obligate the Japanese to contribute their "fair share" to the world's stock of scientific knowledge. In essence, techno-nationalism derives from an understanding that science and technology are contributors to international comparative advantage and that by curbing the *supply* of that knowledge to other nations, the U.S. can retain its comparative advantage in trade.[27]

The U.S. has both formally and informally tried to restrict access to its science and technology knowledge base. Informally, there is the superconductor incident, an occasion when the Reagan Administration excluded foreign science and technology officials and researchers from a 1987 Washington meeting on superconductor research. The conference was sponsored by OSTP, four federal agencies, the National Academy of Sciences and the National Academy of Engineering; curiously, the foreign press was allowed to attend. As was noted in *Science* magazine, "the motivation apparently was to deny information to America's competitors in trade."[28]

More formally, techno-nationalism has shown up in threats to ban the sale of Fairchild Semiconductor Corp. to Fujitsu, to boost (via Defense contracts and subsidies) the U.S. ball bearing industry, and to redefine the terms of the U.S.-Japan FSX co-production agreement. In these and other instances,[29] the intent was to deny foreign access to U.S. science and technology from which foreign competitors could profit, and/or to prevent any further erosion

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[27]For example, Frank Press, President of the National Academy of Sciences, stated at a recent Congressional hearing "Science and technology are our sole comparative advantage over the Japanese. Let's keep it that way" (personal notes from the Senate Budget Committee hearing on "Science, Technology, and Strategic Economic Policy," March 9, 1989).

[28]"Stumbling on Superconductors," *Science*, 31 July 1987, p. 477; see also Robert L. Park "The Superconductor Follies," *The Washington Post*, August 2, 1987.

[29]For example, the Federal Technology Transfer Act of 1986 prohibits federal laboratories from licensing their patents to foreign firms, and Sematech, the federally-sponsored semiconductor consortia, bans "non-U.S." companies from participation.

of the research base in critical technologies.[30] There is an undeniably *nationalistic* orientation in this approach to economic problems:

> The overriding goal...is to protect future American technological breakthroughs from exploitation at the hands of foreigners, especially the Japanese. This new principle presumes the possibility--indeed the necessity--of viewing American technology as a body of knowledge separate and distinct from that possessed by other nations. Technology is viewed as something that can be uniquely American--developed here, contained within the nation's borders, applied in America by Americans. It is like a precious commodity that we should save for ourselves rather than allow foreigners to carry off. (Reich, 1987, p. 66)

The techno-nationalist response to weakening U.S. competitive abilities is apparently to treat science and technology as a strategic raw material, a supply that should--and can--be domestically stockpiled.

Policymakers have likewise been concerned about the relative openness of the U.S. research system to foreigners and their use of that knowledge "against" the U.S. in international trade. Typical are the queries of the Congress:

> What are the implications of the quite open access we provide to foreign nationals to American universities and U.S. government labs? Should and can U.S. technological knowledge be protected from foreign competition? What are the implications of foreign companies supporting research in American universities? (U.S. House of Representatives, 1987, p. 9)

In this vein, the Senate requested the General Accounting Office to conduct studies of both U.S. universities and federal laboratories to evaluate the extent of foreign support of and participation in these R&D institutions.[31] Implicit in all concerns--including those over the high proportion of U.S. science and engineering degree recipients who are foreign nationals--is the belief that there is a wholesale relocation of "American" scientific and technological knowledge overseas. Foreign companies and countries are perceived to be subsidized at U.S.

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[30] In addition to worries over excessive dependence on foreign suppliers for critical defense-related products and components, much of the Defense Department's concerns about the decline in the U.S. bearing and semiconductor industries are over their ability to sustain a vital R&D program. As industries begin losing market shares and sales, they often cut their R&D operations, the very activities which would allow them to regain market share in the future.

[31] See U.S. GAO, *R&D Funding--Foreign Sponsorship of U.S. University Research* (Washington, DC: March 1988), and U.S. GAO, *Technology Transfer--U.S. and Foreign Participation in R&D at Federal Laboratories* (Washington, DC: U.S. GAO, August 1988).

taxpayer expense, or worse, as "buying out" the U.S. through its education system. Although quantitative evidence shows relatively little support for such "penetration" of the U.S. research system, the suspicions linger.[32]

Techno-nationalism does not represent a coherent set of policies as much as it does an emotional response to the leakage of American science and technology. Unlike other policy measures, it is an unpredictable and usually poorly justified prescription to the competitiveness crisis. It is, nevertheless, driven by a "gut feeling" that the supply of science and technology is critical to a nation's competitive abilities. With the exception of the more credible national security rationales, techno-nationalism seems irrational if only in the presumption that knowledge can be contained within national boundaries. Nonetheless, policy investigations continue on the impact of foreign access to U.S. science and technology, in spite of repeated assertions that openness is in the best interest of U.S. research and scientific advance (e.g., National Science Board (1988a).

Efforts at Technology Policy

To a very limited extent, the government has also undertaken efforts to promote specific technologies and industries. In addition to the rather widely known support of Sematech, the government has also "targeted" superconductors, supercomputers, fiber optics, HDTV, and advanced materials as technologies worthy of preferential treatment in federal policymaking. However, the nature of this targeting is limited and covers a range of seemingly innocuous policy recommendations and actions, including:

- the call for more R&D and a better coordinated research agenda in high Tc superconductors,

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[32]In my position at NSF, I was frequently contacted to provide quantitative evidence of this penetration, which invariably could never be substantiated. For example, the GAO found that less than 1% of U.S. university-conducted R&D was sponsored from overseas, and half of this amount was concentrated in 5 universities. Pearson (1988) notes that the significant majority (80%) of foreign PhD science and engineering students in the U.S. are supported from non-U.S. sources; even so, most of these students intend to stay in the U.S. (half of the science majors and nearly 60% of engineers). Moreover, most inquisitors were invariably disappointed to find out that very few Japanese students studying in the U.S. were engineering or science majors, and that Japanese researchers in the U.S. federal labs were no more intensively represented than the other industrialized countries (see Papadakis, 1989, and U.S. GAO, *Technology Transfer--U.S. and Foreign Participation in R&D at Federal Laboratories* (Washington, DC: U.S. GAO, August 1988).

- the formation of a Congressional caucus on advanced materials in order to develop national strategies for strengthening the domestic materials industry,

- the requirement by the Omnibus Trade and Competitiveness Act of executive branch technical reports on superconductivity, semiconductors, and fiber optics,

- proposals by President Bush and Senator Albert Gore for accelerated research on supercomputers and the creation of a national "superhighway" of supercomputer networks, and

- recommendations that the Department of Commerce provide R&D funding for and an industry-government consortium on the development and commercialization of HDTV technologies.

The Omnibus Trade and Competitiveness Act additionally attempted to refocus and redefine the federal government's responsiblities with regard to commercial technology development; the National Bureau of Standards was renamed the National Institute of Standards and Technology (NIST) and it's mission was augmented "to boost U.S. industry in the world marketplace" (U.S. Department of Commerce, 1988, p. 1).[33] The law specifically charged NIST to:

> Assist industry in the development of technology and procedures needed to improve quality, to modernize manufacturing processes, to ensure product reliability, manufacturability, functionality, and cost-effectiveness, and to facilitate the more rapid commercialization, especially by small- and medium-sized companies throughout the United States, of products based on new scientific discoveries. (U.S. Department of Commerce, 1988, p. 1)

Among other activities, NIST was instructed to 1) create a series of regional manufacturing technology transfer centers, 2) design a program to make federal technology available to state and local technology programs and extension services, and 3) establish an advanced technology program to encourage the commercialization of new high-technology products. However, in the Administration's Budget requests for FY89 and FY90, the new NIST programs have gone unfunded except for the regional Manufacturing Technology Centers, for which the Administration was proposing funding decreases.

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[33]The Reagan Administration has also reorganized the science and technology activities of the Department of Commerce into a new Technology Administration, headed by an Undersecretary of Commerce for Technology. Consolidated were the functions of NIST, the Office of Productivity and Innovation, the National Telecommunication and Information Administration, the National Technical Information Service, and the Office of Japanese Technical Literature.

The new, development-oriented activities of NIST are not the only programs to suffer from lukewarm political support. In spite of the fact that the above initiatives represent limited efforts to create what the Office of Technology Assessment calls "technology policy" ("a cohesive, focused strategy for developing [technologies] and applying them to commercial products"; OTA, 1988), several of these programs receive marginal institutional support at best. In essence, the debate is centered on whether or not these measures constitute "industrial policy" and whether it is the proper role of government to provide aid to specific industries.

In the area of technology policy, the U.S. is confronting a conflict between the apparent need for government contributions to the technological competitiveness of key industries and the traditional aversion to industrial policy.[34] This tension is complicated by a poorly defined role for the government in technology development, or what Greenberg calls the lack of a "clear focus of authority for federal R&D linked to industrial goals."[35] Indeed, the Congress itself admits:

> The proper role for the Federal Government in the process of fostering technology development is less well understood, defined, or accepted than its role in the support of scientific research....America does not have a formal and articulated policy for stimulating and guiding technology development. We do have numerous laws as well as many ingrained patterns and practices that govern the way that we envision, develop, and utilize technology. These guidelines and influences, viewed collectively, form an "ad hoc" national policy for technology. (U.S. House of Representatives, 1987, p. 3)

Perhaps in response to this ambiguity of authority over technology and the ad hoc nature of U.S. technology policy, there seems to be some dissatisfaction with U.S. science and technology policy on the part of industry. A survey of the membership of the Council on Competitiveness revealed that "while 48 percent of respondents felt that science/technology

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[34]Note that the objections to technology policy are not that these industries aren't in need of attention. The issue is whether or not "free market" dynamics are responsible for allocating resources and support among industries, however imperfect that process may be. However, many in government and industry *do* see a proper role for government in enhancing the development of specific technologies, largely out of an explicit recognition of the "non-linearity" of the innovation process and the limitations of translating science into product. See U.S. House of Representatives (1987, 1989).

[35]Dan Greenberg, "With More Rhetoric Than Money, Bush Nods to R&D," *Science and Government Report*, vol. XIX, #3, Feb. 15, 1989: 1-2.

policy is very important to America's ability to compete with other nations, only 1 percent rated government policy excellent in this area" (Council on Competitiveness, 1988, p. 7).

There are in fact persistent calls for a clearly-defined U.S. technology policy, one that recognizes that "the development of many new products and improvements in manufacturing methods result from incremental market demands, not major new breakthroughs in basic science" (Cordes, 1988, p. 1).[36] However, these efforts to make science and technology policy more "relevant" to the reality of industrial innovation are constrained by the traditional roles of government and private sector behavior. The incrementalism which the government is being asked to enhance is wholly within the development end of the innovation spectrum, an area explicitly outside of all but the most macroeconomic of government actions:

> Government's proper role in improving our competitiveness is to improve the context in which our industries compete and to help markets work better. (The Young Report, 1985, p. 6)
>
> The primary responsibility for commercializing technology in our society rests with the private sector. But...only the federal government can establish the economic environment...necessary to help put American industry back on the fast track of global competition. (Council on Competitiveness, 1989, p. 3)

What then, is the government able to do? In its quest for innovation/technology policy, the government has already built up an ad hoc tool box of policy measures, nearly all macroeconomic policies aimed at fostering a more attractive investment climate (see Averch, 1985; Rosenberg, 1976; OECD, 1981; U.S. House of Representatives, 1987). Except for intellectual property rights and until the very recent technology targeting, there really has been no special effort to either encourage development-oriented innovation or specific industrial technologies in the private sector. Yet industry is asking for technology policy that is more cognizant of the industrial innovation process and for more support in establishing national capabilities in advanced technologies (see U.S. House of Representatives, 1989, p. 31). At the same time, it holds government at arms length by arguing:

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[36]Representative of these calls for technology policy are the positions laid out in the Council on Competitiveness, *Picking Up the Pace: The Commercial Challenge to American Innovation* (Washington, DC: Council on Competitiveness, 1988). An articulation of the "incremental" model of innovation may be found in Gomory and Schmitt (1988). Note that this model challenges nearly all of the policymaking assumptions about the linear nature of the innovation process.

> Beyond establishing broad macroeconomic policies that help U.S. firms compete--from lowering the cost of capital to promoting world-class education and training--government should provide additional help judiciously.[37]

It would appear, then, that the call for technology policy is for a more rational application of existing tools, not for a significant departure from culturally acceptable government practice. Technology targeting--essentially the intensification of basic and applied research in particular technologies--will in all liklihood continue to be the result of the intersection between scientific and private sector interests, industrial lobbying, and defense needs--all tempered by the conflict over the proper role of government in this arena.

Although Mowery and Rosenberg (1989) argue that current technology policies do indeed focus on commercializing science and technology, and "are intended to accelerate the national realization of the commercial benefits...of basic research breakthroughs," the examples which they provide (high Tc superconductivity, HDTV, Sematech, the National Center for Manufacturing Sciences) are still very much at the R&D end of the spectrum (pp. 285-289). To the extent that the R&D is oriented more toward the "development" than the "research" end of activities, then perhaps we can say that U.S. technology policies are geared toward the utilization of technology, and not its supply. However, a recent clarification of the goals of U.S. technology policy by OSTP indicates that there is a retrenchment back to a supply orientation. This "white paper" states that one of the government's most significant roles in technology policy is to "participate with the private sector in precompetitive research on generic, enabling technologies that have the potential to contribute to a broad range of government and commercial applications."[38] Far from helping the private sector effectively utilize science and technology, the government is still well within the supply-side sphere, acting only to enhance technological innovation, and not commercialization.

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[37]"Council and Japan Society Explore Technology Policy," *Challenges* (Council on Competitiveness) vol. 3, #1 (November 1989): 1.

[38]As quoted in Council on Competitiveness, *Legislative and Policy Update*, Vol. 2, #19, October 29, 1990.

Conclusions

In many respects, U.S. competitiveness policies represent a highly unified set of initiatives. Focusing on the need for higher rates and volumes of technological innovation in the United States, these policies attempt to stimulate a greater supply of new scientific and technological knowledge, particularly that which derives from basic research. More than any other kind of R&D, basic research is thought to yield much higher economic and social returns on investment, simply because it is assumed that knowledge resulting from this research is comparatively more *radical*--and hence, more profitable--than others. The "supply of knowledge" policies have been complemented by those attempting to encourage greater communication between the sectors which produce basic research and those that use it; the policy objectives in this case are to make the research more responsive to industry (e.g., be of a character that is more useful) as well as overcome information bottlenecks that might prevent industry from exploiting otherwise promising research. Finally, the policies also tried to "jump-start" the industrial innovation process by eliminating barriers to innovation and reordering the R&D incentive system.

The evolution and articulation of these policies was not quite as rational as they might seem. While there is implicitly some diagnostic policymaking--decision-makers undoubtedly concluded that the U.S. competitiveness crisis was fundamentally an innovation crisis, and that innovation crises are best overcome with more science and technology--much of the substance of these policies was simply the result of *no other options* being available to the government at the time of "crisis" or in a *laissez-faire* environment. As has been argued here, the science policy paradigm predisposes us to certain assumptions and conclusions about the nature of innovation and economic performance, but the political system is nonetheless the final arbiter of policy arenas and contents. Interestingly enough, the language of competitiveness policymaking perfectly mimics that of the paradigm and linear model of innovation, not so much out of conviction but of convenience. The appearance is one of an exceedingly rational policymaking process (e.g., policymaking guided and informed by theories and models of particular phenomena); the reality is not irrational but constrained.

Policies that result by default, as opposed to a more "strategic" surveillance of the range of problems, causes, and appropriate policy solutions may nevertheless be effective. The questions at hand for assessing the likely ability of U.S. policies to "turn around" the crisis are deceptively simple. Do they really overstress the impact of science and technology on competitiveness; are these policies likely to be sufficient treatments of the crisis? Are science and technology so important that supply-sided enhancements can singlehandedly overcome economic malaise? While many would reasonably argue that no one expects science and technology alone to be the solutions to the competitiveness crisis, the absence of significant policy action in other relevant areas (education, fiscal policy, labor policy, monetary policy) does leave the science and technology arena "holding the bag". We have to ask ourselves what the likely success of these policies will be in the absence of any other activity, since that is, in effect, what is happening.

Economic theory and some superficial empirical evidence suggest that U.S. competitiveness policies are woefully limited. The next chapter explores contemporary economic theories and research on the role of science and technology in the economy, and as will be seen, much of the research on science and technology does *not* deal with industrial (or international) competitiveness, but with economic development, growth, and productivity. Nevertheless, there is an abundance of theory and information which will allow us to reasonably speculate on the appropriateness of U.S. competitiveness policies, speculations that can be put to the test once the matter of the crisis itself is settled.

Part II
The Contingencies of Innovation

In a fundamental sense, the history of technical progress is inseparable from the history of civilization itself.

Nathan Rosenberg, "*The Historiography of Technical Progress*"

CHAPTER 4

Science, Technology, and Competitiveness

As should be apparent by now, the legacy of the Bush paradigm and the political environment of the early 1980s has given us a supply-sided strategy to the competitiveness crisis. The question is, will it work? One can take the jaded view and say that government policies are rarely effectual, let alone those that derive from a crisis-oriented political environment. The premium in those circumstances is usually on "action" as opposed to thoughtful response. But in this case, the politics generated a set of policies that were in fact consistent with theories (albeit flawed) and historical evidence on the role of science and technology in society. If the history of human civilization indeed cannot be separated from the advance of technology, then should we be so skeptical about the nation's competitiveness policies?

The answer is yes and no. No because it certainly never hurts to have a healthy science and technology base, and government expenditures in this area are miniscule compared to other budget categories. As long as we are prepared to let science and technology spillover into society in their own serendipitous way, then there is no reason to be especially cynical. We can expect that science and technology will ultimately "come to market" and make significant contributions to our health and welfare.

But with the competitiveness crisis came a new set of *expectations* about science and technology. No longer are we content to support science and technology as a sound, but unpredictable, investment. This time we expect it to have a systematic effect on a particular national problem. Much like the sputnik and space era, science and technology are promoted as prescriptions to national ills.

And this *is* where we should be relatively concerned about policy effectiveness. From a theoretical and empirical standpoint, there is not much reason to assume that science and technology can bear the primary responsibility for "fixing" America's competitiveness. Nor is there much evidence that lack of science, technology, or technical innovation created the problem in the first place. This is in effect the paradox that confronts anyone willing to recognize it: how can more science and technology overcome competitive problems if the crisis occured *in spite of* a relative abundance of technical innovation and opportunities?

This chapter explores a number of additional issues relevant for a more complete understanding of bringing science to market, especially as it relates to competitiveness. Perhaps the most significant contribution of the discussion to follow is the distinction between the process of technical change and that of innovation: while the concept of innovation allows us to understand how innovative activity (technological or commercial) takes place, *only* the concept of technical change allows us to understand how innovation actually has economic consequences (and what kind). Note that the distinction between innovation and technical change is not original; it has been a rather routine understanding in economics research for decades.

The theory of technical change suggests that the supply-sided approach to U.S. competitiveness won't work in the way the policies are intended. Because technical change is a multi-stage process involving invention, innovation, diffusion, and economic impact, the disjunctures between each stage of the process disrupt (and may abort) the transformation of many technological innovations. Since each stage is driven by different sets of variables, then the process of bringing science to market is contigent upon the successful "completion" of each stage. With the exception of those few industrial technologies that are closely linked with the scientific frontier, there is no reason to assume that an uninterrupted (or inevitable) connection between science and market will take place. To expect that science and technology can "overwhelm" other determinants in the process of transformation is to privilege them beyond what may be supported by history, theory, and empirical evidence.

The conceptualization of "competitiveness" which follows the discussion of technical change shows just how complex the relationship between innovation and competitiveness is. Environmental, organizational, and economic variables all interact to shape the rate, direction, and nature of a firm's innovative response to its competitive environment. What the description portrays is an innovation (and technical change) process that is essentially a system of matching technical opportunities with economic needs. One gets "competitiveness" through a dynamic of opportunity cultivation, innovation selection, and economic execution. Scientific and technological opportunities that are inappropriate to a given market will lie fallow; similarly, the economic environment may prevent the adoption and exploitation of otherwise atttractive know-how. To put it a bit crudely, we can expect science and technology to have their biggest impact on competitiveness when "supply" and "demand" conditions are mutually supportive.

Since it is not clear if it is the "supply" of technological opportunities or "demand" from economic users that is dysfunctional in the competitiveness crisis, there is always the possibility that U.S. policies are remedying a significant cause of the crisis. This chapter wraps up with a series of hypotheses about the relationships between science, technology, and competitiveness that we would expect to find if the principal constraint indeed lies with the supply of scientific and technological opportunities.

Technical Change and Innovation

Generally speaking, technical change is considered to be the process of technological advance *and associated changes the economic use of technology*. As such, the process of technical change captures a wide range of innovative activity, including technological change, invention, incremental improvements in processes and products, and technique change.[1] Technical change subsumes innovation by making critical distinctions between types of innovative activity: (a) the *initiation* of technological or technical innovation, (b) the *commercial adoption* of such innovation, and (c) the *imitation* of the innovation by others in the economy.[2] Technical change theory is designed to answer questions about the role science, technology, and innovation have in the economy; innovation theory focuses principally on the determinants of innovative behavior rather than its economic consequences *per se.*

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[1]Technological change as it is understood by most people--as a significant change in the way we produce goods and services or the types of goods and services that may be produced--is not the only change phenomenon considered in the economics of technical change. A distinction should therefore be drawn between technological change, which implies an addition or modification to the stock of technological knowledge; technical innovation, a novel application of the existing stock of knowledge; technique change, the switch to an alternative production technology from all those currently in use; and imitation (or diffusion), the adoption of a commercial innovation by someone other than the original innovator. "Invention" encompasses both technological change and technical innovation. Since "invention is assumed to...represent the time at which the technical possibility of a new process or product is worked out and proven" (Tisdell, 1981, p. 79), it may constitute the tangible execution of a technological change or a unique and significant configuration of existing know-how.

[2]Note that others may portray technical change as the initiation, utilization, and consequences of technical innovation.

Technical change is represented as a multi-stage process involving invention, innovation, diffusion (sometimes refered to as imitation), and economic impact (Stoneman, 1987; Rosenberg, 1982). Figure 4-1 presents this model of technical change, and the types of activities that occur within each stage. Confusion over the distinction between innovation and technical change is inevitable because understanding innovative activity is integral to assessing the role of science and technology in the economy--innovation is what transforms knowledge into socially (or economically) useful outputs. Typically defined as the first commercial introduction of a new (or improved) product or process, "innovation" is therefore also a process which spans the invention, innovation, and diffusion stages of technical change: industrial innovation "concerns the search for and discovery, experimentation, development, imitation, and adoption of new products, new production processes and new organisational set-ups" (Dosi, 1988, p. 222).

Innovation-oriented behavior spans the stages of technical change, but each stage (or type of innovative activity) is dominated by different sets of technological, economic, and organizational variables, and each has its own associated probabilities of "success"--that is, the liklihood of technical success (invention), the liklihood of commercialization (industrial innovation), the liklihood of market acceptance (diffusion), and the liklihood of net economic welfare (impact).[3] The stages of technical change are nevertheless sequential; you can't innovate what hasn't been invented, and you certainly can't diffuse an invention throughout an economy if provisions haven't been made for its commercial production. An appreciation of this "sequentialness" of technical change is critical to understanding the role of science and technology in the economy in general and competitiveness specifically: as Stoneman remarked, "the impact on an economy of a new technology will only be realized as that new technology is diffused, implying that invention and innovation *per se* are not important in this sense (1987, pp. 14-15).

It doesn't take much imagination to realize that the linear model of innovation (or its variants) operates in policymaking not as a model of innovation, but of technical change. The conceptualizations and discussions which surround each stage of the linear model are far more consonant with a rudimentary apprecation of how science and technology get processed into economic welfare than with an explanation of the determinants of innovative activity. However, as was suggested in previous chapters, it isn't really the sequence of these stages that are

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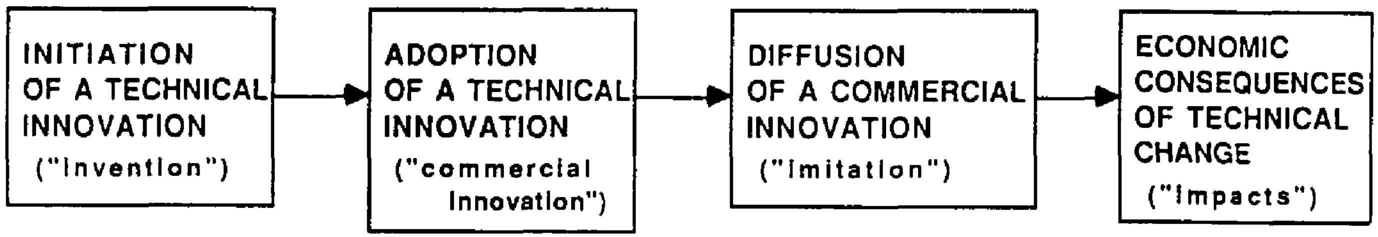
[3]These "probabilities" are adapted from Mansfield (1982).

Figure 4-1. The Stages of Technical Change



- technological change
- invention
- discovery

- organization-based decision to adopt, and how
- process of converting innovation into a product, process, or service [R&D, engeering, design]
- coordination of functional interfaces of the firm

- diffusion of innovation among producers, suppliers
- diffusion among end users [market acceptance]

- growth
- development
- productivity
- sales
- profits
- competitiveness
- employment

problematic, but the implicit assumptions of scientific determinism. It should now be apparent why–technical change is driven by different sets of factors which can disrupt, divert, and abort the transformation of science and technology into economically and socially useful output. The stages of technical change simply cannot be equated with the basic-applied-development typology of R&D, which is what the linear model does. What is lost by concentrating on R&D alone is the *disjuncture* which occurs between each stage or type of innovative activity: there is a vastly larger stock of knowledge than that which is commercialized, many innovations are not successful in the marketplace, and many that are do not have an appreciable net impact on the economy.

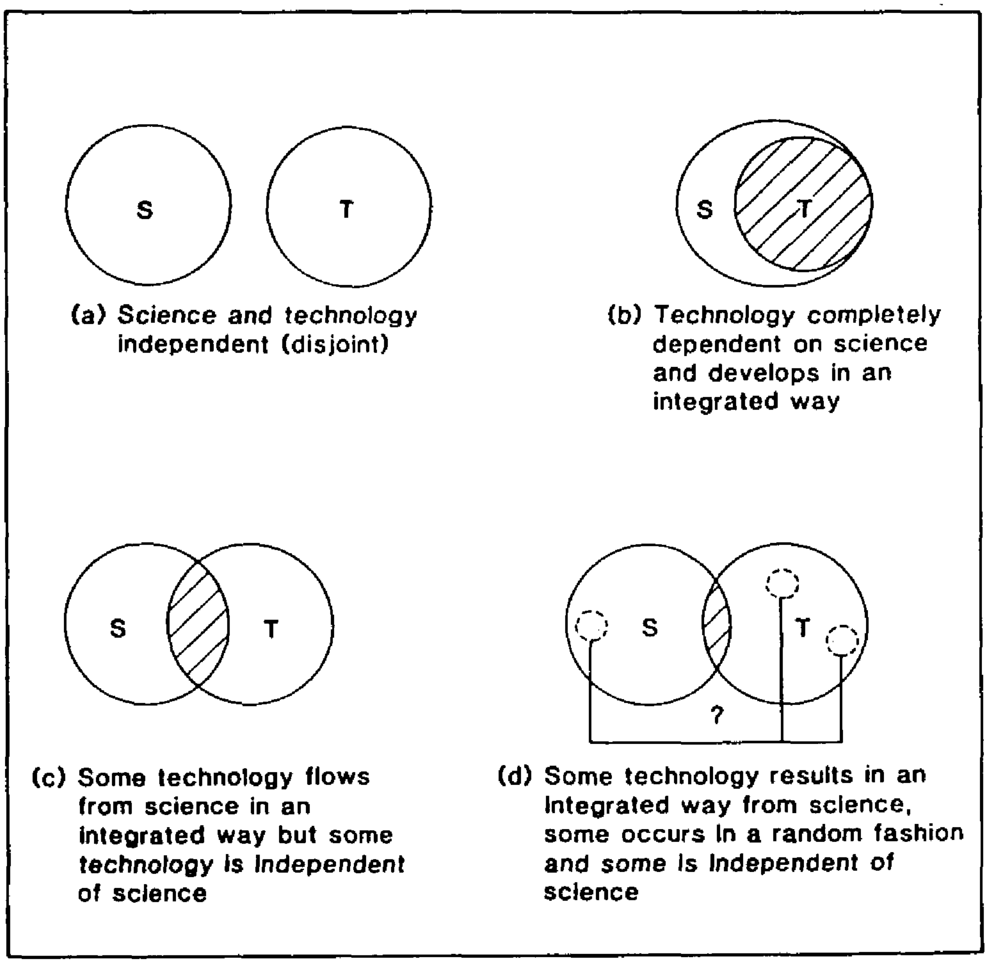
The question of what role science and technology play in both innovation *and* technical change thus arises. There is a vast literature on both questions, much of it very unsystematic, muddled, and ambiguous. What is relevant to issues of science policy and competitiveness are three particular avenues of research and theorizing: (1) the relationship of science to technology, (2) "science push" versus "demand pull" debates on the causes of industrial innovation, and (3) theories and evidence on the economic impacts of technical change.

What is Science to Technology?

The debate over the relationship between science and technology is not trivial, although much of it derives simply from how one defines the concepts of "science" and "technology". Since technological change is the first step in the process of generating economic welfare, how science contributes to that change is a critical science policy issue. U.S. science policy is built on the presumption that technological change results from scientific discovery and basic research, and there is a substantial political stake in maintaining the validity of this presumption. However, as was discussed at length in chapter 2, there are serious limitations to both the assumption and the linear model which derives from it. Additional critiques of this approach may be found in De Solla Price (1965), Shapley and Roy (1985), and Kline and Rosenberg (1986).

Tisdell (1981) observes that new technological knowledge may be the result of scientific information, trial-and-error experimentation, learning by doing, fusion of existing technologies, or some combination of these (figure 4-2); the history of technical change certainly supports the arguments that new technology can derive from sources other than new scientific knowledge (see, for example, Mowery and Rosenberg, 1989). However, the contemporary debate on this

Figure 4-2. Relationships Between Science and Technology



Source: Tisdell (1981)

issue asserts that science's role vis-a-vis technology is changing, and relative to other sources of technological change, science is paramount.[4] Nelson (1988) finds, however, that few industrial technologies actually draw extensively from the scientific frontier; although many industries innovate based on well-established bodies of scientific knowledge, this knowledge is well distanced from the fronteiers of academic research.[5] What Nelson's research points to is the tendency for university (e.g., basic) research to be a signficant contributor to technological change only during the period in which the commercial utility/feasibility of a field of research has been recognized, and that over time such research "diminishe[s] as a source of important new knowledge for industry" (p. 320).

In an attempt to formalize the dynamics of technological change and its relationship to science, Dosi (1982, 1984, 1988) has come up with what is by far the most elegant theory of technical change to date.[6] Applying Kuhnian concepts of scientific paradigms to technology, Dosi argues that:

> Technological paradigms define technological opportunities for further innovations and some basic procedures on how to exploit them. Thus they also channel the efforts in certain directions rather than others: a *technological trajectory* is the activity of technological progress along the economic and technological trade-offs defined by a paradigm. (1988b, p. 225)

A technological paradigm is thus a basic stock of technological knowledge with an implicit set of heuristics. These heuristics guide the direction (trajectory) of technological innovation by specifying the questions of interest. Most critical, however, is Dosi's "crucial hypothesis" that "innovative activities are strongly *selective, finalised* in rather precise directions, often *cumulative* activities" (1988, p. 225). In other words, real-life cognitive selection bias,

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[4]There is also the related debate (to be reviewed in the next section) that science contributes more significant innovations than other sourcs of technological change.

[5]Nelson's empirical research is supported by historiographic work by Mowery and Rosenberg (1989), who find separate innovation roles for "new" and "old" science. More specifically, they found that some key industrial innovations *did* rely on recent scientific advances (e.g., "new science"), but others used only well-established ("old") scientific knowledge, e.g., the reliance of the steel industry on chemical assaying.

[6]Dosi (and some of the other more recent innovation theorists) use the term "technical change" in its most comprehensive sense; that is, it covers the spectrum of technological paradigm change to diffusion of existing technologies.

uncertainty, and context specificity drive innovators along different trajectories within the overall knowledge boundaries of the existing paradigm.

Although noting that the emergence of new paradigms is increasingly reliant on scientific progress,[7] Dosi concurs with Nelson that the linkage and utility of such scientific progress is direct and powerful only in a limited number of technologies and industrial sectors; for others, the link may be indirect, weak, or nonexistant. He concludes that the linkage between science and technological change is likely to be most significant during the emergence of new technological paradigms, and that the economic process of paradigm selection depends upon the nature and the interests of bridging institutions which connect basic research to the private sector, science and technology policy, trial-and-error exploration of new technologies, and market/demand needs.

The Determinants of Innovation

Closely related to the science policy debate about where new technology comes from is the debate over the primacy of science in the industrial innovation process. Until recently, thinking on this question essentially polarized around two rather mutually exclusive positions. On the one hand, there were those scholars who advocated a "science push" model of innovation and argued that scientific knowledge and discovery were nearly exclusively the sole "cause" of *significant* innovation, with innovation resulting from the sequential (linear) application of science to technology to social product.[8] Science push advocates therefore frequently appeal to the changing nature of technology's relationship to science, and much of the research in this area involves "proving" (not very successfully) that science is responsible for a far greater proportion of significant innovations that other sources of technical change.

On the other hand, "demand pull" models of innovation were developed when a number of studies indicated that inventive and innovative activity were principally determined by economic influences. These studies followed similar methodologies as those of the "science push" approaches, namely the selection of "significant" innovations whose roots were then

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[7]Dosi states: "...the source of entirely new paradigms is increasingly coming from fundamental advances in science and in the 'general' technologies" (1988, p. 228).

[8]The "science push" literature is almost one and the same with that of the linear model of innovation. Reviews of this agglomeration of literature may be found in Ronayne (1984) and Tisdell (1981).

traced back to a primary cause; in this case, economic factors (e.g., market pressures, changes in "demand"). A thorough critique of the demand pull literature may be found in Rosenberg (1982); its major weakness (as with the science push research) is that the methodological framework is so flawed that it is not really possible to establish the key determinants of innovative activity.[9]

To a large extent, these two approaches to innovation are destined to be mutually exclusive because they are false debates. Whether commercial innovation results from scientific opportunities or responds to market pressures ignores the fact that technical opportunity and economic need must coincide. What the debate seems to be really over is whether the science-induced opportunity or the economic need should be privileged in theory, and hence in policy.

Freeman (1982), Rosenberg (1982), and Kline and Rosenberg (1986) have neatly integrate science push and market pull concepts by arguing that for any given set of technological *opportunities* created by a scientific discovery or body of scientific knowledge, market demand and new economic "needs" will guide the rate and direction of technological change as well as the nature of the industrial innovation. Such an approach is quite consistent with Dosi's theoretical arguments, and it is becoming more and more apparent that innovation results from a match between technical opportunity and economic concerns. Science may provide an opportunity which innovators may then recognize and use; conversely, they may respond to economic pressures by pursuing innovative activity. What these scholars (and others) have been able to convey is that in order to have social consequence, science and technology must be matched with economic imperatives. Technical innovation occurs when, confronted with a market-based inducement, innovators move along a trajectory within the "technological possibilities set" defined by a technology paradigm. Technical change is thus the consequence of the interaction of knowledge push and demand pull:

> Environmental-related factors (such as demand, relative prices, etc.) are instrumental in shaping (a) the rates of technical progress; (b) the precise trajectory of advance within the (limited) set allowed by any given 'paradigm'; and (c) the selection criteria amongst new potential technological paradigms. However, each body of knowledge, expertise, selected physical and chemical principles, etc. (that is, each paradigm) determines both the opportunities of

[9]Note that there is an abundance of economic research on the influence of market-related variables on inventive and innovative behavior (as measured by R&D and patenting). See Kamien and Schwartz (1982) for an overview of this scholarship and empirical work.

technical progress and the boundaries within which 'inducement effects' can be exerted by the environment. (Dosi, 1988b, p. 228)

Science and technology fundamentally constrain the opportunities for innovation because they define the existing knowledge base from which innovation must draw. However, it is the innovator's environment that determines the actual nature, path, and use of innovation.

The cumulative body of research on the determinants of innovation suggests that it all depends upon the nature of the industry and the kind of innovation that is appropriate to its economic environment. The work of Freeman (1982) and Rosenberg (1982) find strong science-based influences in R&D intensive industries (chemicals, synthetic materials, electronics, scientific instruments), as does Nelson (1988) for the computer science, materials, metallurgy, and life-science industrial technologies. However, as Von Hippel (1988), Pavitt (1984), Nelson (1988), and Archibugi *et al.* (1987) find, there is significant inter-industry variation in the role of science in industrial technology and innovation, with the strongest and most direct linkage only in the science-related industries.[10]

The debates on science push and demand pull have consequently evolved into far more serious discussions about how and why different kinds of innovative activity take place, and with what economic consequence. Most contemporary research and theorizing looks at innovation as the consequence of both "supply" and "demand" factors, and evaluates the circumstances under which scientific and technical opportunities versus economic factors tend to predominate in the process, as well as how they interact. At present neither theorizing or research will let us establish the relative economic weights and degree of importance of various innovative activities--science-based technological change, major change resulting from other than new science, incremental improvements, technique shifts, product versus process innovations, etc. (see Stoneman, 1987, for this argument as well). About the best that can be said is that on balance, the radical changes (science-induced or otherwise) are as equally important as the incremental, since the small enhancements to a technology are most responsive to market forces and are really what enables an innovation to widely diffuse throughout a society and an economy. In the absence of such use and diffusion, the science and technology are for naught.

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[10]Scherer (1986) provides a useful framework for integrating these various approaches by differentiating the types of "technological maturity" among manufacturing industries.

The Economic Consequences of Technical Change

The central purpose of theories and research on *technical* change has been to explain *economic* change. As has been discussed thoroughly (Nelson and Winter, 1982; Dosi, et al. 1988; Rosenbloom and Burgelman, 1989; Stoneman, 1983, 1987) one of the more peculiar developments in modern economic theory has been the general neglect of the subject of economic change. Classical theorists (Smith, Ricardo, Malthus, Mill) and Marx were concerned with long-run economic growth, development, and large-scale transformation of economies, but such concerns were largely abandoned in mainstream economics with the advent of neoclassical static equilibrium approaches.[11]

Attention to the role of technical change in the economy has been revitalized over the past few decades, principally by Schumpeter's theorizing and a plethora of econometric research quantifying the seeming contribution of technical change to economic growth, productivity, and international trade.[12] More recently (as in the past 10 years), technical change has been made the central variable in "evolutionary theories" of macroeconomic performance and microeconomic behavior.[13] The analytical frameworks which characterize these multiple approaches are far from unified, and Nelson and Winter have observed "a curious disjunction in the economic literature on technological advance, with analysis of economic growth at the level of the economy or the sector proceeding with one set of intellectual ideas, and analysis of technological advance at a more micro level proceeding with another" (1982, p. 202).

Notably, Schumpeterian theories (1961 [1911]; 1939, 1950 [1942]) inform most of these studies (but not all of them can be considered "Schumpterian"). Schumpeter is credited with

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[11]The central assumption in neoclassical economics is that long-run growth and efficiency is the cumulative result of short-term equilibrium adjustments because of the ease of substitutability of capital and labor. Stoneman (1987), however, challenges this notion by exploring the circumstances under which static efficiency may not aggregate to long-range dynamic growth and development.

[12]Note that both Kuznets and Galbraith are two contemporary economists who have been consistently concerned with large-scale economic change (development) and the role of technology in that process.

[13]Nelson and Winter (1982) wrote the seminal work in evolutionary theories of change. This has been expanded, refined, and applied to the entire spectrum of economic life (firm to international) in Dosi, et. al (1988); more recently, Rosenbloom and Burgelman (1989) have used evolutionary theory to re-examine business theories of the firm.

being the first scholar to make invention and innovation the central forces of economic growth and development: he argued that economic progress results from the new products, markets, and production efficiencies of existing goods created by entrepreneurial invention and innovation. Schumpeter later asserted that the recurring process of "creative destruction"[14] produces the cycles manifested by market economies, with the length of such cycles determined only by the relative economic importance of the innovations which evoke them (Schumpeter, 1950 [1942]). Society is then "slowly and profoundly transformed" by the cumulative effects of innovation-driven business cycles and long waves (Perez, 1983, p. 359); innovation is an inevitable disturbance generated by the economy, which then recovers equilibrium at a higher level of economic welfare.

While Schumpeter's analysis has been frequently qualified (especially with respect to his assumptions about entrepreneurism and the impact of market structure on innovation), he nevertheless has left an important legacy. Creative destruction--as a descriptor of the causal role of technology in economic change--tends to be the dominant understanding of the impact of science and technology on society.[15] Moreoever, because Schumpeter was explicitly concerned with the causes of major economic change in capitalist economies, he focused primarily on *radical* invention and innovation as the proginators of such change. "Incremental" innovation was only of secondary interest because it represented the diffusion of significant technological shocks to an economic system. Because of Schumpeter's analytical focus, there has been a subsequent preoccupation in science policy with radical scientific-technical change.

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[14]Creative destruction is the process through which an invention and innovation render a whole era of technology economically irrelevant; for example, the automobile "destroyed" the horse and buggy mode of transportation. Creative destruction is essentially the restructuring process an economy goes through as it absorbs radical changes in technology (the steam engine, steel and construction materials, the airplane, microelectronics, etc.).

[15]The awareness of the principles of creative destruction surface repeatedly in science policy making, since most descriptions of the role of innovation in growth and development take on a Schumpeterian flavor, and in some cases (e.g., National Academy of Sciences, 1978) the influence of Schumpeter's theory is explicitly recognized. Schumpeter's work additionally provides the starting point for most of the modern micro theories of innovation (to be discussed below) as well as an interesting body of theory on the relationship between innovation, institutional infrastructure, and long waves (Freeman, 1986; Perez, 1983).

In spite of its descriptive elegance,[16] it is difficult to put Schumpeter's theory about economic development and transformation to an empirical test. Economists have tended to operationalize these processes simply as "economic growth", on the assumption that growth is a necessary ingredient of development and transformation. Our understanding of the impact of technical change on the economy therefore tends to fall into three groups--neoclassical growth and productivity research, neo-technology theories of growth and international trade, and "high tech" theories and research.

Neoclassical approaches. In ground-breaking research, Abramowitz (1956) and Solow (1957) discovered that contrary to expectations, very little of U.S. economic growth could be explained by growth in capital and labor inputs. Using a crude Cobb-Douglas production function[17] in which U.S. economic growth was specified as a function of only capital and labor inputs, they found that it was the residual in the equation that correlated most highly with U.S. growth and productivity, accounting for as much as 90% of the variance in their regression models. Solow labelled this residual "technological change" and declared such change to be the engine driving the U.S. economy.

What Solow called technological change inappropriately included a number of factors--including economies of scale, quality of the labor force, and shifts in product mixes--which can not by any means be considered elements of technical change. In the most tenacious effort to date to isolate the effects of technical change, Denison (1962, 1979, 1985) uses a growth accounting methodology to discriminate more of the variables included in Solow's residual. Denison has determined that roughly 28% of growth in U.S. national income, and 57% of U.S. productivity growth, can be accounted for by "advances in knowledge" (1985, p. 30). While Denison's findings have frequently been interpreted as "technological change causing growth and productivity," what his research actually represents is a strong statistical association

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[16]Note that even though Schumpeter places innovation and technological change in the center of his theories of economic development, his explanations of the causes of innovation itself are complex. On one level the theory is quite parsimonious (explaining how innovation leads to economic transformation), but on another it is unsatisfactory (how, why, and when innovation occurs). It is this latter aspect of his theory that has received the most criticism and revision.

[17]Cobb-Douglas production functions are regression equations in which the dependent variable, some measure of economic output, is specified as a linear (or log-linear) function of several independent economic input variables (labor and capital related).

between a residual and economic output: after he specified all quantifiable factors in his model, he labelled the residual "advances in knowledge". The category incorporates all new knowledge (or new uses of old knowledge) whether managerial, organizational, or technological.

As the above discussion suggests, analyses of the impact of technical change on economic growth can be somewhat confusing because of the general tendency to discuss the relationship in terms of productivity and not growth. By way of explanation, Stewart (1972) observes:

> There are two kinds of growth: the quantitative growth experienced by most of the world--more people, therefore more workers, more equipment, and more output; and qualitative growth--more output per worker, more income per capita. It is this kind of growth, in productivity, which is the prime interest. (Stewart, 1972, p. 11)

Growth accounting typically focuses on the qualitative aspect of economic growth (productivity), which is the increase in output which cannot be accounted for by the simple addition of more people, raw materials, or machinery.

Efforts to isolate the effects of technical change on productivity intensified with the greater clarity of Denison's findings and with the unequivocal declines in U.S productivity that started after the first oil shock in 1973-74. Generally speaking, it has been difficult to associate the decline in U.S. growth/productivity to a reduced rate of technical advance. Denison's analysis finds no support for such an assumption, and Mansfield *et al.* (1982) conclude that although there is some evidence of a general slowdown in the rate of U.S. technological innovation, the magnitude is not known and the empirical evidence does not support the conclusion that U.S. productivity has been substantially affected by this slowdown.

Perhaps more relevant to science policymakers, however, is the relationship between *R&D* and productivity. Since policy is generally concerned with increasing the rate of technological change via R&D expenditures, the rates of return of R&D investment are of particular interest. A whole genre of production function research which estimates the productivity rate of return on R&D generally find high (typically 25-36%) private and social rates of return from R&D spending to productivity increases.[18] However, Griliches (1980) and Griliches and Lichtenberg (1984) conclude (as did Mansfield *et al.*) that the "elasticities of output with respect to R&D stock do not account for more than a small fraction of the observed decline in productivity," and "what cannot be found in the data is strong evidence of the differential effects of the [productivity] slowdown in R&D itself" (Griliches and Lichtenberg, 1984, pp. 465-66). While there appears to be a strong positive association between R&D and productivity increase, the converse is not true; economic declines do not seem to coincide with declines in R&D spending.

Neotechnology approaches. A slightly different approach to the relationship between technology and economic growth has been taken by neotechnology theorists, who attempt to show that differential holdings in technology and varying rates of technical change are the primary cause of international differences in the rate of economic growth and development. The basic hypotheses of technology gap growth theory were advanced by Posner (1961), and include, among others, the proposition that 1) the rate of economic growth of a country is driven by the rate of technical change in that country, and 2) a country for which a technology gap exists between itself and those on the "world innovation frontier" can accelerate its growth and close the gap through a "catching up" process of "imitation".

Empirical research on technology gap theories generally support these hypotheses; regression equations usually show a high level of correlation (e.g., r^2 of 0.75 or higher) between growth and technology gap measures, and most research on the "catching up" hypothesis does seem to support the notion that growth rates can be accelerated through intense technological imitation.[19] However, since these empirical studies typically use GNP per capita as a proxy for levels of, and rates of change in, technological development, one must seriously question the conceptual meaningfulness of the correlations. To the extent that the appeal of technology gap theory is in its descriptive ability to explain the "catching up" of Europe, Japan, and recently the East Asian NICs, this weakness of the empirical tests is often overlooked.

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[18]There is a fair abundance of this literature; the key scholars and archetypes of their work may be found in Griliches (1984).

[19]See Fagerberg (1987) and Choi (1983) for a review of the technology gap literature and examples of empirical approaches.

Neotechnology theories have also been applied to international trade.[20] The original impetus to neotechnology approaches to trade (Posner, 1961; Hirsch, 1967; Vernon, 1970) was the inability of classic and neoclassic comparative advantage theory to accurately describe real-life patterns of international trade. Ricardian models of relative productivity and neoclassic factor endowment theory (Hecksher-Ohlin-Samuelson) are limited in their ability to fully explain actual trade patterns, namely the fact that the bulk of world trade is intra-industry trade among countries with highly similar factor endowments.[21] Moreover, Leontiev's celebrated "paradox" reveals that, contrary to factor endowment predictions, U.S. trade is, by and large, labor and not capital intensive. This anomaly has since been reconciled somewhat by the discovery that U.S. comparative advantage is in R&D-intensive industries, which also tend to be highly labor intensive (Gruber, 1967; Balassa and Noland, 1989).[22]

The neotechnology approach--which is fundamentally a dynamic theory of international trade competition based upon the existence of technology gaps--argues that patterns of international trade evolve according to the techno-economic development of the products being traded. Using Hirsch's concept of a product cycle, neotechnology theory presents a model in

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[20]Mainstream economics is frequently at odds with "neotechnology" approaches to international trade. However, it would seem that the two approaches are explaining different phenomena. Traditional economic theory and research has focused on the macroeconomic determinants of comparative advantage; more specifically, how the structural characteristics of a national economy create differentiation and specialization in trade (the commodity composition of a nation's trade). On the other hand, "neotechnology" trade theory has focused on the international diffusion of technology as a primary explanator of dynamic global trading patterns. Neotechnology approaches attempt to explain the nature of international competition for a given product based upon the business dynamics which arise from weakening appropriability regimes, increased market competition, degrees of product standardization, and comparative cost structures. Comparative advantage and product cycle approaches may not actually be contending theories of international trade, since they are trying to explain different aspects of patterns in international trade. Because Ricardian, factor endowment, and neotechnology theories can all be empirically validated (see Balassa, 1989; Hufbauer 1970), this complementarity would seem to be the case.

[21]For an overview of contemporary international trade theories and their strengths and weaknesses, see Ethier (1987), Leamer (1984), Balassa (1989), Dixit and Norman (1980), and Stoneman (1983).

[22]Even with the understanding that U.S. comparative advantage lies in R&D-intensive industries, comparative advantage theory still cannot adequately explain the large volume of intra-industry trade which occurs between nations. Since comparative advantage purports to explain *specialization* in trade, there may be an inherent inability in the traditional models to capture what is essentially international *competition* in like products; indeed, according to most models, such competition should not even be taking place.

which international competition and trade are a function of where a product is along its cycle, which is generally distinguished by three phases. The first is an innovation phase in which the product is first introduced and the innovating country enjoys competitive advantage by virtue of monopoly power; this phase is characterized by rapid growth, high profits, and a high degree of appropriability of technology. The second, intermediate phase is distinguished by declining appropriability (for whatever reason), increased market competition, and declining prices; during this phase competitive advantage tends towards firms/countries which can effect incremental product improvements and quality mass production. The final, mature phase of the cycle is one in which:

> the production technology is now completely understood and standardized. Possibilities for innovation are rare, monopolies are eroded, output falls off, and price falls to a 'minimum' competitive level. It is at this stage...that underdeveloped countries have a comparative advantage in production since unskilled and semi-skilled labour have become the major imputs, and these are of course cheaper in LDCs. (Clark, 1985, p. 134).

Neotechnology theory in effect explains how--through a process of imitation--technologically "behind" nations may catch up with those at the innovation frontier. This catching up process manifests itself as differential growth rates and more rapid progress in standards of living within the "behind" countries relative to those that are more advanced. Catching up also shows up in international trading patterns as comparative advantage shifts away from the technological leaders to the imitators through the competitive dynamics of product cycles.

High Technology Approaches. High technology "theories" about the relationship between science, technology, and the economy originated with the finding that the U.S. comparative advantage in international trade tends to be in R&D-intensive industries (e.g., pharmaceuticals, aerospace, advanced electronics, etc.), and that the majority of our positive trade balances are in high tech categories.[23] To a large extent, the "high tech" approach draws heavily on Schumpeterian explanations about "how" high technology spills over into the

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[23]Please note that there is no commonly accepted definition of what constitutes "high tech". Definitions tend to revolve around the reliance of various industries on R&D activities, measured as R&D-to-net-sales ratios (and referred to as their R&D intensity). The OECD has one typology of high tech classification, the U.S. Department of Commerce has two, and state governments seems to proceed on the basis that any "high growth" industry is--by definition--high tech.

economy, although most of the empirical work is largely descriptive, and not tests of Schumpeterian theories *per se.*

As a consequence, there has been a growing national emphasis on high technology industries and products out of the presumption that our "competitive" position is strongest in these areas. In fact, there is a major thrust at the state and local level on high technology economic development strategies, much along the lines of recreating the Bostonian "Route 123" phenomenon or that of Silicon Valley. By and large high technology industries do seem to have a greater premium of economic return. Not only do they typically evidence higher rates of employment and growth, but they also provide higher levels of value-added (profit) than less technology intensive industries (see Bollinger, 1983, for a review of this empirical research).

The high tech literature is extraordinarily diffuse, with no particular discipline dominating the theory or research, although much of the most promising scholarship is in location theory and research, which tries to explain the "technopolis" (Silicon Valley) phenomenon. What has typically informed the competitiveness policy debates are the trade patterns for R&D-intensive products and the domestic growth and employment trends for high tech industries.

Implications for Competitiveness Policies

As is hopefully evident from the above discussion, there is almost a complete absence of theorizing and evidence on the relationship between science and technology and competitiveness. Most of the theory and research that "speaks" to science policy is not directly concerned with competitiveness, resulting in the tendency for competitiveness policies to be derived from economic literature having little to do with this phenomena (begging, for a moment, just what the notion of "competitiveness" means). Supply-sided competitiveness policies could thus be quite "rational", but for the wrong purpose.

On the one hand, supply-sided policies make a good deal of sense. Empirical work has repeatedly shown that--as best as we can measure it--scientific and technological change are strongly associated with economic welfare (growth, productivity, employment, trade). And there are plausible and attractive theoretical explanations (Schumpeterian, technology gap, product cycle) to explain how science and technology result in such economic progress. When taken collectively, Schumpterian, neotechnology, and high technology approaches to economic performance would coherently lead to supply-sided approaches.

To be specific, Schumpeter explains that as economies exhaust their available "supply" of innovations they "run down," requiring new rounds of radical invention to provide the source of growth for economic upswings. The neotechnologists let us see that international technology transfer exacerbates the exhaustion problem because it depletes a highly innovative country's bag of tricks that much more quickly: the rapid growth potential gets transferred to other countries as they adopt, produce, then directly compete with the innovating country. The inability to tightly appropriate the returns from innovation within national boundaries places pressure on those at the technological frontier to maintain an *accelerating* rate of technical innovation or risk losing their position on the frontier itself. To do otherwise would allow the technology gaps between countries to narrow, which limits the length of time the first-to-invent country has to reap its reward. As countries converge in technology "space", the ease of imitation increases dramatically. As ease of imitation increases, so do the innovation welfare losses for the inventing country.

If the competitiveness crisis is indeed a crisis of the closing of "technology space" between the U.S. and its major competitors, then the crisis is one of structural adjustment to the new competition: the U.S. must "move out" of competition in its previous strongholds, and create a new, wider technology space for itself. Since emerging technological paradigms are now increasingly reliant on scientific advances, then a heavily supply-sided competitiveness policy seems quite sound. We may reasonably conclude that prior to the crisis the U.S. failed to accelerate its innovation capacities and behavior; the most appropriate corrective measure is to rapidly provide the scientific roots for new technological paradigms from which high tech industries may emerge and prosper.

On the other hand, the neoclassical productivity and growth literature raises some nagging suspicions and identifies a paradox if we are willing to recognize it: not only is there no association in the U.S. economic decline with declines in technological innovation, but diminishing innovation is itself difficult to document. In a time of apparently rapid technological progress, how is it that this fails to manifest itself in U.S. economic health?

To acknowledge the paradox is to affirm the critical role of "demand" factors in technical change. If the supply of scientific and technical opportunities is adequate, then it is the meaningful use of these opportunities that is weak. Unfortunately, there are any number of ways in which the commercialization of these opportunities may go awry: the simple failure to use, a mismatch between what is innovated and what is necessary to successfully compete, or the failure of an otherwise successful innovation to diffuse throughout an economy. In the international sphere, the inability of a country to appropriate the rewards from its innovations may be added to this list; rapid imitation can preempt the profits, growth, and welfare that would "rightfully" accrue to the innovating country.

The current theories and research on industrial innovation identify significant alternatives to the likely cause of the competitiveness crisis, and therefore challenge the appropriateness of the policy solutions. Since economic institutions (broadly understood--firms, industries, markets) ultimately provide the commercialization and diffusion of technical innovations, diagnosing this part of the equation is also called for. The opportunity set (as provided by science and technology) is certainly a precondition to innovation, but the trajectory within the set and selection from it are determined by economic and organizational factors. Moreover, there are apparently entire manufacturing sectors for which scientific advances are irrelevant to their innovations; understanding the causes of economic and innovative decline (if any) in these industries would seemingly require alternative explanators than science or advanced technology.

Just how problematic these "demand" factors are for explaining the role of science and technology in competitiveness is revealed in the next section. The conceptualization of competitiveness which follows is very different from the structural adjustment referred to earlier; distinctions must be drawn between commonly understood microeconomic and market competition and the reallocation of factors of production throughout the macroeconomy. The two are certainly not unrelated: how a nation goes about deriving its most competitive macrostructure is undoubtedly a function of the ability of its firms and industries to prevail in the marketplace.

What is Competitiveness?

It is becoming more and more common for policy discussions of the competitiveness crisis to define competitiveness as economic development (e.g., Schact, 1989). Although economic development itself is a difficult concept to define, at its core most would agree that it is the process of increasing national wealth in conjunction with improving the standard of living/quality of life of a nation's population. This process is typically thought of in the short run as economic growth, while in the long run it consists of structural change (e.g., labor and capital movements) and economic transformations (e.g., from agrarian to industrial economies, successive industrial revolutions). Policy perceptions of competitiveness have revolved around concepts of comparative advantage as well; the commodity composition of nation's trade does indeed reflect what it produces more "competitively" than others, since specialization in trade typically represents the cost advantages engendered by differential national holdings of capital and labor.

However, none of these conceptualizations approximates the immediacies of "competition" as a firm or business organization experiences it. Moving our focus downward to this level of analysis and temporal space is critical, since *innovation* is fundamentally a response to micro-level competition. Nations do not commercialize technological change--organizations do. At this level of understanding, all of the varying determinants of competitiveness come into play and one can begin to get a sense of the complexities of the relationship between technical change, innovation, and competitive success.

Microeconomic Competitiveness

In the microeconomic context, competition is a state of rivalry between firms as they "struggle to create, maintain, and expand favorable market positions" (Encaoua, Geroski, and Jacquemin, 1986, p. 55); to prevail in the marketplace, companies adopt and develop a competitive strategy, "the very heart of which is to generate and maintain advantageous differences" over their competitors (Metcalfe and Gibbons, 1989, p. 159). For manufacturing firms, competition is actualized through the sale of tangible products, goods, or commodities; and consumer theory (as influenced by Lancaster, 1971) further suggests that competition derives from customer preferences for different goods based on the "services" those goods provide via their physical characteristics.[24] Thus, we can say that a firm's competitive strategy is to advantageously differentiate its products relative to those of its rivals. The ability to appeal to consumer taste (and win consumer dollars) through product differentiation is what confers competitive stature; a firm's competitiveness is embodied in the products it sells, which

[24]Lancaster's theory is that it is not actually the products themselves which compete, but the attributes which they possess and the *utility* which these attributes then provide to consumers.

compete on the basis of delivered costs, attributes (physical or service), and a user's perception of the match between a product's "services" and his or her need.[25]

Innovation results from market-induced, competitive pressures to differentiate products. Even monopolists will eventually face competition from the emergence of substitutable goods and may often innovate simply to enjoy more profits through cost reductions, the revitalization of existing markets, or the creation of entirely new consumer demand. The necessity to innovate is a dynamic and relentless process, and as is frequently pointed out by any number of approaches to economic life, the failure to innovate is certain organizational death. Not only is there constant pressure from one's competitors in established product lines, but as Schumpeter warns, firms should be especially wary of:

> competition from the new commodity, the new technology, the new source of supply, the new type of organization (the largest-scale unit of control for instance)--competition which commands a decisive cost or quality advantage and which strikes not at the margins of the profits and outputs of existing firms but at their foundations and their very lives. (Schumpeter, 1950, p. 84)

In response to such an array of competitive challenges, producers may innovate in a variety of ways to enhance the demand for their products. Schmalensee observes that design, packaging, price structures, training, use of sales and service personnel, marketing strategies, advertising, and the contractual dimensions of channels of distribution are all tools which firms may use to differentiate their products and influence consumer choice (1986, p. 373).

Given the range of innovation techniques available, it is useful to distinguish between innovations that relate to infrastructure and organization strategy (e.g., marketing, training, channels of distribution, service networks, organization structure) and those that relate to technology (e.g., the physical design of a product, its manufacturing process). Since technology forms the underpinnings for the physical attributes of products and their production processes, technical innovation is the more powerful of the innovation tools which affect market demand, consumer choice, and the competitiveness of firms. This is not to say that the other methods

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[25]Even in the case of perfectly homogenous products (those with identical physical attributes and quality), price may not be the decisive factor affecting a purchaser's decision: perceptions of vendor reliability, after-sales service support, and timeliness of delivery can all be crucial "differentiations" driving user choice. While price is obviously the singlemost important variable in consumer decision making most of the time, it is rarely an exclusive consideration and often may not be the most important one.

are not significant or useful, but that their capacity to maintain a company's long term competitive stature is limited in the absence of technical innovation.

Given the critical role of innovation--especially the use of technical innovation in the competitive process, what can be said about competition and firm-level innovation? According to Adler, very little:

> In research on competitive behavior, we would expect to find a wealth of technology strategy materials. Unfortunately, the dominant economic paradigm privileges mathematical simplicity over realism when the latter threatens analytic tractability. (Adler, 1989, p. 39)

Adler's pessimism is directed at neoclassical models of competition, which typically make the *cetaris paribus* assumptions of "perfect competition" and place technology outside the model as freely available (and absorbable) by all firms. Such models deny the use of technology as a competitive tool and effectively eliminate our ability to understand the role of technical change and innovation in the competitive process.

The microeconomic innovation literature, which attempts to loosen the restrictions on these models (or even flatly reject them), is nonetheless fragmented among research which focuses on the macroeconomic environment, the organizational characteristics of firms, and the innovation process itself. While all are appropriate units of analysis, they have not yet been incorporated into a uniform framework which can explain the rate, direction, and character of innovation from a competitive perspective.

Nevertheless, a few "stylized facts" may be drawn from this literature about technical innovation and competition at the firm level. First, consistent with consumer demand theory, the nature of demand for a product (or potential product) seems to be the major force inducing firms to innovate (Chesnais, 1986; Freeman, 1982; Dosi, 1988). The strength of demand, its rate of growth, size of the market, demand elasticities, willingness of consumers to switch products or suppliers, etc. are all fundamental characteristics of consumer markets which signal firms to innovate. The actual competitive response may be infrastructure-related, organizational, or technical change.[26]

[26]Price reductions unaccompanied by a change in the cost structure of a product are specifically excluded here as an innovative response. In the absence of a change which alters the unit cost of a good, businesses have a finite ability to sustain a long-run decline in price.

Since technical innovation attempts to address one (or both) of the two major dimensions of product differentiation--delivered cost and product attribute--it may also be induced by a number of "supply" factors as firms try to maintain or improve their competitive position. Rosenberg (1976) discusses these inducers at length, which generally include bottlenecks, the scarcity or abundance of factor inputs, and changes in the relative prices of factor inputs. Shifts in demand structures (which may be the result of innovation by another firm or changes in consumer tastes and expectations), cost-related inducements, and new market opportunities (e.g., those that derive from technological change or innovation) therefore comprise the major types of stimulants to technical innovation.

These "objective" stimulants are, however, filtered through two important structures: that of the market and that of the organization. In terms of market structure, economists have theorized, debated, and studied at length the impact of "purely" competitive, oligopolistic, and monopolistic market structures on the process of innovation (see Scherer, 1984; Stiglitz, 1986; and Kamien and Schwartz, 1982 for summaries of this literature). Since the structure of the competitive environment sets the "'rules' which relate payoffs to actions" (Stiglitz, 1986, p. 399), it determines the overall incentive system by which a firm (or group of firms) will decide when and how to innovate. While there is no consensus at all on the "best" structure for a healthy innovative environment or even on the impact of the various structures on innovation, it does appear that both too much and too little competition impede innovation.[27]

The organizational setting of a firm is, in turn, a critical filter of market demand and structure, since it affects the company's perception of its environment (opportunities, constraints, uncertainty) as well as its competitive strategy and decision-making. The organization theory literature abounds with the organizational contingencies which determine the relative "innovativeness" of a firm and its innovative effectiveness; the critical variables include organization structure, information control systems, boundary spanning networks, leadership decision-making, and corporate culture (Daft, 1989; National Science Foundation,

[27]The notion of "too little" competition and its relationship to technical change has been born out somewhat in the competitive performance of the U.S. auto, steel, and television industries. All three were highly oligopolistic prior to international competition, and the case study literature on the declines in these industries all seem to suggest that the concentration of market power among a handful of firms led them to adopt relatively conservative (or non-existant) technology-based competitive strategies, making them quite vulnerable to foreign competitors who did use technical innovation as a significant component of their business strategy.

1983; Adler, 1989). In essence, organizational context influences the firm's perception of the risk and uncertainty[28] associated with any given (perceived) opportunity or necessity to innovate, the innovative direction the firm takes, and the success with which it does so. With regard to the technical innovation itself, firms may elect to undertake product, process, materials, or energy-related innovations; the change may be radical or incremental and imitative or original in character.

Although the profile of any given innovation is complex, Freeman observes that firms tend to adopt one of several types of technical innovation strategies, ranging from offensive to opportunistic (1982, ch. 8). Firms may change these strategies over time and may use different ones for different product lines, but notably each type of strategy demands different resources and energies from the firm. Generally, the innovation strategies reflect declining degrees of R&D-intensity (and technological novelty), as well as where along a product cycle a firm decides to concentrate its competitive efforts. Thus, the most highly R&D-intensive strategy (offensive) is largely a pre-emptive competitive effort designed to create radical change and thus establish barriers to market entry by rivals (see also Dosi, 1984; Dasgupta, 1986). The first firm to introduce a major change (spawning a new product cycle) typically enjoys monopoly profits until the advent of effective competition.

This strategy is also the most organizationally demanding, since success (prolongued market power and profitability) requires high quality R&D, extensive quality control efforts, technical services, and education and training of personnel and customers, to name a few. It also requires that the firm be adept at "learning by doing" (Arrow, 1962a; Rosenberg, 1976) a process which can further solidify its monopoly position if accompanied by effective functional interfaces within the firm (appropriate coordination and interaction between R&D,

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[28]The risk and uncertainty associated with competition, demand, and technical change are in fact key determinants of the nature, rate, and direction of technological change and innovation. A whole body of literature has grown out of the seminal work by Arrow (1962b) and deals more or less with issues of the relationship between appropriability, risk structures, investments in R&D, and innovation. Since risk and uncertainty are functions of perception and quality of information flows, the organizational environment forms an important milieu for risk perception, reduction of uncertainty, and styles of risk-averseness of the firm. For a discussion of the relationship between organizations and uncertainty, see Daft (1989); for a discussion of the relationship between market structure and risk, see Stiglitz (1986).

manufacturing, sales, and marketing; see Adler, 1989).[29] Even Freeman's defensive and imitative innovation strategies, which are largely "reactive", are R&D intensive in their own right and require types of institutional support not dissimilar to offensive strategies.

As is implied by the above discussion, we can think of the competitive "success" of a firm's innovative efforts in at least two useful ways: its market "success" (whether or not the innovation was accepted by the marketplace, reduced costs, etc.) and whether or not the firm was successful in appropriating the profits of its innovation. With regard to the first, there is a growing body of literature which catalogues the criteria for the success and failure of technical innovations (see Adler, 1989); Freeman (1982) finds that the factors which seem to distinguish successful innovations from non-successful ones are: 1) the "user needs" were clearly understood by successful innovators and intensive efforts were made to ensure market success (a finding consistent with Von Hippel, 1988), 2) failed innovations tended to have a "high number of post-development bugs" and required extensive user adaptations (thus reflecting on the competence of the original R&D), and 3) successful innovations tended to have substantially larger project teams and/or were headed by senior managers.

Whether or not the profits from successful innovations accrue to the initial innovator (or innovating country) is important, since the profit is the reward for the innovation: it covers the cost of innovating and is also what enables the innovating firm (country) to sustain its competitive dynamic. In many respects, the inability to appropriate the economic return from an innovation is a signal of poor competitive skills,[30] since it implies an inability to adequately control one's product. While patents and other legal means of intellectual property protection come to mind as the most predominant form of appropriation, Teece (1986) observes that these instruments work only when the technology itself is highly excludable. Otherwise, once the "dominant design paradigm" is established, imitators with better complementary assets (strong manufacturing capabilities, reliable distribution networks, high quality after-sales service, etc.), can undermine the competitive strength of the original innovator.

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[29] Similarly, Chesnais (1986) argues that R&D and innovation are used for the creation of "asymmetries" between firms, asymmetries which yield monopoly gains and which can be prolonged by the occurrence of high R&D threshhold costs. Additionally, "would-be imitators [can] be repreatedly frustrated if the initial innovators [can] maintain a flow of process innovations related to scale economies and new generations of products" (p. 102).

[30] Especially at the beginning stages of the product cycle, where the monopoly rents are highest.

Similarly, Nelson (1988) finds that there are other, more common means of appropriation available to firms, especially in the innovating stages of a product cycle. Lead times, learning curve advantages, complementary assets are all useful mechanisms through which rents may be appropriated, as well as some forms of secrecy. Notably, process innovations are far more difficult to "protect" than product, and Mansfield (1987) found that only about one-third of U.S. industrial innovations were in fact process innovations. In the later stages of a product (or process innovation) cycle, when competition becomes centered much more intensively on price and services rather than on product design and novelty, technical innovation strategies may need to shift yet again. Abernathy and Utterback (1982) and Moore and Tushman (1982) thus offer specific organizational/management advice on dealing with the changing dynamics of innovation as they relate to both the nature of the innovation itself over time (Abernathy and Utterback) and the product cycle (Moore and Tushman). As a final word, in almost all issues relating to industrial innovation, there are pronounced inter-industry differences in the nature and volume of innovations, relevance of different modes of appropriability, and the degree of importance of different complementary assets.

These stylized facts reinforce the notion that is are a large range of significant variables affecting the rate, direction, adoption, and diffusion of technical innovation, including the extraordinary influence of organizational context. One of the more problematic aspects of our understanding of the economics of innovation is an inability to assess the relative weight and importance of different forms of technical change--that is, which kinds of technical change embue the most economic benefits for firms, industries, and nations. Additionally, as Freeman points out, most of what we do know about the rewards of innovation deals only with R&D: "what is not known is the relative contribution to technical progress of R&D work by comparison with the inventions and improvements generated entirely outside the formal R&D system" (1982, p. 128).

Macroeconomic Competitiveness

The microeconomic competition and innovation discussed above are the building blocks of economic growth and development. As firms compete, they innovate accordingly and consumer demand shifts, investments are made, new efficiencies are created, new markets emerge, resources are reallocated, output and incomes rise, and nations experience growth and development. Understanding firm-level innovative activity is therefore crucial to understanding competitiveness and long term economic growth and development, since it is firms themselves that respond to competitive pressures with particular innovation choices. The type of innovation, its appropriateness to the competition at hand, its rate of development and implementation, and its commercial success are all effected through and within the context of the firm itself. To the extent that companies face foreign rivals at home and can avail themselves of markets abroad, the ability to prevail in "international" competition is a necessary component of domestic growth and development as well.

Successful microeconomic innovation cumulates into national growth and development through the process of imitation and diffusion. Thus, as regards competition, innovation, and growth, there may be a fundamental tension between the needs of an innovator (or innovating country) to preclude the imitaton of an innovation in order to appropriate its profits, and the need to diffuse the innovation in order for widespread economic welfare to occur. Balancing and managing these conflicting needs may require public policy intervention, since a large body of diffusion literature (on the costs of invention versus imitation; see Stoneman 1983, 1987) suggests that imitation is most likely to occur when the risk of not doing so is great (e.g., being left out of bandwagon effects or new markets) or when the costs of imitative innovation are sufficiently low and unrisky (i.e., the rate of return is known and past the firm's hurdle rate). Because both invention and imitation are investment-intensive (they require large capital start-up costs), the broader macroeconomic investment climate (cost of capital) affects both the rates of inventive and imitative innovation, and is yet one more significant determinant of the rates of both innovation and diffusion.

Competitiveness (whether domestic or international) can thus be thought of as the ability of a firm, through a process of innovation, to successfully differentiate its products in the marketplace and maintain (or increase) market shares and profits accordingly. Over time, the dynamics of competition will ideally lead to higher productivity, market growth, and development; it is the competitive pressure of the market which causes innovations to be introduced and diffused throughout an economy.

If, as Chesnais (1986) argues, we can think of a nation's competitiveness as the cumulation of the competitiveness of firms which operate within and export from its boundaries, then competitiveness takes on an additional dimension. Not only must we consider the competitive and innovative environment generated by a market (which may be national or international), but how an economy as a whole competes within the international system.

Competitiveness thus has a horizontal and a vertical dynamic. We may consider the horizontal dimension to be the competition which *firms* within a nation experience in their state of rivalry over product differentiation (and which may include foreign rivals); the vertical dimension reflects the cumulative distribution (by product or industry) of a country's competitive strengths and weaknesses vis-a-vis other nations in the system. The vertical dimension therefore encompasses a nation's comparative advantage (commodity composition of trade) *and* balance of trade. Vertical competitiveness is both static and dynamic. We can capture the vertical competitive profile of a nation at a given point in time (in essence its the disaggregation of its competitiveness among economic sectors, industries, or product classes); however, a country must also be able to respond to changing "macro-rivalry" by reallocating its production resources away from less competitive to more competitive sectors in its economy. "Competitiveness" as a concept thus becomes horizontal market and sector rivalry, comparative advantage profiles, and the ability of an economy to respond to changing international competition through structural adjustment.

Conclusions

Science policy has been rightfully informed by theories and evidence which show that technical change has had a profound impact on industrial market economies. Based on the historical record, it would be foolish to reject the fundamental presumption that science and technology are important for long term economic welfare. But long term economic welfare--understood as growth and development--is not the same thing as competitiveness. Competitiveness simply may not be equated with either its causes or consequences, for to do so denies the uniqueness of the phenomenon.

What may we infer about the role of science and technology in competitiveness, given that theorizing and research typically do not address this question *per se*? Most importantly, it seems reasonable to conclude that innovation plays a critical role in competitive performance, since innovation is what allows firms to differentiate their products in the marketplace. Moreover, while administrative and managerial innovations are important, it is technical innovation that is likely to sustain competitive advantage over time. The innovation-based explanation of competition developed and presented here is quite consistent with the new technology-based competition strategies emanating from the business schools.

However, competitiveness policy has been burdened by the intellectual heritage of science policy. The linear model of innovation mistakenly assumes the primacy of science in generating economic welfare. For science to have an economic impact it must pass through the disjointed stages of technical change; discovery must be accompanied by application, and the resultant commercial innovation must be diffused throughout the economy. The dynamic that "pushes" science through the stages of technical change is one that we may broadly term "innovation," but it is the contingencies of innovation that create disjuncture in the technical change process.

Far from being paramount in the innovation process, science is availed only as a result of pressures from the marketplace. To complicate matters more, science is interpreted and adapted through the imperfect information filters and capacities of organizations. Because of the critical role of markets and organizational psyches and processes, at best we can say that bringing science to market is highly *contingent* upon the presence (or absence) of a number of determinants of successful innovation. Science, quite simply, is not a sufficient condition for innovation, and consequently not for competitiveness either.

The intellectual baggage of science policy goes further, however, for not only does this tradition argue that science is a sufficient condition for economic progress, but that it is a necessary *precondition* for technical (or technological) innovation. Here again, theory and research throw doubt on these views. It would appear that many industries can exploit extant technological regimes without the benefit of science; incremental innovation and trial-and-error experimentation may be far more crucial to competitive success that many would like to admit. Moreoever, technological regimes don't even have to result from scientific discovery. Although science based industries draw more heavily from the scientific frontiers (a somewhat tautological finding), such industries are not preponderant in the manufacturing sector. As several analysts have found, for the vast majority of industries, innovation emanates from in-house R&D, and in certain industries, not from R&D at all. It would appear that science is neither a direct or exclusive path to competitiveness.

Nevertheless, for high tech sectors, science appears to be fundamental to economic advance. High tech development strategies rely on the emergence of science-induced technologies, and are based on evidence that the resultant industries have had unusually high rates of profit, growth, and employment. In the past, such economic gain was enabled by a critical factor: the monopoly power that resulted from having a long lead time on the product cycle. The technological sophistication of U.S. international competitors was sufficiently behind that the nation enjoyed years, if not decades, of competitive advantage by virtue of knowledge alone. The United States was competitive because it was the only producer of consequence for a substantial range of high tech products.

But such is not the case today. The capacity of other nations to imitate (and create) science-based technologies is greatly improved, and contemporary global product cycle dynamics suggest increasingly compressed monopoly-power lead times for high tech industries. As Freeman and Teece so clearly spell out, to create and maintain competitive advantage via science-based technological leadership places extraordinary demands on a firm. Not only must they have highly creative and skilled R&D units, but these must be fully integrated with production, marketing, and sales functions. The scope and intensity of successful leadership requires organizational forms and systems *that are the most difficult to create and maintain.* Competitive success can no longer be assured by science alone, since knowledge lead times are themselves fragile and unstable. It is doubtful that any one nation can command sufficient scientific and technological leadership to enjoy the privileges and rewards of knowledge-induced monopoly in the absence of the requisite complementary assets.

What then may we hypothesize about the utility of public policy for resolving the competitiveness crisis? The heavy supply-sided emphasis in current policies places the "cause" of competitiveness at the initial stages of technical change and neglects the contingencies of innovation. It is tempting to simply propose the "null hypothesis," that is, that there is no systematic relationship between science, technology, and competitiveness because there are too many critical, intervening variables. Bringing science to market is not a direct path, and in all likelihood, it is the intervening variables that are the problem. After all, we have not been able to empirically (or qualitatively) establish declines in scientific or technological innovation.

And this is precisely the problem. While we seem to have a good understanding of all the various inputs and factors which contribute to successful innovation, we are simply ignorant of their relative weights and significance. The supply of science may yet "outweigh" the intervenors in terms of their determinacy of competitiveness; there is really no evidence or research which allows us to establish the strength of "causality" of the multiple contingencies of innovation and competitiveness.

The following hypotheses are therefore offered about the relationship between "science, technology, and competitiveness." These conjectures are consistent with the science and competitiveness policy assumptions, and they derive from the prevailing paradigms and approaches in science policy-making as well as the richer microeconomic innovation theory and research:

I. *Basic research is a direct determinant of competitiveness.*

Because basic scientific research provides the discoveries which lead to technological paradigm change, it can overcome innovation bottlenecks that derive from the economic exhaustion of existing paradigms. Additionally, basic research has been positively associated with a high number of significant inventions which firms have then availed in their competitive efforts. We can equate basic research activities with efforts to produce scientific or science-based technological knowledge.

II. *Industrial R&D is a direct determinant of competitiveness.*

Industrial R&D is the manifestation of the interaction between a firm's efforts at generating technical innovation and the competitive pressures which it faces. There should therefore be a high degree of association between R&D efforts and competitiveness, since these behaviors are mutually reinforcing. We can equate industrial R&D with efforts to produce technical innovation since, in fact, this is what it has been repeatedly shown to be.

III. *Linkages between basic research, industrial R&D, and competitive performance will be strongest for high tech industries.*

Since high tech industries are closest to and most dependent on scientific frontiers, there should be a somewhat stronger relationship between basic research and high tech industries than others. Additionally, because high tech industries are--almost by definition--research intensive, then their competitive performance must be more closely associated with R&D activities than other industries.

The above hypotheses will be "tested" (in the roughest sense) by exploring patterns of competitiveness and expenditures in basic research and industrial R&D. Expenditure data are admittedly imperfect measures of the *quality* of innovative activity; they do not capture the full scope of innovative efforts or outputs, nor are they particularly reflective of inter-industry spillovers of innovation. Nevertheless, years of study have demonstrated that these data represent relatively well the dimensions of organizationally-based innovation. As a somewhat simple control for R&D "output" (both quantity and quality), expenditure patterns are compared with publication data (for basic research) and patent statistics (for industrial R&D).

As will be seen in the following chapters, there does seem to be a reasonable degree of association between the R&D inputs into scientific and technological endeavors and their innovative outputs.

Unfortunately, because these hypotheses have not been previously explored using appropriate, disaggregate measures of competitiveness, it is difficult to specify *a priori* what kind of relationships we might expect to find between indicators of science, technology, and competitiveness. Because competitiveness is a relational activity, it is assumed that *differentials* in R&D efforts are the key patterns to be studied. However, it is not clear whether it is differentials in absolute magnitude, relative intensity, or rates of change that might be the key determinants. Moreover, patterns of association between science, technology, and competitiveness must be discernable from such other economic patterns as business cycles and historical trade patterns. Standard econometric and regression approaches are therefore of limited use at this exploratory phase of research, since we lack sufficient understanding for the constructing of such models. A case study "pattern matching logic" will therefore be employed to evaluate the associations between each country's relational patterns of science, technology, and competitiveness.[31]

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[31]See Robert K. Yin, *Case Study Research; Design and Methods,* revised edition (Newbury Park, CA: Sage Publications, 1982), for an elaboration of the pattern matching method.

Part III
Patterns of Competitiveness and Innovation

Asia imitates. It imitates to the minutest details, and yet it does not advance the knowledge it has borrowed. If by any effective means, all sources of information on technological innovations from Europe and America were cut off from Asia, then Asia would instantly become powerless.

A. Siegfried, *The Spirit of the West*

CHAPTER 5

Patterns of Industrial Competitiveness

As was suggested in chapter 1, there has been a tendency to infer U.S. competitive health from data on the presumed determinants of competitiveness (R&D, productivity) and its consequences (trade, growth). This is problematic to the extent that it equates inputs with outputs, and overlooks all of the additional factors which are contained within the "black box" of competitiveness. Missing in our analyses have been more direct measures of competitive performance, identified in chapter 4 as (at minimum) market share trends, comparative advantage indices, and balance of trade figures *at the industry level of analysis*. Not only are more direct measures of competitiveness required, but a more disaggregate approach is needed to begin refining our understanding of inter-industry variations in performance. The relative ambiguity of the national aggregates dictates detailed examination of more refined breakdowns in the data.

One of the primary difficulties in constructing a competitive profile of the U.S. manufacturing sector has been in obtaining the breadth of data at comparable levels of aggregation necessary to do so. To construct even crude market share data, figures are needed for U.S. industrial output, imports, and exports. Ideally we would also need capacity utilization measures to control for macroeconomic influences, and wage rates to indicate qualitative competitiveness.[1] All these data are available from various sources, but not always at comparable levels: trade data are reported in the Standard Industrial Trade Classification (SITC), several different productivity data series exist at various levels of aggregation (national, manufacturing sector, 2-digit SIC), etc. The biggest problem is typically with the international trade data. Most other data of interest are reported in some fashion at the industry level, whereas trade data are grouped by products (and often by the materials out of which the products are constructed, not industry of origin).

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[1]Hart argues that competitiveness contains both quantitative and qualitative dimensions. That is, it is not enough to prevail in the marketplace; market position cannot be sacrificed to economic welfare. As a consequence, he suggests that wage rates are an appropriate micro-level indicator of the qualitative dynamics of competitiveness. If market share can be maintained (or enlarged) while simultaneously advancing the quality of life of a firm's (or industry's) workers, then we can argue that it is competitive in the most positive sense. See Jeffrey Hart, *Rival Capitalists* (Ithaca: Cornell University Press, forthcoming 1992).

The Organisation for Economic Cooperation and Development (OECD) has been engaged in an ongoing project to construct a database of key economic data for all of its member countries *at comparable levels of reporting*. One of the first activities of this project was to process the ISIC trade data into 2- and 3-digit SIC industries of origin. What this has allowed is the calculation of industry-level balance of trade figures and import penetration ratios, the two critical "first measures" of competitive stature. Unfortunately, the readily available data are highly aggregate (only 24 industries) and do not report the country of origin of imports or country of destination for exports. This limits a more refined assessment via this data set of competitive industries/product groups and the identification of major foreign competitors by industry.

However, data reported by the U.S. Department of Commerce are more detailed (manufactures trade is broken down into 42 product groupings and the origin/destination of trade identified). While the orders of magnitude are somewhat different than those of the OECD trade data, the trends are sufficiently similar in both data series that we can "cobble" them together to provide a more detailed analysis of U.S. manufacturing competitiveness.[2] The discussion below develops a profile of the industrial nature of the U.S. competitiveness crisis using a variety of indicators derived from U.S. industrial trade and production data.

The Crisis in International Perspective

Comparative data suggest that the hallmark of the U.S. competitiveness crisis is indeed its protracted deficit in manufactures trade. An analysis of import penetration ratios and the balance of trade among the Summit 7 from 1970-85 reveals that the U.S. is unique not in its rising levels of import competition, but in its inability to offset growing imports with comparable growth in exports. In the national aggregate, the total magnitude of U.S. import

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[2]The principal problem with the OECD and Commerce data is reconciling the total figures reported for manufactures trade in the two data series. For example, Commerce reports manufactures trade surpluses for all years up to 1982 except 1978, whereas the OECD shows additional deficits for 1970, 1975, 1976, and 1980. The differences are being explored further; however, it seems that the OECD data include products that Commerce considers to be non-manufacturing merchandise trade, e.g., the outputs of petroleum refineries and some agricultural products produced by the food processing and tobacco industries. This causes the OECD deficits to be larger (and surpluses smaller) than Commerce manufactures trade data. Nevertheless, the surplus and deficit status of the individual industries/trade product groups do reconcile to a considerable degree, except where indicated in the text above.

penetration does not seem to be out of line with other countries; in fact, the United States and Japan enjoy the lowest levels of import penetration of the Summit 7, with imports accounting for only 13% and 5% of consumption, respectively (table 5.1).[3] When "distorting" elements of the comparisons are discounted (e.g., the American share of the Canadian market, intra-European penetration), the import penetration ratios for all of the Summit 7 countries (except Japan) range from 8-13%, with the United States and Germany at the upper end of this distribution.

Although the net rise in U.S. import penetration from 1970-85 was high (135%), so was that of other countries. The increase for the United Kingdom was also 135%; the level of foreign market share doubled during the period for Germany and Italy, and France's rose 70%. Only Canada registered a relatively modest increase in import penetration of 35%. The rate of increase in import penetration has also generally been rising, with the result that a disproportionate amount (42%-49%) of the net increase in import penetration from 1970-85 occurred during 1980-85 in all of the Summit 7 countries except Italy (and Japan).

What does distinguish the United States and European members of the Summit 7 is the country-of-origin patterns of their market shares (table 5.1). Japanese imports represent 24% of the total import penetration of the U.S. manufactures market in 1985, roughly 4-5 times higher than the comparable share in the European countries and Canada. Similarly, products from non-OECD countries account for 32% of the total foreign share of the U.S. market, twice the level of some European countries and nearly four times that of Canada. The East-Asian NICs account for a much higher proportion of the U.S. non-OECD market share (44%) than the European (8-22%).[4] As is expected, the vast majority of import penetration in the European nations of the Summit 7 is accounted for by other European countries, a relatively stable

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[3]Japan is excluded from the remaining comparisons because it is anomalous. Balassa and Noland (1988) find that Japanese import patterns so deviate from any that may be reasonably expected from an industrialized nation of its size that major structural differences must exist within its economy. As a consequence, one may assume that Japanese import dynamics are sufficiently different that we cannot make even superficial comparisons with other countries.

[4]A more detailed examination of the market share trends for the non-OECD countries shows that in European markets, none of the regions in this group (developing Asia, Africa, America, Comecon, and the East Asian NICs) are doing appreciably better than others. By comparison, the NICs fare much better in their market shares in the United States, Canada, Australia, and New Zealand than other countries.

Table 5.1--Comparative import penetration levels, all manufacturing industries (in percent)

Year and region of origin of imports	Import penetration levels for:						
	U.S.	Japan	Canada	France	Germany	U.K.	Italy
1970							
Total	5.5	4.7	23.5	16.2	19.5	14.2	16.3
Non-OECD	1.3	1.6	1.2	2.0	2.9	3.2	2.5
OECD	4.3	3.2	22.3	14.2	16.6	11.0	13.8
Japan	1.0	--	1.1	0.2	0.5	0.3	0.3
U.S.	--	1.7	17.3	1.8	2.0	2.0	1.9
Europe	1.7	0.9	3.6	12.0	13.6	6.8	11.0
All other	1.6	0.6	0.3	0.2	0.5	1.9	0.6
1975							
Total	7.0	4.9	25.8	17.9	24.3	19.4	22.0
Non-OECD	2.2	2.0	1.5	2.0	3.7	3.9	3.3
OECD	4.9	2.9	24.2	15.9	20.5	15.5	18.8
Japan	1.2	--	1.1	0.5	0.8	0.8	0.4
U.S.	--	1.4	19.3	1.6	1.7	2.1	2.0
Europe	2.0	0.9	3.6	13.6	17.3	11.4	15.9
All other	1.7	0.6	0.2	0.2	0.7	1.2	0.5
1980							
Total	9.3	5.8	27.7	22.8	30.6	25.3	29.4
Non-OECD	3.2	2.5	2.0	3.5	5.6	5.9	5.3
OECD	6.1	3.3	25.7	19.4	25.0	19.4	24.1
Japan	1.9	--	1.4	0.7	1.3	1.1	0.6
U.S.	--	1.7	20.8	2.2	2.3	2.7	2.3
Europe	2.4	1.0	3.2	16.1	20.6	14.6	20.4
All other	1.8	0.6	0.3	0.4	0.8	1.0	0.8
1985							
Total	12.9	5.2	31.7	27.5	39.1	33.3	31.3
Non-OECD	4.1	2.1	2.7	4.2	6.9	5.5	6.5
OECD	8.8	3.1	29.1	23.3	32.2	27.9	24.7
Japan	3.1	--	2.1	1.0	2.3	1.9	0.7
U.S.	--	1.7	23.2	2.5	2.8	3.9	2.1
Europe	3.2	0.9	3.7	19.3	26.1	21.0	20.8
All other	2.5	0.5	0.1	0.5	1.0	1.1	1.1

Source: Calculated by the author from OECD (1988b).

Table 5.2--Summit 7 trade in manufactured goods, 1970-85
(in thousands national currency, except as noted)

Item	U.S.	Japan 1/	Canada	France	Germany	U.K.	Italy 2/
1970							
Exports......	34,802	6,833,622	12,828,968	88,730	119,064	7,454,918	7,882
Imports......	33,034	3,038,945	11,953,878	81,474	81,497	6,585,634	6,583
Balance....	1,768	3,794,677	875,090	7,256	37,567	869,284	1,299
Ex/Im ratio..	1.05	2.25	1.07	1.09	1.46	1.13	1.20
Bal/Ex ratio.	0.05	0.56	0.07	0.08	0.32	0.12	0.16
1978							
Exports......	109,865	20,436,455	39,447,394	319,093	272,058	33,026,523	47,147
Imports......	130,713	6,385,924	42,140,339	272,579	184,528	31,577,493	31,051
Balance....	(20,848)	14,050,531	(2,692,945)	46,514	87,530	1,449,030	16,096
Ex/Im ratio..	0.84	3.20	0.94	1.17	1.47	1.05	1.52
Bal/Ex ratio.	-0.19	0.69	-0.07	0.15	0.32	0.04	0.34
1980							
Exports......	166,059	29,061,409	52,403,390	431,971	328,641	41,418,358	65,845
Imports......	162,229	11,081,091	54,791,680	401,453	244,761	39,798,543	57,141
Balance....	3,830	17,980,318	(2,388,290)	30,518	83,880	1,619,815	8,704
Ex/Im ratio..	1.02	2.62	0.96	1.08	1.34	1.04	1.15
Bal/Ex ratio.	0.02	0.62	-0.05	0.07	0.26	0.04	0.13
1985							
Exports......	166,413	41,574,940	89,462,340	786,354	507,454	60,015,962	146,574
Imports......	296,568	12,778,782	92,461,047	732,093	352,830	70,383,020	119,372
Balance....	(130,155)	28,796,158	(2,998,707)	54,261	154,624	(10,367,058)	27,202
Ex/Im ratio..	0.56	3.25	0.97	1.07	1.44	0.85	1.23
Bal/Ex ratio.	-0.78	0.69	-0.03	0.07	0.30	-0.17	0.19

1/ Millions national currency.
2/ Billions national currency.

Source: Calculated by the author from OECD (1988b).

Table 5.3--Growth in U.S. import penetration and manufactures consumption

	1970-74	1974-78	1978-82	1982-86
Real average annual growth in U.S. consumption of manufactured goods.........	5.8%	3.3%	-1.9%	4.6%
Percent of net change in U.S. import penetration (1970-86) which occurred in period......	31%	15%	10%	44%

Source: Calculated by the author from OECD (1988b) and unpublished data provided to the National Science Foundation.

two-thirds of the total foreign market share.[5] Notably, all the Summit 7 nations are contributing to their mutual growth in import penetration; each has increased its market share *in absolute* terms in the other countries since 1970. This does not imply that the competitiveness of all nations is declining; rather, it suggests a growing differentiation and specialization in world production and trade. For reasons that are not clear, this specialization and differentiation intensified during the first half of the 1980s.

From all appearances, the principal characteristic of the U.S. competitiveness crisis is indeed the event which signalled it in the first place: an extraordinary, and sudden, worsening in the balance of trade in manufactured goods. While all of the Summit 7 ran reasonable[6] balances of trade throughout the 1970-85 period, only the United States has experienced an intractable, and quite huge, manufactures trade imbalance. By 1985, the deficit was the equivalent of *more than three-quarters* of total U.S. exports for the year (table 5.2).[7] The "cause" of this deficit was the failure to increase exports commensurate with growing import consumption. From 1980 to 1985, there was no change in the nominal dollar volume of U.S. manufactures exports; at the same time the dollar volume of imports increased about 83%. Other nations in the Summit 7 had as high or higher increases in their imports as well (except Germany and Japan, whose growth in import consumption was substantially less), but were able to offset increases in imports with exports.

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[5]The overall high levels of import penetration in Europe undoubtedly derive from the industrial specialization required to overcome the economy-of-scale constraints presented by the small market size of the individual European countries. The very high proportion of their imports coming from other European OECD members substantiates this conclusion; the presence of the EC trading structure also reinforces intra-European trade to the exclusion of other sources of imports. The European countries demonstrate a high propensity to trade among themselves, their previous colonies, and nations in geographic proximity (e.g., the COMECON). This propensity results in the rather substantial underrepresentation of Japanese and NIC imports in the European markets relative to the United States and other "Anglos" in the Pacific Rim (Australia, New Zealand, Canada). Whether the higher levels of Asian imports in the U.S. market is the result of (a) its own historical trading patterns, (b) proximity, (c) the deflection of these imports due to European barriers, (d) differential patterns of manufactures production and consumption between Europe and the U.S., or (e) some combination of these, cannot be said definitively.

[6]Note that it is not necessary for nations to perfectly balance their trade accounts (i.e., to zero). There are acceptable margins of both surplus and deficit which are not considered to be detrimental to the domestic economy.

[7]Although the United Kingdom also began running a net manufactures deficit during this period (starting in 1982), its deficit represented about 20% of British exports for 1985.

These data are admittedly highly aggregate statistics whose interpretation cannot be taken too far. Nonetheless, some conclusions seem reasonable. First, the rapid growth in world trade after the movement to floating exchange rates does seem to have resulted in trade rationalization. Since import penetration increased substantially in all the Summit 7 countries, and all seven nations increased their foreign market shares in absolute terms while maintaining balanced trade, we may take this as rough evidence of growing specialization and gains from trade.

Second, the United States certainly has not been alone in experiencing a rising volume of imports, their gain in home-market shares, and the increased competition which these trends represent. Nor is it unique in the stunning increases in import volumes which took place in the early 1980s. What the U.S. did not participate in was the accompanying growth in exports that other nations enjoyed, with the result that the competitiveness crisis was launched by the dramatic deficit in manufactures trade. Clues to the crisis may lie in macroeconomic influences, since the onset of the U.S. recovery coincided with the slower absorption of imports by Germany and Japan during this period. Not only has import penetration typically been highest during strong growth cycles (table 5.3), but the lack of growth in exports was a direct contributor to the deficit. In other words, export volumes were insufficient to offset the traditional spurts in imports and import penetration which coincide with business cycle upswings. Since the dollar was significantly overvalued through the first half of the decade, it had a dampering effect on the attractiveness of U.S. products overseas. What remains to be seen is whether or not these macro effects were uniform throughout the manufacturing sector, or whether some industries were hit harder than others.

Patterns of Industrial Competitiveness

The Balance of Trade

The OECD and Department of Commerce trade data indicate virtually identical problems in U.S. manufacturing trade performance in the early and mid-eighties. By and large, the trade dimension of the crisis represent (a) the erosion in the balance of trade across all 2- and 3-digit manufacturing industries except aerospace, (b) the substantial worsening in the trade deficit of the existing "big four" deficit generators in 1981-82 (autos, textiles, electronics, and steel), and (c) the large reversal from surplus to deficit in the two industries that have typically generated large (and increasing) surpluses--electrical and non-electrical machinery.

Table 5.4 presents balance of trade data for 24 of the Department of Commerce's 2-digit "schedule A&E" product classifications. The A&E Schedule breaks down manufactures trade into 42 product groups; 24 of these product categories accounted for 90% of U.S. imports and 84% of U.S. exports in 1987. The product groups are organized into three categories in table 5.4 (1) those with balance of trade deficits in both 1981 and 1987, (2) those which experienced a reversal in their balance from surplus to deficit during this period, and (3) those which ran surpluses in 1987.

There are several distinctive characteristics about trade in these products between 1981 and 1987 that are serious cause for concern about the U.S. international competitive position. First, only 3 of the 24 categories showed an improving balance of trade during the period--drugs and medicines, synthetic resin and rubber products, and steel products. In every other category, the balance of trade was worse in 1987 than 1981. Second, of the 14 product groups which ran trade surpluses in 1981, 8 were in deficit by 1987. Third, 9 of the 24 products groups accounted for *three-quarters* of the decline in the trade deficit between 1981 and 1987. These 9 product groups (motor vehicles, wearing apparel, special industrial machinery, telecommunications and sound equipment, miscellaneous manufactures, miscellaneous industrial machinery, miscellaneous electrical machinery, steel, footwear) also accounted for 82% of the total 1987 deficit. Motor vehicles is the single-largest deficit product group, both absolutely and relatively; in 1987 the deficit in motor vehicles trade represented one-third of the total deficit in that year and worsened by nearly $41 billion between 1981 and 1987, a decline nearly 3 times larger than the net decline in wearing apparel, the second-ranked worsening product group.

The OECD industry-level data confirm the trends indicated by Commerce's product data. (See table 5.5 for a list of the OECD industry classes and a brief description of the outputs of these industries.) It is important to keep in mind that data reported at the industry level are at a higher level of aggregation than product level, and include all 42, not just the top 24, of the product groupings. As a consequence, industry trends will be slightly different than

Table 5.4--U.S. balance of trade, 2-digit A&E product groups, 1981 and 1987
(dollars in billions)

	Balance of trade			Product group as a percent of:	
Product category	1981	1987	Change, 1981-87	1987 Deficit	Total decline, '81-87
Products with deficits in 1981 and 1987					
Motor vehicles	($12.8)	($53.3)	($40.5)	33.6%	27.7%
Wearing apparel	($6.7)	($20.8)	($14.1)	13.1%	9.7%
Telecommunications & sound equipment	($5.0)	($15.6)	($10.6)	9.8%	7.3%
Misc. manufactured products	($2.3)	($12.8)	($10.5)	8.1%	7.2%
Footwear	($3.1)	($7.5)	($4.4)	4.7%	3.0%
Non-metallic minerals	($2.5)	($6.8)	($4.3)	4.3%	2.9%
Paper & paperboard	($1.0)	($4.4)	($3.4)	2.8%	2.3%
Nonferrous metal products	($4.3)	($6.0)	($1.7)	3.8%	1.2%
Iron & steel mill products	($9.2)	($8.5)	$0.7	5.4%	
Products with a reversal from surplus to deficit, 1981-87					
Special industrial machinery	$9.5	($1.6)	($11.1)	1.0%	7.6%
Misc. industrial machinery	$6.6	($3.1)	($9.7)	2.0%	6.6%
Misc. electrical machinery	$2.5	($7.0)	($9.5)	4.4%	6.5%
Power generating machinery	$5.0	($0.6)	($5.6)	0.4%	3.8%
Misc. metal products	$0.4	($4.9)	($5.3)	3.1%	3.6%
Textiles & yarn	$0.4	($3.9)	($4.3)	2.5%	2.9%
Metalworking machinery	$0.1	($1.4)	($1.5)	0.9%	1.0%
Inorganic chemicals	$0.7	($0.4)	($1.1)	0.3%	0.8%
Products with a surplus in 1987					
Office & ADP equipment	$6.4	$1.0	($5.4)		3.7%
Scientific instruments	$4.4	$3.0	($1.4)		1.0%
Organic Chemicals	$2.9	$1.9	($1.0)		0.7%
Other transport	$13.5	$12.5	($1.0)		0.7%
Synthetic resin, rubber, and plastic products	$3.0	$3.3	$0.3		0.0%
Drugs & medicines	$1.6	$1.7	$0.1		
non-monetary gold	$1.0	$0.2	($0.8)		0.5%
Total deficit (or decline)	($46.9)	($158.6)	($147.2)		
Total Surplus (or increase)	$58.0	$23.6	$1.1		
Net balance	$11.1	($135.0)	($146.1)		

Source: Calculated by the author from U.S. Department of Commerce (1988)

Figure 5-5. OECD industrial classifications and industrial ouput descriptions

OECD industry class	ISIC	U.S. SIC	Description of major industrial output (not exhaustive)
Food, drink, & tobacco.........	31	20, 21	Processed food, beverages, animal feeds, and tobacco products.
Textiles, footwear, & leather..	32	22, 23, 31	Textile mill products, wearing apparel, shoes (exc. rubber), leather products.
Wood, cork, & furniture........	33	24, 25	Lumber & wood products, furniture, building fixtures.
Paper & printing..............	34	26, 27	Paper & allied products, pulp, paperboard, stationery, book publishing & printing.
Chemicals......................	351, 352, exc. 3522	28, exc. 283	Industrial chemicals, paint, soap & detergent, cosmetics, synthetic resin, rubber, & plast
Drugs & medicines..............	3522	283	Medicinals, botanicals, and pharmaceuticals.
Petroleum refining.............	353, 354	29	Petroleum refining products, paving & roofing materials, lubricants
Rubber & plastic products......	355, 356	30	Tires, rubber footwear, products fabricated from synthetic resins, rubber, & plastics
Stone, clay, & glass products..	36	32	Glass, cement, concrete, pottery & china, non-metallic minerals (e.g., gypsum, asbestos)
Ferrous metals.................	371	331, 332, 3399, 346	Steel & steel mill products, metal forgings and stampings
Non-ferrous metals.............	372	balance of 33	Non-ferrous metals and products (mostly aluminum and copper)
Fabricated metal products......	381	34, exc. 3462, 3489	Metal cans, hand & garden tools, hardware, boilers, ordnance, heating & plumbing fixtures
Nonelectrical machinery........	382, exc. 3825, 3829*	35, exc. 357	Engines & turbines, construction/mining/materials handling equipment, industrial machiner
Office & computing machines....	3825	357	Computers, peripherals (exc. communications), caluclators, typewriters, cash registers
Electrical machinery...........	383, exc. 3832	361-64, 369	Motors, electrical industrial machinery, electrical transmission equipment, appliances
Electronic equipment & components................	3832	365-67	Consumer electronics (TV, VCR, all audio), telephones, FAXs, modems, ICs, semiconductors
Motor vehicles & equipment.....	3843	371	Cars, trucks, busses, and parts
Aerospace......................	3845, 3829*	372, 376	Aircraft & parts (including engines), guided missiles and spacecraft
Other transportation equipment....................	3841, 3842, 3844, 3849	373-375, 379	Ships & boats, RR equipment, motorcycles, bicycles, trailers, campers, tanks, ATVs
Instruments....................	385	38	Avionics, laboratory equipment, medical/surgical/optical equipment, cameras, watches/clock
Other manufacturing............	39	29	Jewelry, plated ware, musical instruments, sporting goods, sewing notions, art supplies

(*): Denotes part of the ISIC class number.
Exc.: Excluding.

Source: OECD and Office of Management and Budget (1987).

Table 5.6--U.S. Balance of trade, by industrial class, 1970-86
(dollars in millions)

Industry	1970	1974	1978	1982	1986	Decline in balance, 1982-86	Industry as a percent of total decline	Industry as a percent of 1986 deficit
Food, drink, & tobacco.........	($2,186)	($2,771)	($3,895)	($2,686)	($7,006)	($4,320)	3.0%	4.0%
Textiles, footwear, & leather..	($2,276)	($2,787)	($8,316)	($11,742)	($28,295)	($16,553)	11.6%	16.0%
Wood, cork, & furniture........	($790)	($1,221)	($3,913)	($2,645)	($7,469)	($4,824)	3.4%	4.2%
Paper & printing...............	($303)	($305)	($1,406)	($803)	($4,004)	($3,201)	2.2%	2.3%
Chemicals......................	$2,259	$4,707	$6,330	$9,089	$4,632	($4,457)	3.1%	
Drugs & medicines..............	$312	$529	$712	$1,279	$893	($386)	0.3%	
Petroleum refining.............	($878)	($8,198)	($6,512)	($8,469)	($8,878)	($409)	0.3%	5.0%
Rubber & plastic products......	($371)	($516)	($1,835)	($2,388)	($6,377)	($3,989)	2.8%	3.6%
Stone, clay, & glass products..	($148)	($212)	($783)	($854)	($3,953)	($3,099)	2.2%	2.2%
Ferrous metals.................	($782)	($3,025)	($6,563)	($8,501)	($8,984)	($483)	0.3%	5.1%
Non-ferrous metals.............	($801)	($2,561)	($3,738)	($2,958)	($6,037)	($3,079)	2.2%	3.4%
Fabricated metal products......	$113	$210	($343)	$277	($4,940)	($5,217)	3.6%	2.8%
Nonelectrical machinery........	$4,617	$8,925	$11,726	$17,969	($3,007)	($20,976)	14.7%	1.7%
Office & computing machines....	$1,055	$1,694	$2,743	$6,088	$1,434	($4,654)	3.3%	
Electrical machinery...........	$388	$1,176	$1,549	$1,504	($6,328)	($7,832)	5.5%	3.6%
Electronic equipment & components................	($322)	($954)	($3,980)	($5,179)	($19,027)	($13,848)	9.7%	10.8%
Motor vehicles & equipment.....	($1,586)	($2,861)	($9,397)	($16,776)	($51,805)	($35,029)	24.5%	29.3%
Aerospace......................	$2,770	$5,893	$7,887	$9,184	$10,579	$1,395		
Other transportation equipment....................	($87)	($521)	($625)	$915	($1,684)	($2,599)	1.8%	1.0%
Instruments....................	$730	$1,367	$999	$2,832	($635)	($3,467)	2.4%	0.4%
Other manufacturing............	($502)	($682)	($2,365)	($3,824)	($8,472)	($4,648)	3.2%	4.8%
Not elsewhere classified......	$552	$927	$858	$838	$1,446	$608		
All manufacturing............	$1,762	($1,185)	($20,867)	($16,851)	($157,915)			
Total deficit (or decline).....	($11,032)	($26,614)	($53,671)	($66,825)	($176,901)	($143,070)		
Total surplus (or increase)....	$12,796	$25,428	$32,804	$49,975	$18,984	$2,003		

Source: Calculated by the author from OECD, Compatible Trade and Production Database; unpublished data provided to the National Science Foundation.

those of individual product groups.[8] For example, the OECD industry data show declines in the balance of trade from 1982-86 for every industry except aerospace, whereas product group data show improving surpluses in several product groups.

However, industry trade data *do show* surpluses in the chemicals, drugs, office and computing machines, and aerospace industries (table 5.6), industries which manufacture the product groups running surpluses. (The instruments industry, however, shows a trade deficit in 1986 compared with a trade surplus in the Commerce data; this difference is explained by the fact that watches, clocks, and photographic equipment are included in the industry-level data of the OECD but are reported in a separate product group by the Department of Commerce.) There was a reversal during the 1980s in the historical trade surplus of the fabricated metals, nonelectrical machinery, and electrical machinery industries, corresponding to the five machinery trade groups and the miscellaneous metal products group showing reversals in table 5.1. Additionally, the top five deficit-generating industries--motor vehicles, nonelectrical machinery, textiles, electronic equipment, and electrical machinery--match seven of the "worse nine" trade groups discussed previously. These five industries represent 66% of the worsening of the trade deficit between 1982 and 1986, and about 61% of the total 1986 deficit. The inclusion of the steel and miscellaneous manufactures industries raises these figures to 69% and 71%, respectively.

The balance of trade data consistently portray a core set of industries generating the worsening trade position. On the eve of the crisis, four troubled industries represented a significant proportion of the U.S. trade deficit, both over time and in 1982. The motor vehicles, steel, textile, and electronics industries had been running deficits since at least 1970, with a serious worsening between 1975-78. In 1982, these four industries accounted for two-thirds of the total deficit in manufactures trade.[9] With the onset of the economic recovery in 1982, not only did the deficit generated by this "Group of 4" worsen dramatically (accounting for half of the total decline between 1982-86), but industries for which the U.S. traditionally ran surpluses went into decline.

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[8]Additionally, some product groups have multiple industries of origin. For example, "power generating machinery" includes both engines (nonelectrical machinery) and motors (electrical machinery).

[9]In "product" terms, five groups--motor vehicles, steel, wearing apparel, footwear, and telecommunications and sound equipment (consumer electronics)--generated 80% of the total deficit in the top 24 product groups in 1981.

While declines were "modest" in most other industries compared to erosion of the Group of 4, the reversal from surplus to deficit for the machinery industries was critical: these two industries typically garnered enough surplus to balance deficits created by the Group of 4. Most notable was the reversal in non-electrical machinery, which has historically been the single-largest surplus-generating industry, substantially larger even than aerospace (until 1983). The pervasive decline in the balance of trade throughout the manufacturing sector indicates that the U.S. trade position worsened also as a result of "systemic" effects, e.g. the economic recovery and improperly valued currencies.

Trends in Import Penetration

The low level of U.S. import penetration compared with others in the Summit 7 masks substantial variation among industries. Some industries are clearly doing worse than others, with the automotive industry having 30% of its market taken up by imports, and the paper and printing industry, less than 5% (table 5.7). Of the 21 industries for which data are available to calculate market share ratios, the top 10 "penetrated" industries have been remarkably consistent since 1970.[10] The major changes were the addition of electrical machinery to the list in 1982 (wood and furniture dropped off), and the addition of nonelectrical machinery in 1986 (replacing steel). There has, however, been considerable movement in the import penetration ranking of these 10 industries. For example, the motor vehicle industry moved from 5th place in 1970 to 2nd in 1986; office and computing machines fell from 4th in 1970 to 9th in 1982, but jumped quickly back to 4th position again in 1986. In spite of this variation, almost without exception a third or more of the net increase in import penetration from 1970-86 occurred during the 1982-86 period. For most industries, more than *one-half* of their net increase in import penetration was registered during this 4-year period.

A juxtaposition of the import penetration data with trends in the trade balance is instructive. Table 5.8 presents the manufacturing industries in two groups, those with import penetration ratios above roughly 10%, and those below. By and large, those industries which manifest the worst trade performance are also highly penetrated industries. The five industries which accounted for the substantial worsening in the trade deficit from 1982-86 (motor vehicles, nonelectrical machinery, textiles, electronic equipment, and electrical machinery) are the 2nd,

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[10]They are: other transportation, other manufacturing, nonferrous metals, ferrous metals, office and computing machines, motor vehicles, electronic equipment, instruments, wood and furniture, textiles, electrical and nonelectrical machinery.

Table 5.7--Import penetration of U.S. manufactures consumption, by industry, 1970-86

Industry	1970	1974	1978	1982	1986	Percentage point change	Percent of net change occurring during--			
						1970-86	1970-74	1974-78	1978-82	1982-86
Food, drink, & tobacco.........	4.8%	5.4%	6.1%	5.0%	5.4%	0.6	102.9%	123.1%	-191.8%	65.8%
Textiles, footwear, & leather..	6.2%	7.7%	12.0%	13.8%	21.7%	15.5	9.8%	28.1%	11.5%	50.6%
Wood, cork, & furniture........	6.5%	7.3%	10.3%	9.6%	13.5%	7.0	11.9%	42.0%	-9.4%	55.4%
Paper & printing..............	3.5%	4.3%	4.2%	3.8%	4.3%	0.8	93.6%	-9.4%	-50.8%	66.6%
Chemicals......................	3.8%	5.9%	6.7%	7.7%	8.4%	4.6	45.7%	18.3%	20.5%	15.5%
Drugs & medicines..............	1.4%	2.3%	5.0%	4.2%	6.6%	5.2	18.0%	51.5%	-14.7%	45.1%
Petroleum refining.............	5.9%	14.2%	7.3%	6.8%	5.0%	-0.9	-887.8%	737.8%	55.3%	194.7%
Rubber & plastic products......	4.4%	5.2%	6.7%	7.0%	10.0%	5.6	13.1%	27.5%	5.0%	54.4%
Stone, clay, & glass products..	3.3%	3.9%	5.2%	6.0%	9.2%	5.9	10.2%	21.8%	13.7%	54.2%
Ferrous metals.................	7.0%	9.7%	10.9%	16.6%	13.2%	6.1	44.1%	19.4%	93.3%	-56.7%
Non-ferrous metals.............	10.3%	13.3%	12.8%	13.5%	14.8%	4.5	67.2%	-12.0%	15.7%	29.2%
Fabricated metal products......	2.2%	3.1%	3.8%	3.9%	5.3%	3.1	28.7%	22.2%	3.3%	45.8%
Nonelectrical machinery........	4.8%	6.0%	8.1%	10.2%	15.2%	10.4	11.7%	20.3%	19.5%	48.5%
Office & computing machines....	10.2%	10.7%	12.1%	11.1%	25.0%	14.8	3.3%	9.7%	-6.7%	93.7%
Electrical machinery...........	3.5%	5.1%	7.3%	10.7%	17.3%	13.8	11.2%	15.8%	25.0%	48.0%
Electronic equipment & components................	7.9%	14.0%	16.6%	16.3%	21.3%	13.3	45.5%	19.6%	-2.3%	37.1%
Motor vehicles & equipment.....	9.0%	14.2%	15.2%	22.2%	30.3%	21.3	24.3%	4.8%	32.7%	38.2%
Aerospace......................	2.3%	4.5%	4.9%	9.0%	11.0%	8.7	25.4%	4.5%	47.7%	22.4%
Other transportation equipment....................	9.2%	13.8%	12.2%	12.7%	16.1%	6.9	66.0%	-23.4%	7.4%	50.0%
Instruments....................	6.8%	8.9%	14.7%	13.2%	18.6%	11.8	17.3%	49.5%	-12.4%	45.6%
Other manufacturing............	10.9%	14.2%	20.0%	22.4%	31.2%	20.2	16.2%	28.4%	12.2%	43.2%
TOTAL........................	5.5%	7.9%	9.0%	9.7%	12.9%	7.4	31.4%	15.0%	9.8%	43.8%

Source: Calculated by the author from OECD, Compatible Trade and Production Database; unpublished data provided to the National Science Foundation.

Table 5.8--U.S. manufacturing industry import penetration ratios and trade status in 1986

Industry	Import penetration ratio (in %)	Trade balance status	Type of good 1/
Other manufacturing	31.2	6th largest deficit	Durable
Motor vehicles & equipment	30.3	largest deficit	Durable
Office & computing machines	25.0	declining surplus	Durable
Textiles, footwear, & leather	21.7	2nd largest deficit	Non-durable
Electronic equipment & components	21.3	3rd largest deficit	Durable
Instruments	18.6	small reversal from surplus	Durable
Electrical machinery	17.3	large reversal from surplus	Durable
Other transportation equipment	16.1	small deficit	Durable
Nonelectrical machinery	15.2	large reversal from surplus	Durable
Non-ferrous metals	14.8	11th largest deficit	Durable
Wood, cork, & furniture	13.5	7th largest deficit	Durable
Ferrous metals	13.2	4th largest deficit	Durable
Aerospace	11.0	stable surplus	Durable
Rubber & plastic products	10.0	worsening small deficit	Non-durable
Stone, clay, & glass products	9.2	worsening small deficit	Durable
Chemicals	8.4	declining surplus	Non-durable
Drugs & medicines	6.6	declining surplus	Non-durable
Food, drink, & tobacco	5.4	worsening small deficit	Non-durable
Fabricated metal products	5.3	moderate reversal from surplus	Durable
Petroleum refining	5.0	improving deficit	Non-durable
Paper & printing	4.3	worsening small deficit	Non-durable

1/ Based on classification in Eckstein, et. al (1984)

Source: Calculated by the author from OECD, Compatible Trade and Production Database; unpublished data provided to the National Science Foundation.

Table 5.9--Competitiveness indicators for U.S. manufacturing industries, by competitive status

Industry	Import penetration, 1986 (%)	Trade balance status	Technology classification	Comparative Advantage 1/ OECD 1972	OECD 1982	OECD 1986	Source of 1987 imports (in %) Japan	EC-12	NICs	Canada	All other
I. NON-COMPETITIVE											
Motor vehicles & equipment.....	30.3	largest deficit	medium	100	69	74	43	19	nsa	28	11
Textiles, footwear, & leather..	21.7	2nd largest deficit	low	38	47	41	nsa	14	46	nsa	40
Electronic equipment & components..................	21.3	3rd largest deficit	high	104	115	111	51	nsa	29	nsa	20
Ferrous metals................	13.2	4th largest deficit	low	32	24	16	25	28	7	nsa	40
Other manufacturing...........	31.2	6th largest deficit	medium	88	100	268 2/	15	23	36	nsa	26
Other transportation..........	16.1	16th largest deficit	low	NA	NA	80	NA	NA	NA	NA	NA
Non-ferrous metals............	14.8	11th largest deficit	medium	60	71	61	nsa	16	nsa	35	49
Wood, cork, & furniture........	13.5	7th largest deficit	low	70	74	77	NA	NA	NA	NA	NA
II. NEWLY NON-COMPETITIVE											
Instruments....................	18.6	reversal from surplus	high	143	142	144	27	35	nsa	10	26
Electrical machinery 3/........	17.3	reversal from surplus	high	108	107	91	27	29	10	8	26
Nonelectrical machinery 3/.....	15.2	reversal from surplus	medium	133	136	106	3/	3/	3/	3/	3/
Office and computing machines..	25.0	declining surplus	high	186	215	205	48	11	30	nsa	11
III. AT-RISK COMPETITIVE											
Rubber & plastic products......	10.8	worsening deficit	medium	67	58	69	22	32	nsa	21	25
Stone, clay, & glass products..	9.2	worsening deficit	low	61	60	55	10	36	10	nsa	44
Fabricated metal products......	5.3	reversal from surplus	low	80	78	56	18	19	31	nsa	32
IV. COMPETITIVE											
Aerospace......................	11.0	stable surplus	high	343	239	340	9	51	nsa	25	16
Chemicals......................	8.4	declining surplus	medium	112	110	107	nsa	47	nsa	13	40
Drugs & medicines..............	6.6	declining surplus	high	105	108	142	11	48	9	nsa	32
Food, drink, & tobacco.........	5.4	worsening deficit	low	104	94	105	NA	NA	NA	NA	NA
Petroleum refining.............	5.0	improving deficit	low	59	76	88	NA	NA	NA	NA	NA
Paper & printing...............	4.3	worsening deficit	low	102	100	105	NA	NA	NA	NA	NA

1/ Based on OECD-11. A value of 100 represents no comparative advantage or disadvantage in trade.
2/ The high comparative advantage for "other manufacturing" in 1986 is due to a one-time shipment of gold bullion to Japan. (The Japanese were minting a special commemorative coin to honor Emperor Hirohito's 60th anniversary.)
3/ The "source of 1987 imports" figures shown for electrical machinery represent electrical and nonelectrical machinery combined. The figures for Canada and the NICs are slightly understated.

NA: Not available.
nsa: Not separately available but reported under "all other."
NICs: Hong Kong, South Korea, Singapore, and Taiwan.

Source: Department of Commerce (1988), OECD "Compatible Trade and Production Database," unpublished data provided to the National Science Foundation.

9th, 5th, 6th and 8th most highly penetrated industries. Additionally, in three of these five industries (textiles, electrical and nonelectrical machinery), half of the net increase in import penetration of these industries occurred during 1982-86. In contrast, three of the four industries which ran trade surpluses in 1986--aerospace, chemicals, and drugs--are found among the less penetrated industries; the exception is office and computing machines, which experienced a doubling in import penetration during this period.

The two groups of industries also fall out rather neatly in terms of whether they produce durable or non-durable goods, with durable goods being much more highly penetrated than non-durable. Generally, durable goods are more price-elastic, making them more vulnerable to both business cycle recessions and intensive price competition. One reasonable conjecture about the sudden decline in U.S. competitive performance in the durable goods industries after 1982 is that the protracted stagnation experienced by these industries during 1978-82 prohibited their adjustment to the intense import competition which would emerge with the recovery in 1982.

By pairing trends in industrial trade balances and import penetration, the 21 manufacturing industries can be ordered into four types of competitive performance:

I) **Non-competitive**--those industries which have traditionally run large trade deficits and which have relatively high import penetration levels.

II) **Newly non-competitive**--those industries which have historically run trade surpluses but which experienced a dramatic reversal in their trade accounts and large increases in import penetration during the 1982-86 period.

III) **"At risk" competitive**--those industries which have had low import penetration levels and relatively low trade deficits (or even surpluses), but whose trends during the 1980s indicate declining competitive strength.

IV) **Competitive**--those industries which have consistently had low and relatively stable import penetration levels and run either trade surpluses or relatively low trade deficits.

Table 5.9 presents the manufacturing industries classified by this competitive typology. With the notable exception of textiles, all of the non-competitive and newly non-competitive industries of consequence are durable goods industries. As a class these industries seem to have suffered far more than others in the recovery, but even so, among the durable goods sectors some are acutely worse off than others. A competitive decline (or further erosion) in autos, electronic equipment, electrical machinery, non-electrical machinery, instruments, and miscellaneous manufactured goods seems irrefutable. Steel is neither better or worse off (and constitutes the fourth largest deficit), and the competitive performance of office and computing machines is distinctly poor in spite of the fact that it still maintained a modest trade surplus in 1986-87.

The Foreign Competition

By and large, the chief U.S. competitors (at home and abroad) are the advanced industrialized nations, a somewhat obvious point given the dominance of north-north trade flows in the world trading system. However, Japan alone accounted for $71 billion of the manufactures deficit in 1987, far more than the next largest source, Taiwan, with which the U.S. had a $20.6 billion deficit (figure 5-1). The four NICs account for $42.7 billion, and together with Japan created 72% of the total U.S. manufacturing deficit in 1987. Japan represents the single most interesting U.S. competitor, in terms of both the range of its exports to the United States and the imbalance in U.S.-Japan trade: the U.S. receives 36% of Japanese exports but accounts for 75% of Japan's merchandise trade surplus (U.S. Department of Commerce, 1988, p. 37).

Tables 5.9 presents the regions/country of origin for U.S. manufacturing imports in each industry. These are not OECD figures; they were obtained by collapsing the Department of Commerce data for the 24 A&E product groups into "industry" groups. These country of origin data are therefore a rough approximation of the chief foreign competitors for some, but not all, of the products within their associated industries. This information shows that almost without exception, the presence or absence of Japan as major foreign competitor (e.g., accounting for 25% or more of total imports in the product groups) is a strong indicator of the overall competitive status of the U.S. industry. Japan is a major competitor in virtually all of the non-competitive industries of consequence[11]; of the industries classified as competitive or at risk competitive, Japan accounts for about 10% or less of the total imports in all but rubber and plastic products (22%) and fabricated metals (18%).

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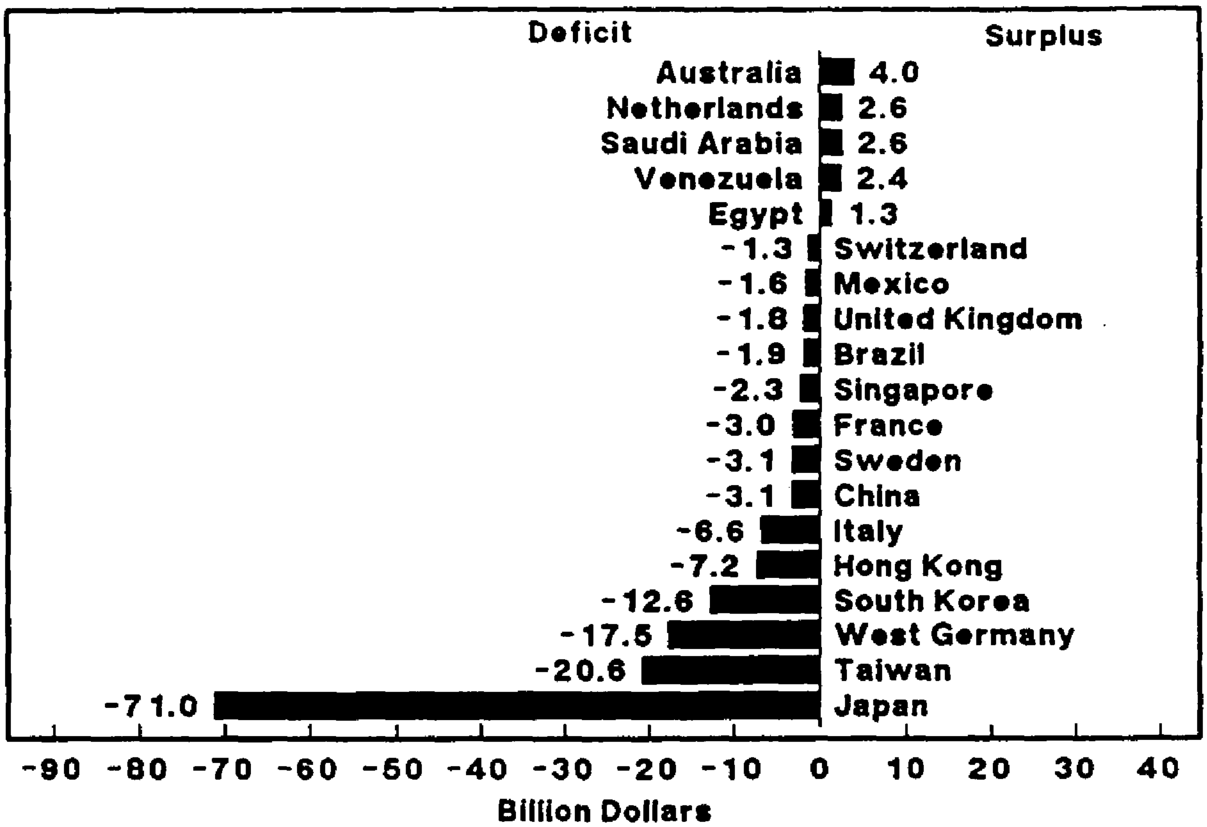
[11]Of consequence meaning those industries which contribute in substantial part to the trade deficit. Additionally, the absence of Japan as a key competitor in the remaining major industries is easily explainable; other than steel and fabricated metals, Japan is not an international presence in low technology industries because it either doesn't have the natural resources or can't compete against low-skilled labor.

Figure 5-1. Country-of-origin of Largest U.S. Surplus and Deficit Manufactures Trade Balances, 1987



Source: U.S. Department of Commerce (1988)

Comparative Advantage and High Technology

As the world economy becomes more interdependent and comparative advantage shifts among industries and countries, it becomes critical that nations be able to respond and adapt to such change. In international trade, for example, large deficits in textiles are not so critical if a nation can shift its productive resources to products and industries in which it has a comparative advantage. Presumably, this nation can then run sufficiently large surpluses in areas of comparative advantage to offset its deficits in areas where it is at a disadvantage.

U.S. comparative advantage has long been understood to be in high technology[12] products and in natural resource intensive goods and industries. Calculations of U.S. revealed comparative advantage[13] in world trade show this to generally be the case (e.g., Balassa and Noland, 1988).[14] The revealed comparative advantage indices calculated here for U.S. trade within the OECD also find that U.S. comparative advantage is in high tech industries (table

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[12]There are multiple definitions for high technology goods, but they are usually considered to embody the highest proportion of R&D relative to other products. Thus, calculations of R&D to sales ratios determine the inclusion or exclusion of products/industries in the high tech category. This research uses those industries identified by the OECD as high technology: drugs and medicines, instruments, office and computing machines, electrical machinery, aerospace, and electronic equipment.

[13] A comparative advantage index is the proportion of an industry's exports to total manufacturing exports in relation to the same proportion for a group of countries combined (here, the OECD-11). To state it mathematically, if X_{ij} is equal to the exports of country i and industry j, and X_{ima} is equal to the manufacturing exports of country i, then the comparative advantage indicator CA_{ij} of country i and industry j is:

$$CA_{ij} = \frac{X_{ij} / X_{ima}}{\Sigma X_{ij} (1..11) / \Sigma X_{ima} (1...11)}$$

[14]Balassa and Noland (1988) calculate revealed comparative advantage indices for the United States for world, as opposed to OECD, trade for several years, including 1971 and 1981. Although the actual indices are different, Balassa and Noland's calculations reinforce the data presented here. That is, generally speaking 1) the trends in the indices (increasing or decreasing) are the same as the OECD-based figures, 2) the industries for which they find the U.S. has a comparative advantage correspond to the ones found to have comparative advantage within the OECD, and 3) the rank order of industries from highest to lowest comparative advantage is also the same as that obtained with the OECD data. The Balassa and Noland data are not presented here because data are not available to update the indices through 1986, and they provide data only at the 2-digit ISIC level (the data here are both 2- and 3-digit). Consequently, the manufacturing coverage is not as good as the OECD data.

5.9). However, little association between technology classification, comparative advantage, and competitive status can be found. The most notable findings are summarized below:

- The United States is non-competitive in four of the six high tech industries (electronics, instruments, electrical and nonelectrical machinery).
- The United States is generally competitive in a number of low tech industries for which it has no appreciable comparative advantage, and in some, is disadvantaged. Several of these industries are also nondurable goods producers, indicating that these markets are more immune to foreign competition (by virtue of their price inelasticity) or simply relatively uninteractive with the world trading system.
- The United States is typically non-competitive and without comparative advantage in durable goods industries, regardless of the technological classification of the industry. The exceptions to this are the electronics and instruments industries (which have comparative advantage but are not competitive) and the aerospace industry (which has comparative advantage and is also competitive).

The lack of correspondence between competitiveness (as indicated by balance of trade and import penetration trends) and revealed comparative advantage is somewhat troubling. A good deal of the U.S. policy response to the crisis has been to focus on the scientific and technical roots of competitive performance, especially for the purpose of boosting the high tech industries where we are know to have comparative advantage. However, the competitiveness-comparative advantage linkage may not be as simple or direct as many suspect.

At minimum, we can conclude that having comparative advantage in some industries does not equate with competitive health. It seems unlikely that the U.S. will be able to generate sufficient surpluses in the few high technology trade groups to offset the large deficits in other categories. Given that most of the industrialized nations are competent at most of these technological frontiers it is questionable whether there is enough market demand abroad that the U.S. can satisfy to compensate for the large and growing volume of imports in the traditional deficit trade groups.

Individual Industry Profiles

Alternative sources of data allowed for more appropriate examination of the sources of foreign competition and world export performance at the industry level for eight industries--autos, steel, electronics, instruments, electrical machinery, office and computing machines, drugs and medicines, and aerospace. These eight industries together constitute a relatively good sampling of manufacturing industries, since they represent three of the four groups in the competitiveness typology, all three technology classes, and industries in which Japan is and is not a major competitor. A detailed analysis of balance of trade, import penetration, and world export share trends for these industries showed that they share no common patterns of difficulty, at least in terms of the time periods in which their competitive troubles begin.

What does emerge from these data is supporting evidence that the presence of Japan as a significant competitor is a strong predictor of the health of the U.S. industry. The key characteristic of the non-competitive industries in this set is Japan's dominance as the major foreign competitor. In all of the non-competitive industries except electrical machinery and steel, Japan accounts for one-half of the total foreign share of the U.S. market (table 5.10). In electrical machinery, this share is just less than one-third; the decline in this industry is largely attributable to Germany and countries other than the Summit 7. Japan is not a significant competitor in either aerospace or drugs, the two high tech industies in which the U.S. is competitive; additionally, for motor vehicles, electronic equipment, and instruments, competitive decline (as measured by import penetration, the trade balance, and world export shares) started in 1978, the same time the trade balance with Japan began a substantial worsening.

Non-Competitive Industries

The three non-competitive industries for which more detailed import data are available (autos, steel, and electronic equipment) share two common features: high levels of import penetration and large contributions to the trade deficit. Additionally, of the foreign market share of products in these industries, Japan accounts for one-third or more of the total. Upon further analysis, however, the steel data were not found to be helpful for a competitiveness assessment. Japan has been operating under a voluntary export restraint for over 15 years, and as a consequence the Japanese share of the U.S. steel market has been a constant 5-7% since 1970. It is therefore not possible to conduct any systematic "pattern-matching" analysis between the Japanese market share data and science and technology indicators. Additionally, formal bilateral steel agreements between the United States and several other nations have been in force since 1984; these agreements likewise have the effect of fixing market share ratios and thus interfere with analyses of competitiveness. A more detailed examination of only the auto and electronics industries are therefore presented below.

Table 5.10--Summary of selected industry competitiveness profiles

Industry	Competitive status	Period of most dramatic worsening in-- Import penetration	Trade balance	World export share	Japan's share of total foreign penetration	"Cause" of competitive decline
Motor vehicles........	Non-competitive	1979-82	1977-78; 1982-86	Not applicable	50%	Imports from Japan starting in 1978
Electronic equipment..	Non-competitive	1975-76; 1983-86	1978+; 1982-86	1977-78; 1984+	50%	Major decline in U.S. exports after 1984; reversal of trade surplus in 1978
Instruments...........	Newly Non-competitive	1974-78; 1984+	1977-78; 1983+	1977-78; 1983-84	50%	Deficit w/ Japan doubles 1977-78; U.S. exports decline 1981-1984/85
Electrical machinery..	Newly Non-competitive	1978-82; 1982-86	1980-81; 1984+	1984+	28%	Deficit w/ Japan increases 1980-81; Deficits w/ FRG and all other" 1984+
Office and Computing Machines............	Newly Non-competitive	1982+	1982+	1982+	46%	Deficits w/ Japan severe after 1982; decling surplus w/ Italy, "all other"
Drugs & medicines.....	Competitive	1974-78; 1982-86	1982+	1984+	12%	Not applicable
Aerospace.............	Competitive	gradual	Not applicable	1978	1%	Not applicable

Table 5.11--Market shares of U.S. motor vehicle consumption, by country, 1970-87 1/

Country	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
United States.....	NA	78.2%	79.7%	82.0%	77.3%	78.7%	79.7%	NA	77.8%	76.0%	66.9%	65.9%	63.1%	65.5%	62.7%	65.0%	62.4%	63.5%
Japan............	NA	6.2%	6.0%	4.7%	6.8%	6.8%	8.5%	NA	10.2%	11.9%	19.3%	21.6%	21.3%	19.7%	20.6%	20.6%	22.4%	20.2%
France...........	NA	0.2%	0.1%	0.1%	0.2%	0.2%	0.2%	NA	0.2%	0.2%	0.4%	0.4%	0.9%	1.6%	1.7%	0.2%	0.1%	0.2%
West Germany......	NA	6.0%	5.0%	4.6%	5.2%	3.6%	2.6%	NA	2.7%	3.6%	4.3%	3.4%	3.3%	2.6%	2.5%	2.9%	2.8%	2.4%
United Kingdom....	NA	0.8%	0.5%	0.4%	0.6%	0.7%	0.6%	NA	0.2%	0.3%	0.3%	0.1%	0.1%	0.4%	0.2%	0.2%	0.2%	0.3%
Canada...........	NA	7.2%	7.3%	6.7%	7.9%	8.3%	7.4%	NA	7.8%	6.9%	7.7%	7.7%	10.2%	9.2%	9.6%	9.7%	9.4%	8.3%
Italy............	NA	0.4%	0.5%	0.4%	0.9%	1.0%	0.6%	NA	0.5%	0.5%	0.4%	0.2%	0.1%	0.0%	0.1%	0.1%	0.1%	0.1%
All others........	NA	1.0%	0.9%	1.0%	1.2%	0.9%	0.4%	NA	0.6%	0.5%	0.6%	0.6%	0.9%	0.9%	2.6%	1.3%	2.7%	5.0%
Total imports.....	NA	21.8%	20.3%	18.0%	22.7%	21.3%	20.3%	NA	22.2%	24.0%	33.1%	34.1%	36.9%	34.5%	37.3%	35.0%	37.6%	36.5%

1/ Consumption and shares based on units of quantity.

Source: Motor Vehicle Manufacturers' Association (1989)

Table 5.12--Market shares of U.S. electronic and communication equipment consumption, by country, 1970-86

Item	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
Electronic and communication equipment, total																	
United States........	92.4%	91.3%	89.6%	88.3%	86.8%	88.1%	83.8%	85.4%	84.5%	85.3%	85.6%	84.3%	84.8%	85.7%	81.9%	83.9%	83.8%
All imports..........	7.6%	8.7%	10.4%	11.7%	13.2%	11.9%	16.2%	14.6%	15.5%	14.7%	14.4%	15.7%	15.2%	14.3%	18.1%	16.1%	16.2%
Japan..............	4.6%	5.2%	5.8%	5.5%	5.1%	5.0%	8.2%	7.0%	6.8%	5.5%	5.2%	6.6%	6.2%	5.7%	8.1%	8.2%	8.4%
France.............	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%
West Germany.......	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.3%	0.3%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%
United Kingdom.....	0.2%	0.3%	0.4%	0.4%	0.4%	0.3%	0.4%	0.4%	0.4%	0.3%	0.2%	0.2%	0.2%	0.1%	0.2%	0.2%	0.2%
Canada.............	0.6%	0.6%	0.4%	0.5%	0.6%	0.6%	0.4%	0.4%	0.5%	0.6%	0.6%	0.7%	0.6%	0.4%	0.7%	0.5%	0.5%
Italy..............	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.0%	0.1%
All others.........	1.9%	2.3%	3.6%	5.1%	6.8%	5.7%	6.8%	6.6%	7.4%	7.9%	7.9%	7.9%	7.9%	7.7%	8.7%	6.9%	6.8%
Electronic and communication equipment, exc. radio & TV																	
United States........	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
All imports..........	2.4%	3.0%	3.6%	4.9%	6.7%	6.5%	8.6%	7.6%	8.0%	8.8%	9.3%	9.7%	9.9%	9.2%	11.6%	8.9%	9.0%
Japan..............	0.7%	0.9%	1.2%	1.4%	1.6%	1.8%	3.5%	2.7%	2.4%	2.4%	2.4%	2.9%	3.0%	2.7%	4.0%	3.2%	3.3%
France.............	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%
West Germany.......	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.2%	0.2%	0.2%	0.1%	0.1%	0.1%	0.2%	0.2%	0.2%
United Kingdom.....	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.2%	0.2%	0.1%	0.2%	0.2%	0.2%
Canada.............	0.4%	0.4%	0.3%	0.3%	0.4%	0.4%	0.3%	0.3%	0.3%	0.5%	0.5%	0.6%	0.5%	0.3%	0.5%	0.4%	0.5%
Italy..............	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.0%	0.1%
All others.........	1.1%	1.3%	1.9%	3.0%	4.3%	3.9%	4.5%	4.2%	4.8%	5.5%	5.8%	5.8%	5.9%	5.7%	6.5%	4.8%	4.7%
Radio & TV																	
United States........	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
All imports..........	5.2%	5.8%	6.8%	6.8%	6.6%	5.5%	7.5%	7.1%	7.5%	5.9%	5.1%	6.0%	5.3%	5.0%	6.5%	7.2%	7.2%
Japan..............	4.0%	4.3%	4.6%	4.2%	3.6%	3.1%	4.7%	4.3%	4.4%	3.1%	2.7%	3.7%	3.2%	3.0%	4.1%	5.0%	5.1%
France.............	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
West Germany.......	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
United Kingdom.....	0.2%	0.2%	0.3%	0.3%	0.3%	0.2%	0.3%	0.3%	0.3%	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
Canada.............	0.2%	0.2%	0.1%	0.2%	0.2%	0.2%	0.1%	0.2%	0.2%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%
Italy..............	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
All others.........	0.8%	1.0%	1.7%	2.1%	2.5%	1.9%	2.3%	2.4%	2.6%	2.4%	2.1%	2.1%	2.0%	2.0%	2.2%	2.1%	2.0%

Note: Consumption and shares based on dollar values.

Table 5.13--U.S. balance of trade in electronic and communication equipment, by country, 1970-86 (in millions of dollars)

Item	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
Electronic & communication equipment, exc. radio & TV																	
Japan	(31)	(97)	(195)	(243)	(284)	(400)	(1,089)	(1,059)	(1,132)	(1,192)	(1,537)	(2,122)	(2,379)	(2,349)	(4,140)	(3,964)	(4,394)
France	57	43	57	82	119	107	131	140	113	109	150	152	141	88	42	(3)	78
West Germany	111	83	107	134	182	150	186	190	181	232	330	339	295	189	194	102	14
United Kingdom	90	58	85	145	167	153	169	180	201	274	314	335	460	353	378	288	172
Canada	36	52	112	131	126	134	177	191	134	23	15	25	125	208	5	(135)	(12)
Italy	30	24	30	51	74	82	77	78	77	103	132	98	95	35	14	83	23
All others	377	295	279	244	345	636	801	772	(547)	(973)	(1,503)	(1,808)	(391)	(1,297)	(2,244)	(4,020)	(4,230)
Total	669	458	475	544	728	863	452	492	(972)	(1,425)	(2,100)	(2,980)	(1,654)	(2,774)	(5,750)	(7,648)	(8,349)
Radio & TV																	
Japan	(909)	(1,011)	(1,221)	(1,260)	(1,101)	(947)	(1,736)	(1,912)	(2,412)	(1,970)	(2,041)	(3,158)	(3,022)	(3,053)	(4,874)	(6,705)	(7,435)
France	7	5	5	4	5	4	4	10	8	5	7	5	4	1	(0)	(0)	0
West Germany	(2)	(1)	5	(7)	(11)	(7)	(6)	(6)	(19)	(18)	(30)	(13)	(8)	(9)	(17)	(18)	(29)
United Kingdom	(26)	(39)	(59)	(59)	(62)	(30)	(54)	(73)	(108)	(54)	(20)	(10)	11	0	5	3	6
Canada	8	28	62	73	53	31	54	38	(76)	(63)	(52)	(71)	(60)	(75)	(140)	(124)	(102)
Italy	3	2	3	5	3	5	3	3	4	6	4	11	11	3	3	3	3
All others	(99)	(151)	(338)	(499)	(553)	(331)	(546)	(798)	(1,336)	(1,395)	(1,397)	(1,604)	(1,650)	(2,012)	(2,600)	(2,743)	(2,943)
Total	(1,018)	(1,167)	(1,543)	(1,744)	(1,664)	(1,276)	(2,282)	(2,739)	(3,939)	(3,490)	(3,530)	(4,840)	(4,714)	(5,145)	(7,624)	(9,585)	(10,501)
Total																	
Japan	(940)	(1,108)	(1,416)	(1,503)	(1,385)	(1,347)	(2,825)	(2,971)	(3,543)	(3,163)	(3,578)	(5,280)	(5,401)	(5,402)	(9,014)	(10,669)	(11,829)
France	65	48	61	86	124	111	135	150	121	113	157	157	145	89	41	(3)	78
West Germany	109	82	111	127	171	143	179	184	162	214	300	326	287	180	177	84	(15)
United Kingdom	64	19	27	86	105	123	115	107	93	220	293	326	471	353	383	291	178
Canada	44	80	174	204	179	166	231	229	58	(40)	(37)	(45)	65	133	(134)	(259)	(113)
Italy	32	26	33	56	78	86	80	80	80	108	136	109	105	37	17	86	25
All others	277	144	(59)	(255)	(208)	305	255	(25)	(1,883)	(2,368)	(2,900)	(3,412)	(2,041)	(3,309)	(4,844)	(6,764)	(7,173)
Total	(349)	(709)	(1,068)	(1,200)	(936)	(414)	(1,830)	(2,247)	(4,912)	(4,915)	(5,630)	(7,820)	(6,369)	(7,918)	(13,374)	(17,233)	(18,849)

Source: Data Resources, Inc., high-tech trade tables provided to the National Science Foundation

Table 5.14--World export shares of electronic and communications equipment, by country, 1970-86 (in percent)

Item	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
Electronic & communication equipment, excluding radio & TV																	
United States	27.7	24.2	24.1	24.7	26.8	24.4	24.4	23.8	18.8	19.4	19.0	20.0	25.9	27.7	26.5	16.1	14.0
Japan	9.8	12.1	13.5	14.3	14.2	14.9	20.2	19.4	23.0	22.6	24.7	30.5	27.3	31.2	35.5	37.0	38.7
France	6.6	6.9	6.8	7.7	7.6	7.9	7.1	7.5	7.9	8.6	8.3	7.3	6.4	6.2	6.1	7.9	7.8
West Germany	15.2	15.4	15.4	16.0	15.4	15.0	13.7	13.6	15.8	15.2	14.4	12.5	11.7	11.3	10.4	12.1	12.6
United Kingdom	9.5	9.8	8.2	7.2	7.1	7.6	7.1	7.7	8.1	8.1	8.1	7.6	7.6	7.0	6.4	8.6	7.8
Canada	4.8	4.1	3.4	3.4	3.3	3.0	2.7	2.2	0.7	1.0	1.1	1.2	1.4	0.0	0.0	0.0	0.0
Italy	4.2	5.0	5.2	5.0	4.1	4.2	4.3	4.4	4.5	4.3	3.7	3.4	3.6	3.7	3.8	4.6	4.3
All others	22.3	22.5	23.5	21.7	21.5	23.0	20.6	21.5	21.3	20.9	20.7	17.6	16.0	12.9	11.3	13.7	14.8
Radio & TV																	
United States	6.4	6.2	6.4	6.5	6.6	6.5	6.1	5.1	2.2	2.4	2.4	2.2	2.1	0.5	0.5	0.6	0.5
Japan	54.8	56.3	56.0	52.0	48.2	46.3	55.5	55.7	58.1	57.0	62.2	71.4	69.9	76.7	79.5	78.2	69.1
France	1.6	1.7	1.4	1.5	1.6	2.0	1.7	1.6	1.8	2.0	1.4	1.1	1.1	1.2	1.0	1.0	1.6
West Germany	12.4	11.7	11.8	14.1	14.0	14.3	13.2	12.9	13.0	13.8	12.1	9.0	9.5	9.3	8.2	9.1	12.5
United Kingdom	3.4	3.9	4.2	4.0	4.6	5.5	4.6	4.3	4.1	3.8	3.4	2.1	2.1	1.8	2.2	2.5	3.3
Canada	1.1	0.9	0.7	0.6	0.6	0.5	0.4	0.6	2.2	2.6	3.1	3.4	3.6	0.0	0.0	0.0	0.0
Italy	3.6	3.2	3.4	3.0	3.8	3.8	2.0	1.7	1.6	1.7	1.9	1.2	1.2	1.3	0.8	0.9	1.4
All others	16.8	16.1	16.0	18.3	20.6	21.1	16.6	18.2	17.0	16.7	13.7	9.7	10.5	9.4	7.8	7.7	11.7

Source: Data Resources, Inc., High-tech trade tabulations provided to the National Science Foundation

Autos.--The OECD industry data show an import penetration level of 30% by value in 1986; this data includes imports of assembled cars, trucks and busses as well as unassembled vehicles and automotive parts. As discussed earlier, the trade deficit in motor vehicles has consistently been the single-largest source of the U.S. trade deficit, accounting for about one-third of the total deficit since 1980. The United States has run a deficit in motor vehicles trade every year since 1968.

Over time, the source of U.S. imports of motor vehicles has shifted. Japan, Canada, and West Germany each accounted for roughly equal market shares in 1971 (a 1:1:1 ratio); however, imports from Japan have far outpaced those of other countries, and the market share ratios between these countries shifted to an 8:3:1 ratio in 1987 (table 5.11). In comparison, U.S. automobile exports to Canada have consistently accounted for about 85% of its total exports since the early 1970's. By value, in 1987 Japan accounted for 56% of the U.S. trade deficit in automotive products; West Germany, 17%; and Canada, 11% (DOC, 1988, p. 87).

Data from the Motor Vehicle Manufacturers Association (MVMA) allows market share ratios for automotive vehicles to be calculated on the basis of units of quantity, a more accurate reflection of competitive market position (MVMA, 1989). As can be seen in table 5.11, import penetration of the U.S. auto market has been rather high, representing 22% of the market even in 1971. The foreign share, however, remained relatively stable at 20-22% of all vehicles until 1978, after which time imports began rising rapidly relative to domestic production and sales. From 1979 to 1982, import penetration jumped from 22.2% of the total to 36.9%; *three-quarters* of this increase was accounted for by imports from Japan. Japanese vehicles demonstrated their competitiveness slightly earlier, however; Japanese motor vehicles accounted for just less than one-third of the total foreign market share from 1971-74 but increased steadily to account for nearly half of the total by 1978. Starting in 1980, Japan accounted for half of the total foreign share of the U.S. motor vehicle market.

Since 1982, the year after the Voluntary Restraint Agreement went into effect with Japan, the import penetration ratio by quantity has stabilized at about 37% for all foreign vehicles and 20% for Japan.[15] However, in response to the VRA the Japanese have shifted their

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[15]The VRA is renewed annually and was changed to a voluntary export agreement (VER) in 1984. The Japanese export ceiling increasing at that time from the 1.68 million unit level set for 1981-84 to 2.3 million units from 1984-88.

exports to more expensive (and profitable) models, contributing to the sharply rising dollar value of the trade deficit. As the Department of Commerce reported, "the 1987 value of cars imported from Japan was more than double the pre-VRA 1980 value" (DOC, 1988, p. 86).

Japan surpassed the United States in 1980 as the world's largest producer of motor vehicles and is also the largest exporter, accounting for one-third of world exports in 1987. Japan's world market share was 12.5% in 1970, 25% in 1975, and nearly 40% in 1980 (MVMA, 1988, p. 34). In recent years, the increasing volume of auto exports from Korea, and to a lesser extent, Yugoslavia and Mexico, has begun to erode Japan's large share. U.S. exports are nominal as a proportion of world trade; the United States exports the lowest proportion of its domestic car production of the industrialized nations, 9% in 1985 (excluding U.S.-Canada passenger car trade), compared with 62% for Germany, 58% for Japan and France, and 22-55% for the rest of the EC (DOC, 1988, p. 84). Although fuel economy and price were the initial factors contributing to the influx of Japanese cars into the U.S. in the 1970s, product quality has emerged as a major consideration in consumer decision-making.

Electronic and Communications Equipment.--This industry produces the vast array of consumer electronics--stereos, radios, televisions, VCRs, etc.--as well as telecommunications equipment, computer components, semiconductors and integrated circuits. As such, it is a composite category where the U.S. is still rather competitive in some product fields (telecommunications and broadcasting equipment), quite non-competitive in others (most consumer electronics), and in competitive decline in still others (e.g., semiconductors). As a consequence, this industry is the third largest contributor to the trade deficit after autos and textiles.

Detailed trade data available from Data Resources Inc. (DRI, 1988) encompass nearly all the trade in this industry class. Although these data are not a perfect match to those reported by the OECD, they are sufficiently comprehensive to allow meaningful country comparisons. As table 5.12 illustrates, the U.S. has experienced a substantial erosion in its market position in this industry, declining from a 92% market share in 1970 to 84% in 1986 (note that this is slightly higher than the 78.3% market share of the OECD data).[16] While

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[16]As will be seen below, the import penetration ratios calculated for the electrical machinery and instruments industries are also slightly lower than those obtained using OECD data. I (continued...)

Japan's share of the U.S. market in this industry group increased by nearly 80% during 1970-86 (from 4.6% to 8.4%), the bulk of the increase occurred during 1974-78 and 1983-86. In fact, throughout 1976-83, Japan's market share fluctuated somewhat but demonstrated an undeniably downward trend while that of the U.S. remained stable. Japan's revival in market share in recent years has occurred in radio and TV trade as well as other communications equipment, with slightly stronger performance in radio and TV.

As can be seen in table 5-12, the majority of Japan's market share in the electronics industry derives from radio and TV imports, although the amount has varied considerably throughout the 1970-86 period. In 1970, radios and TVs accounted for 87% of Japan's total market share in this industry; it dropped dramatically to 55% in 1974, and has since fluctuated between about 50-65% and in 1986 was 61%, compared to 52% in 1982. Nevertheless, more than two-thirds of Japan's net increase in market penetration during 1970-86 stems from increases accounted for by communications and electronic equipment other than radios and TV; two-thirds of the net increase in the Japanese market share in these products occurred by 1978.

Vying with Japan as the major supplier of imports in this category are the East Asian NICs, which together with all countries other than the Summit 7 held 6.8% of the U.S. market in 1986. The competition between Japan and these other countries is most substantial in the communications equipment subclass, since Japan supplies nearly two-thirds of U.S. radio and TV imports but only about one-third of communications equipment imports. The most dramatic jump in import penetration by countries other than the Summit 7 occurred from 1970-74, from 1.9% to 6.8%. Although this share increased somewhat after 1974 and peaked at 8.7% in 1984, it was again 6.8% in 1986. During the 1980s, it would appear that, relative to other countries, Japan is in the strongest competitive position, especially in the communications equipment subclass. The competitive decline of the U.S. television industry has been the

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[16](...continued)
believe this difference is accounted for by the differences between the international trade classifications and the industrial classifications. For example, much of the complicated electronics and avionics in jet aircraft and space vehicles are classified as instruments and electronics in the SIC, but as aerospace in the SITC. The result is that the market share ratios for electronics, electrical machinery, and instruments obtained using the DRI SITC-based data are slightly lower than that obtained using the industry-level data of the OECD. However, the ratios for aerospace are considerably higher, as discussed in the text under the aerospace industry.

subject of some attention, and the deficit with Japan in radio and TV equipment accounts for nearly 40% of the total trade deficit in electronic and communications equipment (table 5.13).

Quite noticeable in Table 5.13 is the abrupt reversal in the U.S. trade balance in the communications equipment subclass during 1977-78. Although the U.S. had historically run deficits with Japan in these commodities, large surpluses with other countries were enough to keep the balance of trade in the black overall. However, the large increases in the surplus from 1970-75 began to decline sharply in 1976 due to increasingly large deficits with Japan. Between 1977 and 1978 the U.S. quite suddenly began running deficits with the "other nations" group, with absolutely no indication of its imminence: the surplus with these countries was at a record high during 1975-77.

The U.S. has not been a major presence in world radio and television markets since at least the early 60s--Japan accounted for one half of all world exports in this sub-class by 1967, compared to only 9% for the United States (table 5.14). From 1970 to about 1977, both U.S. and Japanese world export shares held steady, at roughly 6% and 55%, respectively. However, after 1977, Japan's share began increasing substantially, to a peak of nearly 80% of world exports in 1984-85. A recent big export push by West Germany and the NICs reduced Japan's share to 69% in 1986. Similarly, the U.S. share of world exports in the communications equipment subclass was relatively constant during the 1960's at about 30% and at 24% from 1971-77; after 1977 the U.S. share of world exports began declining, while that of Japan began increasing. In fact, Japan's increasing share of world exports has come at the expense of virtually all other nations; only France and Germany have been able to maintain their market shares.

Newly Non-Competitive

The most disconcerting characteristic of the four newly non-competitive industries is that three of them--instruments, electrical machinery, and office and computing machines--are considered to be high-tech industries. The fourth industry, nonelectrical machinery, is classified as medium technology, but shares two attributes with the other three industries: all ran trade surpluses until the mid-1980s, and Japan is by far the most aggressive foreign competitor. Each of the three high-technology industries is discussed separately below.

Instruments.--This industry produces professional, scientific, and control equipment (e.g., laboratory equipment), radar, avionics, cameras, watches and clocks. Unfortunately,

Table 5.15--Market shares of U.S. consumption of instruments, world export shares, and U.S. balance of trade, by country, 1970-86

Item	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
Market Shares																	
United States.......	93.2%	92.8%	92.1%	91.3%	91.4%	91.5%	89.7%	89.0%	86.2%	87.0%	86.9%	86.2%	88.1%	87.6%	88.1%	86.5%	85.4%
Total imports.......	6.8%	7.2%	7.9%	8.7%	8.6%	8.5%	10.3%	11.0%	13.8%	13.0%	13.1%	13.8%	11.9%	12.4%	11.9%	13.5%	14.6%
Japan............	2.2%	2.5%	3.1%	3.3%	3.2%	3.0%	3.8%	4.5%	6.5%	6.0%	6.0%	7.0%	5.9%	6.2%	6.0%	6.6%	7.2%
France...........	0.3%	0.4%	0.4%	0.4%	0.4%	0.3%	0.4%	0.4%	0.4%	0.4%	0.4%	0.3%	0.3%	0.4%	0.4%	0.4%	0.4%
West Germany......	1.3%	1.2%	1.2%	1.4%	1.4%	1.2%	1.2%	1.2%	1.5%	1.3%	1.3%	1.1%	1.0%	0.9%	0.9%	1.1%	1.3%
United Kingdom....	0.4%	0.5%	0.5%	0.5%	0.5%	0.5%	0.4%	0.4%	0.4%	0.4%	0.4%	0.5%	0.4%	0.4%	0.4%	0.5%	0.5%
Canada...........	0.4%	0.4%	0.3%	0.3%	0.3%	0.3%	0.4%	0.4%	0.4%	0.4%	0.5%	0.5%	0.4%	0.5%	0.4%	0.6%	0.5%
Italy............	0.3%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.3%	0.3%	0.3%	0.3%	0.2%	0.2%	0.2%	0.2%	0.3%	0.4%
All others........	2.0%	2.0%	2.1%	2.6%	2.6%	3.0%	3.8%	3.9%	4.2%	4.1%	4.2%	4.2%	3.6%	3.8%	3.7%	4.0%	4.4%
World export shares (percent)																	
United States.......	21.8	20.4	19.3	18.3	19.6	19.6	19.8	18.4	15.5	15.6	15.0	15.9	16.7	15.8	13.7	16.9	14.5
Japan..............	12.8	13.5	15.2	14.6	15.8	15.3	18.4	21.3	22.9	21.7	22.8	27.3	25.1	27.7	31.2	30.0	29.1
France.............	6.2	6.3	6.3	6.6	6.2	7.2	6.7	6.6	6.5	7.0	7.1	6.2	6.2	6.0	5.7	5.5	5.9
West Germany........	20.1	19.3	19.3	20.7	19.7	18.5	18.6	18.4	17.8	17.9	16.9	15.3	15.7	14.6	15.3	15.4	16.6
United Kingdom......	9.5	10.4	9.6	9.1	8.5	9.0	7.7	7.7	8.0	8.7	9.7	8.4	9.1	8.1	7.4	6.9	6.6
Canada.............	0.8	0.9	1.0	0.8	0.8	0.9	1.0	0.9	1.0	1.1	1.2	1.4	1.6	1.8	1.9	1.4	1.5
Italy..............	3.6	3.5	3.5	3.2	3.0	3.1	2.9	3.1	3.0	3.2	3.2	2.9	2.9	3.0	3.1	3.2	3.4
All others..........	25.2	25.7	25.9	26.8	26.4	26.5	24.8	23.7	25.3	24.9	24.2	22.6	22.8	23.0	21.7	20.8	22.5
U.S. balance of trade ($ millions)																	
Japan..............	-92.5	-134.6	-227.7	-253.1	-264	-248.5	-431.9	-663.5	-1402.8	-1355.4	-1575.7	-2139	-1912.5	-2158.4	-2657.2	-2813	-3439.7
France.............	17.7	14.8	15.9	14.7	50.9	61	78.1	75.2	63.5	89.9	127.9	133.3	140.4	107.9	-27	138.2	125.7
West Germany........	-29.4	-22.3	-19.6	-38.5	-25.1	42.8	91.2	83	-79.7	-31.6	-28.3	-24.4	-95.3	-98.1	-151.4	-180.9	-231.2
United Kingdom......	62.3	57.9	55.8	90.1	122.4	136.6	151.6	192.3	223.5	252.3	281.9	288.9	303	336.7	156.4	231.7	229.4
Canada.............	189.2	207.5	229.8	270.8	370.5	382.1	397.4	473.8	426.5	436.4	466.1	527.4	545.2	510.5	451.8	456.3	452.1
Italy..............	18.7	26	23.8	40.2	49.3	60.9	56.1	41.7	34	51.3	47	58.4	52.5	19.8	-47	-65.3	-82.7
All others..........	350.4	379.5	408.8	454.4	737.9	797.9	764.2	799.1	589.2	870.5	1038.8	998	1037.6	659.3	-109	290.5	-19.7
Total..........	516.5	528.8	486.7	578.6	1041.9	1232.9	1106.6	1001.7	-145.8	313.3	357.9	-157.3	70.9	-622.2	-2383.3	-1942.5	-2966.1

Source: Production data, OECD Compatible Trade and Production Database, unpublished data provided to the National Science Foundation; import and export data, Data Resources, Inc., high-tech trade tabulations provided to the National Science Foundation.

Table 5.16--Market shares of U.S. consumption of electrical machinery, world export shares, and U.S. balance of trade, by country, 1970-86

Item	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
Market Shares																	
United States.......	97.5%	97.5%	97.0%	96.4%	96.0%	96.0%	95.4%	94.9%	94.4%	93.6%	92.5%	91.8%	90.6%	89.6%	87.2%	86.6%	85.1%
Total imports.......	2.5%	2.5%	3.0%	3.6%	4.0%	4.0%	4.6%	5.1%	5.6%	6.4%	7.5%	8.2%	9.4%	10.4%	12.8%	13.4%	14.9%
Japan.............	0.6%	0.6%	0.8%	0.8%	0.9%	0.8%	1.0%	1.3%	1.5%	1.5%	1.7%	2.0%	2.4%	2.7%	3.4%	3.6%	4.2%
France............	0.1%	0.1%	0.1%	0.1%	0.1%	0.2%	0.1%	0.2%	0.2%	0.2%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.4%
West Germany......	0.3%	0.3%	0.3%	0.4%	0.4%	0.4%	0.4%	0.5%	0.6%	0.7%	0.8%	0.7%	0.8%	0.9%	1.0%	1.1%	1.4%
United Kingdom....	0.3%	0.2%	0.2%	0.2%	0.2%	0.3%	0.3%	0.3%	0.3%	0.4%	0.5%	0.5%	0.6%	0.6%	0.7%	0.8%	0.9%
Canada............	0.5%	0.4%	0.4%	0.4%	0.5%	0.5%	0.5%	0.6%	0.6%	0.8%	1.0%	1.1%	1.2%	1.1%	1.4%	1.3%	1.4%
Italy.............	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.2%	0.1%	0.1%	0.1%	0.2%	0.2%
All others........	0.7%	0.7%	1.1%	1.5%	1.8%	1.8%	2.1%	2.3%	2.3%	2.7%	3.2%	3.4%	4.0%	4.8%	5.9%	6.0%	6.4%
World export shares (percent)																	
United States.......	21.9	20.7	20.3	20.3	21.4	21.2	21.7	20.3	17.7	19.3	20.4	23.2	22.9	22.9	23.9	21.9	18.1
Japan...............	8.6	8.8	10.1	10.1	10.2	8.7	10.2	12.0	13.6	12.3	13.0	16.1	14.6	16.7	19.3	18.4	18.8
France..............	8.7	9.2	9.1	9.5	9.2	10.5	10.2	9.4	9.4	10.5	10.0	9.1	8.6	8.7	8.2	8.6	8.2
West Germany........	22.5	22.8	22.4	24.3	24.2	22.1	22.2	23.3	24.9	23.1	20.8	17.8	19.1	18.3	17.3	18.8	21.3
United Kingdom......	10.0	10.8	9.6	8.3	8.2	9.5	8.6	8.8	9.3	9.0	10.3	9.6	9.9	9.6	9.2	9.9	9.5
Canada..............	3.1	2.5	2.2	2.1	1.8	1.7	1.6	1.2	0.8	1.0	1.0	1.0	1.1	1.3	1.3	1.3	1.0
Italy...............	4.9	4.6	4.6	4.0	3.8	4.2	4.0	4.5	4.4	4.5	4.5	4.6	4.7	4.7	4.2	4.3	4.5
All others..........	20.2	20.7	21.8	21.5	21.1	22.1	21.5	20.7	19.9	20.5	20.0	18.5	19.1	17.8	16.6	16.9	18.6
U.S. balance of trade ($ million)																	
Japan...............	-18	-33.6	-81.1	-23.5	-19.9	-36.8	-133.3	-258.4	-326.3	-230.7	-290.7	-409.3	-579.3	-711	-1290.4	-1528.1	-1871
France..............	43	41.2	51.8	65.4	93.9	94.1	114.3	118.5	156.5	192.1	262.9	269.7	280.3	238.1	212.8	169.9	194.1
West Germany........	42.5	18.3	28.7	17.7	49.4	77.7	81.9	82.9	113.9	155.3	249.1	277.3	201.9	101.2	56.9	-60	-244.6
United Kingdom......	46	34	65.9	102.7	153	145.1	138.4	166.8	253.6	327.6	414.8	419.8	465.2	450.7	447.6	317.4	206.7
Canada..............	165.9	223.8	246.3	287.8	395.2	398.1	443.1	407.2	421	398.6	480.5	606.3	494.9	550.6	535	535.6	381.5
Italy...............	37.6	36	34.6	47	68.9	98	78	92.5	116.5	133.6	194.7	142.5	182.2	165.4	151.7	114.1	125.9
All others..........	484.5	529.7	523.3	627.1	1004.6	1489.2	1779.7	1946.4	1672.3	2104.6	2567.5	3093.4	2835.2	2185.6	1327.8	856.8	681.7
Total..........	801.5	849.4	869.5	1124.2	1745.1	2265.5	2502	2555.9	2407.6	3081	3878.8	4399.7	3880.5	2980.6	1441.3	405.6	-525.8

Source: Production data, OECD Compatible Trade and Production Database, unpublished data provided to the National Science Foundation; import and export data, Data Resources, Inc., high-tech trade tabulations provided to the National Science Foundation.

Table 5.17--Market shares of U.S. consumption of office and computing machines, world export shares, and U.S. balance of trade, by country, 1970-86

Item	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
Market Shares																	
United States.......	91.8%	89.9%	90.0%	88.7%	89.4%	88.3%	87.7%	88.3%	88.2%	89.4%	89.9%	89.8%	89.0%	84.4%	79.9%	79.3%	75.2%
Total imports.......	8.2%	10.1%	10.0%	11.3%	10.6%	11.7%	12.3%	11.7%	11.8%	10.6%	10.1%	10.2%	11.0%	15.6%	20.1%	20.7%	24.8%
Japan.............	2.4%	3.1%	2.8%	4.0%	3.5%	3.8%	4.9%	4.8%	4.2%	3.3%	3.2%	3.6%	4.5%	6.7%	9.0%	9.2%	11.3%
France............	0.3%	0.3%	0.3%	0.4%	0.5%	0.6%	0.8%	0.8%	0.7%	0.6%	0.5%	0.3%	0.2%	0.2%	0.3%	0.3%	0.3%
West Germany......	1.3%	1.3%	1.2%	1.4%	1.3%	1.5%	1.2%	1.1%	1.1%	1.0%	0.7%	0.6%	0.6%	0.7%	0.7%	0.9%	1.1%
United Kingdom....	0.6%	0.6%	0.6%	0.8%	0.6%	0.8%	0.5%	0.5%	0.6%	0.7%	0.7%	0.4%	0.4%	0.4%	0.6%	0.8%	0.8%
Canada............	1.1%	1.9%	2.5%	1.5%	1.2%	1.3%	1.6%	1.4%	1.6%	1.7%	1.7%	1.7%	1.6%	1.5%	1.7%	1.6%	1.6%
Italy.............	0.7%	0.7%	0.6%	0.5%	0.4%	0.6%	0.5%	0.5%	0.5%	0.4%	0.4%	0.2%	0.2%	0.2%	0.3%	0.9%	0.8%
All others........	1.9%	2.3%	2.1%	2.7%	3.0%	3.2%	2.8%	2.6%	3.1%	2.8%	3.0%	3.3%	3.5%	5.9%	7.4%	7.2%	9.0%
World export shares (percent)																	
United States.......	37.5	33.7	31.0	30.8	33.2	31.3	30.8	32.7	31.9	32.2	34.3	39.1	38.0	35.6	35.5	33.1	28.2
Japan...............	8.0	8.5	9.4	11.8	9.0	9.2	10.6	10.2	11.8	10.3	9.9	11.0	12.2	16.4	19.1	17.7	21.3
France..............	7.8	8.4	8.9	8.5	7.9	8.2	9.0	8.9	8.9	9.0	7.8	7.4	6.3	6.2	5.6	5.6	6.5
West Germany........	15.1	16.5	19.2	18.5	18.5	16.5	17.2	16.4	14.3	13.7	12.9	11.9	11.5	10.8	9.2	10.4	11.7
United Kingdom......	8.8	9.7	9.7	10.3	10.4	11.3	9.7	9.9	10.6	11.5	11.0	8.6	9.1	8.8	9.5	10.4	9.2
Canada..............	3.1	3.7	4.2	3.6	3.5	3.7	4.0	3.5	3.6	3.9	3.4	3.9	3.7	3.6	3.5	3.1	2.6
Italy...............	8.6	7.8	6.3	5.1	5.4	6.0	6.0	5.4	5.4	5.8	7.5	4.8	4.9	4.2	3.6	4.7	4.7
All others..........	11.1	11.6	11.5	11.5	12.1	13.7	12.8	13.1	13.5	13.6	13.2	13.5	14.2	14.4	14.0	15.0	16.0
U.S. balance of trade ($ million)																	
Japan...............	56.8	-4.6	-32.1	-90.1	-70.3	-147.6	-290.9	-351.4	-368.9	-264.7	-191	-286	-698.2	-1781.6	-3430.7	-3411.3	-4762
France..............	132.8	149.1	160.3	183.1	215.4	196.8	210.4	231.7	302.2	407.8	639.1	738	762.5	693.5	715.7	737.8	755.7
West Germany........	129.1	148.2	134.5	131.6	180.9	173.7	182.8	239.6	343.1	548.3	825.5	888.1	802.3	795.1	914	872.3	932.7
United Kingdom......	198.6	144.1	122.3	193.5	267.1	240.4	275.9	363	485.2	599.3	868	1038.4	1226.8	1507.6	1693.9	1407.5	1412.8
Canada..............	146	151.1	139.8	212.2	300.3	282.5	317	391.3	347.9	322.6	492.2	720.8	723.5	865	1279.3	1461.8	1085.8
Italy...............	2	3.4	12.9	27.2	59	37.6	49.9	52.3	60.3	107.6	203.7	265.7	236.9	221.6	235.1	-22	30.3
All others..........	376.8	362.4	384.7	512.6	725.9	789.1	839.6	1128.8	1326.7	1812.6	2578.1	3121.6	2999.6	2661.7	2502.7	2881.5	2040.9
Total..........	1042	953.7	922.6	1170.3	1678.4	1572.4	1584.8	2055.4	2496.5	3533.6	5415.6	6486.7	6053.4	4962.9	3909.9	3927.6	1496.3

Source: Production data, OECD Compatible Trade and Production Database, unpublished data provided to the National Science Foundation; import and export data, Data Resources, Inc., high-tech trade tabulations provided to the National Science Foundation.

of the three sets of trade data reported for these products and industries, none of them reconcile: the Department of Commerce data show trade surpluses through 1987, the OECD data show declining surpluses throughout the 1980s and a deficit in 1986, and the DRI data, which are analyzed here, show steady deficits beginning in 1983. As mentioned previously, the Department of Commerce data exclude photographic equipment and watches and clocks, all popular imports, and thus show steady trade surpluses. On the other hand, the OECD data and the DRI data should be in agreement, at least on the nature of surplus or deficit, especially since they are including essentially the same products. These differences are being explored further, but it seems that the DRI data is based on a narrower set of products than the OECD data; avionics appear to be classified not in instruments trade, but aerospace. As will be seen below, the import penetration ratios for the aerospace industry calculated with DRI data are appreciably higher than those obtained with OECD data.[17]

Nevertheless, the DRI data are instructive. As table 5.15 shows, 90% of the increase in import penetration in this industry occurred during 1970-78, with the most extensive increase during 1974-78. The import penetration ratio remained constant at 13-14% during 1978-81, then declined through 1984, and began rising again to a high of 14.6% in 1986. The fact that the import penetration level dropped between 1983-84 when the trade deficit jumped so significantly in the same period (it nearly quadrupled) suggests rapidly growing consumption, which is indeed the case. From 1983-84 consumption increased 10% in real terms. However, imports have continued to outpace exports and U.S. producers' domestic sales; the import penetration ratio has slowly inched up and the deficit dramatically worsened.

As table 5.15 also illustrates, the U.S. has historically run a surplus in trade in this category, but has also run permanent deficits with Japan and West Germany. The U.S. was able to successfully offset these growing bilateral deficits *and increase* the trade surplus in this industry until 1978, when the deficits with Japan took a dramatic turn for the worse, more than doubling from 1977-78. The surplus overall began declining at that time. The worsening in the balance of trade and import penetration for this industry during recent years is not attributable to Japan, however; new deficits with Italy and non-Summit 7 countries, combined with

[17]The differences between the DRI and the OECD data are being explored further. Based on a preliminary analysis, it would appear that some avionic and aerospace equipment are classified in the electrical machinery, electronics and instruments industries by the OECD, but are included in guided missile trade by DRI.

reductions in surpluses with other nations, have reversed the U.S.'s traditional net surplus to a net deficit.

U.S. world market strength declined coincident with the shifts in trade balance and import penetration. Between 1977 and 1978, the U.S. world market share dropped 3 percentage points, or by 16%. Another large drop (about 2 percentage points) occurred between 1983 and 1984. Only Japan has been able to dramatically increase its world export share of instruments since 1978, at the expense of all other countries except Canada and Italy.

Electrical Machinery.--This industry, which produces electrical transmission and distribution equipment, industrial machinery, and household appliances, was able to maintain large and increasing trade surpluses until 1981, after which time the surplus declined and went into deficit in 1984 (table 5.16). This industry is now the 8th most highly penetrated industry, and accounts for about 4% of the total trade deficit (it is 10th in rank in terms of deficit-running industries). As table 5.16 shows, however, the decline in U.S. market share has been rather steady since 1970 and accelerated in 1978; from 1978 to 1982, import penetration increased by two-thirds, and from 1982-86, by 59%. The U.S. has run a trade deficit with Japan since 1965 in this industry; the only U.S. bilateral deficit was with Japan until 1984, when the United States began running deficits with West Germany and the non-Summit 7 nations. The deficit with Japan doubled during 1980-81, and declining trade surpluses with other nations have likewise contributed to the reversal in the trade balance in this industry.

The U.S. did well in maintaining its world export share in this industry until 1984, at which time it began to decrease, concomitant with the growing trade deficit. Japan increased its share (which nearly doubled from 1974 to 1986), largely at the expense of West Germany until the post-1984 period, during which time the world export share of Germany and the non-Summit 7 nations began increasing. Note, however, that even though Japan accounts for a relatively low share of the total foreign penetration of the U.S. market (about 28% in 1986), it's share has been growing faster than those of other countries except West Germany.

Office and Computing Machines.--The office and computing machine industry, which produces office machinery (typewriters, copiers, adding machines) and automated data processing equipment (computers and personal computers), is the only one of the four newly non-competitive industries that is actually running a trade surplus. It was included in this category because of its rapidly worsening import penetration ratio, the fourth highest in 1986. Additionally, the industry, which has typically been a major contributor to the U.S. trade surplus, has experienced a worsening trade balance since 1982, and is now making only nominal contributions (about 4% of total) to the U.S. trade surplus.

As can be seen in table 5.17, the competitive problems in office and computing machines occur after 1982 with the widespread commercialization of the personal computer. Prior to that time, import penetration in the U.S. market was relatively stable at 10-12% and the U.S share of world exports was increasing and peaked in 1982 at 38%. Similarly, the U.S. balance of trade was positive and rose to an all-time high of $6.5 billion in 1981. Most notably, the United States runs a net surplus with every country except Japan, and the worsening of the U.S. trade balance is directly attributable to the nearly 7-fold increase in the bilateral deficit with Japan--trade with all other countries except Italy and the non-Summit 7 nations increased or remained relatively stable during the period. Japan accounted for one-third of the total foreign share of the U.S. market in 1981, and nearly half by 1986. The non-Summit 7 nations (principally the NICs) account for another one-third of the foreign market share total. Japan's competitive strength is also reflected in the world export share figures; Japan nearly doubled its share from 1981 to 1986 from 11% to 21%. This increase has come largely at the expense of the United States, as other nations have been able to maintain (or increase) their share of world exports.

The Department of Commerce reports that imports from Japan in this industry are dominated by computers and parts, but especially "by small scale peripherals and items where they have the advantage of low-cost, high-volume production" (DOC, 1988, p. 29). The NICs and Mexico are also important suppliers of such products. In an effort to improve market access in foreign countries, the U.S. negotiated with the Japanese government in 1985 to extend copyright protection to software; tariffs on computers and parts were virtually eliminated as part of the MOSS talks. Additionally, the U.S. has been negotiating with the Korean government, which effectively banned the imports of computers and peripherals in Korea if their equivalents were produced indigenously; Korean local content requirements were in place until 1988, and tariffs are generally high.

Competitive

The pharmaceuticals and aerospace industries have long been strongholds of U.S. competitive strength. Although these industries have faced increasing competition of late--from East Asian generic drugs and the European Airbus Consortium in particular--they remain steadily healthy.

Drugs and Medicines.--The pharmaceuticals industry is one of the least penetrated industries in the United States--only 6.6% of total U.S. consumption is accounted for by foreign imports. In addition, the "worst" of the penetration occurred from 1974-78; about half of the net increase in import penetration occurred during these four years (table 5.18). The single-largest increase occurred between 1977 and 1978.

There are several indications, however, that this industry may be on the verge of some competitive difficulties. First, because of the decline in import penetration that occurred during the 1978-82 recessionary period, half of the net increase in import penetration from 1970-86 occurred during 1982-86. Second, as shown in table 5.18, the net trade surplus that this industry typically runs has been declining since 1982. With the exception of Canada and Italy, there is a downward trend in the bilateral trade surpluses; moreover, the size of chronic trade deficits with West Germany and the United Kingdom have been increasing significantly since 1982. Prior to that time, the total surplus had been steadily increasing. Third, as is shown in table 5.18, the U.S. has been *increasing* its share of world exports in pharmaceuticals; its share was nearly 20% of world exports in 1984, compared to 14% in the early 1970's. This share took a pronounced dip between 1984 and 1986, however, to 16%.

Japan is not a presence in this industry--the United Kingdom, West Germany, and Switzerland are the major competitors in this industrial class. The Department of Commerce reports that Japan and Singapore are up-and-coming competitors, however, principally in their production of generic drugs. Japan has consistently accounted for 8-10% of the total foreign share of the U.S. market. This industry is also notable for its *lack* of concentrated foreign competition; the market shares are rather evenly distributed across a range of countries and regions.

Table 5.18--Market shares of U.S. consumption of drugs and medicines, world export shares, and U.S. balance of trade, by country, 1970-86

Item	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
Market Shares																	
United States.......	98.6%	98.2%	98.0%	97.9%	97.7%	97.6%	97.6%	97.4%	95.0%	95.3%	95.3%	95.2%	95.8%	95.2%	94.3%	94.2%	93.4%
Total imports.......	1.4%	1.8%	2.0%	2.1%	2.3%	2.4%	2.4%	2.6%	5.0%	4.7%	4.7%	4.8%	4.2%	4.8%	5.7%	5.8%	6.6%
Japan.............	0.1%	0.2%	0.1%	0.2%	0.3%	0.2%	0.2%	0.3%	0.5%	0.6%	0.6%	0.6%	0.5%	0.6%	0.5%	0.5%	0.8%
France............	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.2%	0.2%	0.2%	0.2%	0.2%	0.3%	0.3%	0.2%	0.3%
West Germany......	0.1%	0.2%	0.2%	0.3%	0.4%	0.4%	0.3%	0.4%	0.6%	0.7%	0.7%	0.7%	0.6%	0.7%	0.7%	0.7%	0.8%
United Kingdom....	0.2%	0.2%	0.3%	0.3%	0.4%	0.3%	0.3%	0.3%	0.8%	0.7%	0.7%	0.8%	0.7%	1.0%	1.4%	1.3%	1.3%
Canada............	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.2%	0.1%	0.1%	0.2%	0.1%	0.1%	0.1%	0.1%
Italy.............	0.1%	0.1%	0.1%	0.1%	0.1%	0.3%	0.3%	0.3%	0.5%	0.5%	0.6%	0.6%	0.4%	0.4%	0.5%	0.5%	0.4%
All others........	0.8%	1.0%	1.1%	1.0%	1.0%	1.0%	1.0%	1.1%	2.1%	1.7%	1.9%	1.8%	1.7%	1.8%	2.2%	2.5%	2.8%
World export shares (percent)																	
United States.......	16.5	13.7	13.9	14.0	14.1	13.6	14.4	13.6	14.9	14.5	14.9	16.7	15.9	18.6	19.6	18.4	15.9
Japan...............	2.4	2.9	2.5	2.3	2.5	2.0	2.2	2.4	2.3	2.4	2.2	2.5	2.1	2.6	2.6	2.7	2.7
France..............	9.3	9.3	9.4	10.2	9.3	10.7	9.7	10.0	9.8	10.9	11.7	11.0	18.5	10.7	10.7	10.9	10.8
West Germany........	19.5	19.0	19.0	19.5	18.8	17.3	18.0	17.5	16.7	17.4	17.0	16.0	14.4	15.5	15.8	15.9	16.4
United Kingdom......	13.0	14.3	13.5	12.2	12.6	13.2	12.0	12.3	12.6	11.7	12.6	12.2	11.5	11.6	11.9	12.4	11.5
Canada..............	1.3	1.1	1.2	1.1	1.0	0.9	0.8	0.9	0.7	0.7	0.7	1.0	0.8	1.1	1.0	0.9	0.7
Italy...............	6.4	7.2	7.0	6.3	6.4	6.6	6.7	6.5	5.8	5.8	5.5	5.5	5.1	5.5	5.9	6.2	5.7
All others..........	31.6	32.5	33.4	34.5	35.3	35.7	36.2	36.8	37.1	36.7	35.3	35.0	31.7	34.5	32.6	32.8	36.3
U.S. balance of trade ($ million)																	
Japan...............	32	32.2	44.6	64.5	91.3	94.1	121.4	125.6	121.8	153.8	213.7	298	370.7	365.3	389.9	390.4	343.9
France..............	10.1	10.3	18.9	24.4	16.6	36.1	38	45.9	68.2	93.4	116.2	137.3	137	126.5	108.2	91	67.8
West Germany........	7.8	-0.9	-1.4	2.1	0.2	-2.7	-2.6	2.5	-19.2	-28.1	-1	-12	-1.5	-28.3	-12.9	-33.2	-34.4
United Kingdom......	2.1	0.1	-6.7	-0.3	1.9	-0.1	-1.2	0.1	-30	-35.1	-11.9	-40.9	-44	-71.9	-202.8	-212.9	-218.8
Canada..............	29.3	31.7	41.5	45.8	58.9	58.9	64.7	77.7	83.6	85.8	106.4	112.1	119.8	136	130.1	131.8	141.6
Italy...............	8	4	7.6	20.9	15.6	10.6	22.9	7.6	-15.6	-12.4	-25	-13.7	-13.3	6.5	-22.2	-17.3	33.9
All others..........	216.6	169.1	180.7	255.5	333.5	346.4	382.3	394.5	469.9	565.8	647.1	667	671.3	671.9	601.3	490.8	509.8
Total...........	306	246.4	285.3	413	517.9	543.4	625.4	654	678.8	823.3	1045.5	1147.8	1240	1205.9	991.5	840.6	843.7

Source: Production data, OECD Compatible Trade and Production Database, unpublished data provided to the National Science Foundation; import and export data, Data Resources, Inc., high-tech trade tabulations provided to the National Science Foundation.

Table 5.19--Market shares of U.S. aircraft consumption, world export shares, and U.S. balance of trade, by country, 1970-86

Item	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
Market Shares																	
United States	98.2%	97.5%	96.0%	95.3%	95.5%	95.8%	97.0%	96.4%	95.2%	94.7%	91.3%	90.0%	91.0%	93.6%	91.7%	91.1%	89.1%
Total imports	0.1%	0.1%	0.1%	0.2%	0.2%	0.1%	0.1%	0.1%	0.2%	0.2%	0.4%	0.4%	0.7%	0.3%	0.3%	0.3%	0.4%
Japan	0.1%	0.2%	0.2%	0.2%	0.3%	0.4%	0.3%	0.7%	0.6%	1.1%	1.5%	1.9%	1.7%	1.4%	1.9%	2.3%	2.7%
France	0.0%	0.0%	0.0%	0.1%	0.3%	0.2%	0.1%	0.1%	0.3%	0.2%	0.2%	0.2%	0.2%	0.3%	0.5%	0.3%	0.4%
West Germany	0.4%	0.6%	1.6%	2.1%	1.7%	1.9%	1.1%	1.0%	1.7%	1.4%	2.5%	2.9%	2.2%	1.6%	1.9%	2.3%	2.6%
United Kingdom	1.1%	1.5%	1.8%	1.7%	1.6%	1.3%	1.0%	1.1%	1.5%	1.7%	2.4%	2.8%	2.5%	1.8%	2.3%	2.2%	2.6%
Canada	0.0%	0.1%	0.1%	0.2%	0.2%	0.1%	0.1%	0.1%	0.2%	0.1%	0.3%	0.4%	0.3%	0.2%	0.2%	0.2%	0.3%
Italy	0.0%	0.1%	0.1%	0.2%	0.3%	0.2%	0.3%	0.3%	0.3%	0.6%	1.5%	1.4%	1.4%	0.8%	1.1%	1.4%	1.9%
All others	1.8%	2.5%	4.0%	4.7%	4.5%	4.2%	3.0%	3.6%	4.8%	5.3%	8.7%	10.0%	9.0%	6.4%	8.3%	8.9%	10.9%
World export shares (%)																	
United States	60.7	64.6	57.8	59.9	64.9	61.9	57.9	54.3	55.4	49.5	50.2	52.5	44.2	48.7	45.1	50.9	49.7
Japan	0.7	0.5	0.6	0.5	0.3	0.3	0.2	0.2	0.3	0.4	0.3	0.4	0.6	0.6	0.5	0.4	0.6
France	7.2	5.7	7.2	6.3	5.5	7.5	9.7	10.1	7.2	11.9	6.3	7.1	9.7	9.3	11.8	9.7	9.0
West Germany	3.4	2.2	2.6	3.8	3.3	4.0	7.0	9.1	8.8	9.6	10.0	11.6	16.0	13.2	15.2	11.7	9.5
United Kingdom	11.7	12.3	15.4	14.9	13.6	14.2	11.9	12.9	17.6	17.7	21.7	14.6	15.9	14.9	14.5	14.8	17.2
Canada	8.3	6.1	8.3	5.7	4.9	4.2	4.3	4.5	2.4	2.7	3.1	3.4	4.1	3.5	3.6	3.9	4.6
Italy	1.9	2.3	2.5	2.2	2.5	2.6	3.2	2.9	3.5	2.7	2.2	4.2	4.2	4.2	4.6	4.0	4.1
All others	6.1	6.2	5.7	6.7	5.0	5.4	5.8	6.1	5.0	5.7	6.2	6.1	5.4	5.7	4.7	4.6	5.3
U.S. balance of trade ($ million)																	
Japan	274	365	470	248	618	408	337	262	510	846	999	1,230	730	1,332	1,077	1,550	1,904
France	157	98	167	297	281	194	246	164	250	240	274	261	166	216	(423)	(677)	(527)
West Germany	257	305	287	321	309	356	297	335	490	504	543	1,063	787	407	336	698	908
United Kingdom	124	162	46	(73)	37	(36)	65	234	92	268	579	(374)	(411)	140	65	(49)	(594)
Canada	89	7	(21)	167	204	304	54	64	114	274	(81)	(69)	(389)	(97)	(359)	(603)	(844)
Italy	128	143	91	139	148	167	192	74	120	149	326	457	113	199	307	571	290
All others	1,741	2,415	1,994	2,927	4,296	5,052	5,323	4,935	6,318	6,745	8,073	9,285	8,194	8,344	6,987	9,195	9,337
Total	2,771	3,495	3,034	4,025	5,893	6,444	6,513	6,067	7,892	9,025	10,714	11,852	9,189	10,540	7,990	10,685	10,475

Source: Production data, OECD Compatible Trade and Production Database, unpublished data provided to the National Science Foundation; import and export data, Data Resources, Inc., high-tech trade tabulations provided to the National Science Foundation.

Table 5.20--Market shares of U.S. aerospace 1/ consumption, world export shares, and U.S. balance of trade, by country, 1970-86

Item	1978	1979	1980	1981	1982	1983	1984	1985	1986
Market Shares									
United States	89.4%	88.9%	83.3%	81.2%	84.8%	89.0%	86.3%	84.8%	81.4%
Total imports	0.8%	0.8%	1.3%	1.2%	1.6%	1.2%	0.4%	0.4%	0.5%
Japan	2.0%	3.0%	3.3%	4.3%	4.0%	3.6%	3.6%	4.5%	5.0%
France	0.6%	0.6%	0.5%	0.6%	0.5%	0.7%	1.0%	0.6%	0.8%
West Germany	3.4%	2.6%	4.2%	5.1%	3.5%	2.6%	3.1%	3.8%	4.6%
United Kingdom	4.1%	5.1%	5.9%	6.7%	4.3%	4.1%	3.5%	3.2%	4.0%
Canada	0.4%	0.2%	0.5%	0.7%	0.4%	0.3%	0.3%	0.3%	0.4%
Italy	-0.7%	-1.2%	1.0%	0.2%	1.3%	-1.5%	1.8%	2.5%	3.3%
All others	10.6%	11.1%	16.7%	18.8%	15.6%	11.0%	13.7%	15.2%	18.6%
World export shares (%)									
United States	75.3	73.5	75.5	73.2	65.2	68.7	65.6	69.2	64.6
Japan	0.0	0.0	0.0	0.1	0.2	0.1	0.1	0.2	0.4
France	3.2	3.9	1.2	1.2	2.7	3.2	4.7	4.6	5.3
West Germany	3.4	3.1	1.6	1.2	1.8	2.5	4.0	2.9	3.0
United Kingdom	10.3	10.6	12.1	11.9	14.9	10.7	11.4	10.9	11.9
Canada	4.6	5.4	6.3	6.6	9.3	7.7	9.2	8.2	9.4
Italy	1.6	1.0	1.0	1.3	1.3	1.4	1.7	1.2	2.2
All others	1.5	2.6	2.3	4.7	4.7	5.7	3.3	2.9	3.2
U.S. balance of trade ($ million)									
Japan	(108)	(140)	(219)	(227)	(303)	(346)	639	1,093	1,406
France	(168)	(323)	(379)	(539)	(468)	(488)	(329)	(480)	(101)
West Germany	(15)	(40)	(56)	(98)	(91)	(93)	(28)	371	572
United Kingdom	157	178	398	355	331	187	162	240	(380)
Canada	(121)	(361)	(259)	(288)	273	(45)	(11)	(71)	(310)
Italy	(9)	6	(13)	(23)	(16)	3	281	518	290
All others	5,995	7,386	9,049	10,283	6,838	8,169	4,023	6,016	6,084
Total	5,731	6,707	8,522	9,464	6,563	7,386	4,737	7,686	7,560

1/ aircraft plus guided missiles and spacecraft. Data on guided missiles and spacecraft not available prior to 1978.

Source: Production data, OECD Compatible Trade and Production Database, unpublished data provided to the National Science Foundation; *import and export data, Data Resources, Inc., high-tech trade tabulations provided to the National Science Foundation.*

Aerospace.--The U.S. aerospace industry is by far the most competitive of all manufacturing industries. Not only does it run large trade surpluses, but these surpluses have been increasing throughout the 1980s. Additionally, the aerospace industry has typically been one of the least penetrated industries in the manufacturing sector; about 11% of the U.S. market was accounted for by foreign imports in 1986. This industry is not without competitors, however; efforts by France, Germany, and the United Kingdom to boost their aerospace industries have largely paid off, and after 1978 these countries began making significant inroads in the world market.

Competitiveness data on the aerospace industry are slightly difficult to interpret, however. If DRI data on aircraft alone are used, the subsequent market share ratios are identical to that obtained by the OECD data. As can be seen in table 5.19, the aerospace industry continues to be quite vigorous, and in spite of declining world market shares and rising import penetration since 1978, the U.S. trade surplus in this industry is large and generally rising. The data also reflect the insignificance of Japan as a competitor in this industry; its share of the U.S. market is less than 0.5% and Japan accounts for less than 1% of all world exports.

However, trade in guided missiles and spacecraft--also part of the aerospace industry according to the ISIC--are reported separately by DRI. If these trade data are included with aircraft trade, then the market penetration level for the aerospace industry jumps to nearly 20% (table 5.20). Since this degree of import penetration is entirely inconsistent with other information on the competitive standing of the aerospace industry, then one can only assume that guided missile and spacecraft trade has been allocated by the OECD to other industrial classes. Given the slightly lower levels of import penetration in the electronics, instruments, and electrical machinery industries--all critical to the production of spacecraft and missiles--obtained with the DRI data, it seems reasonable to assume that at least part of the missile/spacecraft trade shows up in these industries in the OECD data.[18]

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[18]As indicated earlier, this supposition is being explored further. I am trying to obtain the concordance that the OECD uses in allocating ISIC-based trade classes to SIC-based industrial classes.

Summary of industry profiles

It is generally difficult to find identifiable patterns of competitive difficulties among the six high tech industries and motor vehicles, at least in terms of time periods in which U.S. competitive troubles begin. There are, however, some rough guides which can serve as benchmarks for the future chapters in which patterns in U.S. and Japanese science and technology are matched against patterns of competitiveness. Specific details for the seven industries were presented in table 5.10; the more general similarities (and differences) among these industries include:

- The key distinction between the competitive industries and the non-competitive ones is Japan's dominance as the major foreign competitor. In all of the non-competitive industries except electrical machinery, Japan accounts for one-half of the total foreign share of the U.S. market. In electrical machinery, this share is just less than one-third.

- Japan is not a significant competitor in either aerospace or drugs, the two high tech industies in which the U.S. is competitive.

- For motor vehicles, electronic equipment, electrical machinery, and instruments, competitive decline started in 1978, the same time their trade balances with Japan began a substantial worsening. Notably, Japan had just finished restructuring its economy to adjust to the 1973 oil shock, which put it in a dramatically improved competitive position vis-a-vis the U.S. (see Dore, 1988).

- In all industries except aerospace, there has been a pronounced worsening in competitive position during the 1982-86 period.

- Of the newly non-competitive industries, Japan has *not* been a major "cause" of the competitive decline in the 1980s in the electrical machinery industry, although it may have contributed to a competitive weakening in this industry. The U.S. trade balance and world export share worsened after 1984, the same year in which the United States began running chronic deficits with West Germany and "all other" countries.

Conclusions

The foregoing analysis has provided significant insight into the nature of the decline in U.S. competitiveness in the early 1980s. Importantly, it is possible to distinguish among what appear to be declines in "intrinsic" competitive ability and extrinsic causes of the trade deficit.

The findings may be summarized quite briefly. First, the hallmark of the crisis was indeed the burgeoning trade deficit. Other nations also experienced dramatic increases in their levels of import penetration, but what was unique to the United States was the dramatic decline in its trade position. The systematic erosion in the balance of trade for all product and industry categories suggests that part of the problem was a "recovery" effect exacerbated by improperly valued exchange rates (this will be discussed in more detail at the end of the dissertation in the Epilogue). More than likely, strong domestic demand stimulated the influx of imports and rediverted some (unknown) proportion of typical exports into the domestic market; the overvalued dollar accentuated both of these trends by making foreign goods that much more attractive, and U.S. exports that much less.

However, it is clear that a handful of industries contributed to a substantially disproportionate amount of the trade decline. A juxtaposition of the trade data with market share data shows a core of chronically non-competitive U.S. industries, and the litany is familiar: autos, steel, textiles, and electronics. Somewhat shockingly, there was a complete reversal and significant competitive decline in two key manufacturing industries: electrical and non-electrical machinery. Moreover, the instruments and computer industries appear to be tottering on the non-competitive brink. While all of these latter four industries were classified here as newly non-competitive, the competitive decline in the machinery industries was far more pronounced. The non-competitiveness of instruments and office and computing machines is somewhat tentative because the durable goods industries as a class demonstrated a weakened competitive position with the onset of recovery, again suggesting that macroeoconomic and trade factors might be stronger determinants of competitive decline than intrinsic business or innovation variables. Nevertheless, it is quite possible that the trend for the durable goods industries is masking latent intrinsic disability, or even worse, indicative of future decline.[19]

Perhaps one of the most surprising findings is the relatively weak association between comparative advantage, technology status of industries, and competitive strength. Of the six high tech industries, the U.S. has revealed comparative advantage (or no disadvantage) in four industries in which it is *not competitive*. This reveals one of the critical limitations of

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[19]While macroeconomic factors create an environmental non-competitiveness (e.g., in distorting relative prices, suppressing capital investments), their cumulative effect may be to seriously damage intrinsic competitive abilities. Lost revenues and insufficient investment directly impinge upon the capacity of firms to modernize and innovate, the two critical endogenous determinants of intrinsic competitiveness.

comparative advantage indicators: they are based exclusively on export performance and do not account for developments in the domestic market. In all but electrical machinery, the foreign competition is especially intense not in the narrow, high tech end of the product lines, but in the high quality mass production markets. Quite simply, high technology niches cannot compensate for competitive disadvantage in large consumer markets.

Finally, there is the undeniably bilateral nature of U.S. competitive problems. Japan is certainly the most troublesome foreign competitor, with the NICs a somewhat distant second. No other country presents such an intense challenge to U.S. economic welfare than Japan. The data also hint at the possibility of a threshold effect: in most of the industries in which the U.S. demonstrates weakened competitive performance, Japan accounts for a quarter--and typically one-half--of all imports in that industry.

For purposes of analysis in the following chapters, we can summarize the U.S.-Japan competitive profile somewhat simply. Table 5.21 provides a breakdown of U.S. manufacturing industries by technology classification, and indicates whether Japan or the United States is relatively more competitive (if applicable). As can be seen, Japan dominates in the high tech industries and in two critical medium tech industries--autos and nonelectrical machinery. For all of the industries which Japan is the stronger competitor, U.S. competitive decline started in approximately 1978 for all but two industries. The weakening in office and computing machines clearly began in 1982 (with the onset of both the recovery and the explosion of the PC market); the U.S. steel industry has been disadvantaged since at least 1970. The next chapter will thus explore whether or not these patterns can be explained by efforts in scientific research.

Table 5.21--Competitive status of U.S. and Japanese Industries

Industry	Industries in which U.S. is competitive 1/	Industries in which Japan is competitive 2/
High Technology		
Instruments.....................		X
Electronic equipment & components..................		X
Electrical machinery............		X
Office & computing machines.....		X
Drugs & medicines...............	X	
Aerospace.......................	X	
Medium Technology		
Motor vehicles & equipment......		X
Nonelectrical machinery.........		X
Rubber & plastic products.......	X	**
Other manufacturing.............		
Non-ferrous metals..............		
Chemicals.......................	X	
Low Technology		
Ferrous metals..................		X
Fabricated metal products.......		**
Textiles, footwear, & leather...		
Wood, cork, & furniture.........		
Stone, clay, & glass products...	X	
Food, drink, & tobacco..........	X	
Petroleum refining..............	X	
Paper & printing................	X	

1/ See table 5-9.
2/ Japan accounts for 25% or more of all imports in category as of 1987.

**: Japan accounts for approximately 20% of imports in these industries.

CHAPTER 6

Patterns in Basic Research

One of the most critical assumptions about Japanese competition with the United States is that Japan's success has derived largely from its skill in applying and commercializing *foreign* science and technology. Since the beginning of the Meiji Restoration in 1868, Japan's history of industrial modernization has ostensibly been one of borrowing, imitating, and duplicating the efforts of the West. From its 19th and early 20th century efforts to "catch up" in heavy industries and light manufactures, to present day "piracy" in fiber optics and semiconductors, Japan is understood to owe its economic success to the intellectual wealth of others.

Even though the technological strengths of Japan are now being explicitly recognized as a factor in its trade performance, the technological dependency theory is still potent. Consider the following statement in recent study by Congress:

> The Japanese are very efficient in improving and applying technologies developed by others. It is more cost effective to copy than it is to invent. (USHR, 1989, p. 55)

Our understanding of Japan's dependence on foreign technology extrapolates to national activities in basic research as well:

> U.S. companies [are] much more basic-research oriented, and the Japanese [are] much more application/development oriented. They are taking someone else's technology and doing a hell of a job producing new products with it, whether it's radios, television sets, or automobiles.[1]

> The United States, for better or worse, has supported basic research whose results are easy to predict, *as well as* basic research whose results are more difficult to envisage. Japan, to a large extent, for better or worse, has supported neither. The Japanese have been able to gain enough understanding of the basic scientific principles to pursue advanced development and product engineering without actually engaging in basic or applied research themselves. (Gamota and Frieman, 1988, p. 6)

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[1]These remarks are by James Olson, Chairman of AT&T, on why the Japanese have done so well at exporting their products. He was summarizing the conclusions of a U.S.-Japan Business Advisory Council meeting on this subject. See "AT&T Chairman James Olson, On Exporting U.S. Technology," *High Technology Business*, November 1987, p. 49.

Such allegations about Japanese weaknesses in basic research are hard to refute given the conventional understanding of the Japanese university system, the traditional source of basic scientific research. The higher education system in Japan, a creation of the Meiji era, borrowed heavily from the highly structured German "chair" system, and during the sytem's formative period research had an imitative character. The translation of foreign textbooks and replicative experiments were regarded as acceptable and desirable forms of scholarly activity, practices alleged still to be acceptable forms of scholarship. The subsequent hierarchy of the Japanese university system, its traditions in "incremental" research, and Japanese culture interact to give the impression of a conservative and uncreative research system, attributes scarcely conducive to risky, imaginative approaches to science. As a recent study reported:

> In Japan, universities are often called the weakest part of the research system. Japanese universities are hierarchically organized on the basis of seniority, oriented to a group effort that creates lifelong ties, and funded on the basis of a rigid system that leaves only small leeway to reward individual excellence on the part of younger researchers. Compared to corporate laboratories, the equipment and facilities of many Japanese university labs leave much to be desired. (Office of Japan Affairs, National Research Council, 1989a, p. 3)

These observations help to explain why the Japanese university system is thought to be relatively resource poor, shabby, and uncreative; in other words, a constrained producer of basic research.[2] The same report concludes, "These standard images go far to explain why some of Japan's most outstanding scientists and engineers have found it necessary to go abroad to do the kind of path-breaking research that brings worldwide acclaim" (Office of Japan Affairs, National Research Council, 1989a, p. 4).[3]

Because of images about Japan's industrial dominance in applied research and development, its dependency on the West for science and technology, a weak and underdeveloped university research system, and a sense that Japan has not produced any truly pioneering basic research, the net impression is that Japan conducts little (or as Gamota and Frieman would claim, none) basic research and of that research which is conducted, "the

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[2]See also Akio Yamamoto, "Japanese Universities Feel the Chill," *Nature* 339 (22 June 1989): 575-576; "Japan Faces Big Task in Improving Basic Science," *Science* 243 (10 March 1989): 1285-1287.

[3]The reference here is to Dr. Tonegawa, the recent Nobel prize winner. Tonegawa is an expatriate Japanese researcher, and has frequently criticized the cultural and structural limitations to Japan's ability to do creative basic research.

balance between private and public knowledge has been struck at a point much closer to proprietary knowledge than in the U.S." (Brooks, 1988, p. 54). In short, Japan seems incapable of imaginative basic research and certainly not of the kind of public domain, curiosity driven science characteristic of the West.

These cumulative impressions have in fact shaped one of the major U.S. bilateral policy responses to the competitiveness crisis: it has insisted that Japan begin contributing its fair share to the world's knowledge base by conducting more basic research, and, as a *quid pro quo* measure, that the U.S. be allowed access to the "proprietary" research which dominates the Japanese R&D system. The recently concluded U.S.-Japan science agreement codified such objectives by affirming that the U.S. and Japan have an obligation to contribute to the world's stock of scientific knowledge and to allow "comparable access to each [other's] research and development systems."[4] More commonly understood as an issue of "symmetrical access," the goal of the Agreement was to "trade access to MIT for similar work at Fujitsu".[5]

The Japanese have themselves acknowledged the need for the country as a whole--and the universities especially--to engage in more basic research.[6] In fact, the promotion of more, higher quality basic research and improved linkages between industry, universities, and government is an official policy of the Japanese Government.[7] The explanations vary for this

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[4]"Agreement Between the Government of the United States of America and the Government of Japan on Cooperation in Research and Development in Science and Technology," June, 1988.

[5]This statement was made by Frank Press, president of the National Academy of Sciences. For the source of quote and a succinct overview of the U.S.-Japan bilateral science issues (and their origins), see "Strains in U.S.-Japanese Exchanges," *Science* 237 (31 July 1987): 476-478.

[6]Although Japanese policy rhetoric specifically targets universities for improvement in basic research, the actual operationalization of this goal remains vague. Significant structual (and cultural) reforms seem in order, but the universities are dominated by powerful bureaucratic and constituent interests in Japan. Since the Japanese university research system is so tightly connected to the structure of higher education, any tinkering in effect challenges the entire education system. A rudimentary understanding of bureaucratic and education politics in Japan is sufficient to reveal what an enormous--and threatening--undertaking it is to try to change the research system, to say the least of the cultural norms driving many of its rigidities.

[7]Within the Japanese Government, there has been rather persistent policy-related discussion on the role and promotion of basic research beginning with the report "Toward New Research and Development" (1981) issued by the Agency of Industrial Science and Technology, an agency of MITI. This was followed by the recommendations for increased basic research by the 11th and 12th Inquiries of the Council for Science and Technology, "Comprehensive (continued...)

emphasis, including arguments not dissimilar to what may be found in the United States, e.g., that basic research is the most likely source of radical innovation. There are, however, a few twists to this policy: the Japanese have expressed concerns about keeping international relations "harmonious" and a fear of embargoed U.S. science and technology. However, there is also the concern that since Japan is now at the *forefront* of many areas of science and technology, there is no longer anything to "borrow" from the West. As a recent *Business Week* article summarized, "There is no longer a vast reservoir of technology in the U.S. and Europe that they can tap. The pace of research is accelerating, and the turnaround time for technology to move from the lab into commercial products is shorter than ever. At the same time, many of Japan's competitors are becoming less willing to license their technology."[8]

There is an interesting contradiction to the U.S. policy approach and Japanese response to the basic research and symmetrical access issues.[9] First is the issue as to how Japan has emerged as a world-class technological competitor in many research fields by drawing only on U.S. (or other Western) science and technology. At the very least this suggests some disturbing ideas about the capability of the United States to commercialize the products of its own research system. At the very most it makes the Japanese superhuman in their ability to identify, acquire, and commercialize foreign knowledge and know-how. In an era when basic and applied research (science and technology) are blurring, technology is ever more science-based,

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[7](...continued)
Fundamental Policy for Promotion of Science and Technology to Focus Current Changing Situations from the Long Term View" (November 1984) and "General Guideline for Science and Technology Policy" (December 1985). In tandem with these inquiries was the basic research focus of the 1983 annual science and technology white paper of the Science and Technology Agency, "Towards Creation of New Technology for the 21st Century" (December 1984). The Japanese Cabinet formally adopted the promotion of basic research in its "General Guideline for Science and Technology Policy," a Cabinet decision issued in March 1986. Since that time, the Science and Technology Agency has again made basic research the theme of its annual white paper (the 1988 report). Moreover, the first-ever AIST White Paper on Industrial Technology ("Trends and Future Tasks in Industrial Technology", September 1988) calls for more basic research in the private sector and greater government-industry-university collaboration.

[8]"Japan Focuses on Basic Research to Close Creativity Gap," *Business Week*, February 25, 1985, pp. 94, 96.

[9]To a large extent, the Japanese response seems to be acquiescence on their part that the U.S. claims are legitimate. Not only do they acknowledge their dependence on foreign science and technology by anticipating techno-protectionism, but their own effort to stimulate basic research reflects similar assumptions about the role of basic research in innovation and the needs for Japan to have an indigenous source of scientific breakthroughs.

and the time lag between discovery and commercialization is diminishing at a rapid pace, it seems rather incredible that Japan's competitiveness is predominantly the result of its applications of other's science and technology.

Indeed, if one proposes the alternative--that Japan's emergent technological prowess is the result of indigenous research efforts--then it would be hard to argue that Japan is *not* doing basic research, especially if we accept the precepts about the synergism between science and technology and the role of basic research. This is probably what Press was referring to when he indicated that the U.S. wanted access to research at Fujitsu; the "enlightened" impression is that Japan *is* doing some type of fundamental research, but because it is performed in industry, it is by necessity proprietary and secret.

However, it would seem--based on anecdotal evidence--that frontier research in Japan is not terribly secret, at least to U.S. scientists with relevant interests. The largest Japanese electronics corporations (NEC, Fujitsu, Hitachi) invite and support U.S. academic researchers in their corporate basic research labs. They, as well as other corporations, additionally sponsor international conferences on research emanating from the corporate labs. The technology assessments in Gamota and Frieman (1988) reflect a familiarity by the scientific community with Japanese public and private science, and a recent study at MIT revealed that 90% of the 1,100 respondents (PhD-level researchers) said Japanese developments in their fields were very important, over 33% said the Japanese had "greatly contributed" to their personal work, and nearly one-half had been to Japan in the past 5 years.[10]

Given the relatively high degree of integration between MIT and the Japanese scientific community, the issue may be not the supply, quality, or location of Japanese science, but U.S. "connectedness" with it. Even still, the U.S. scientific community may be well versed with their Japanese colleagues at the research frontiers, and the problem is the lack of linkages between that knowledge and the commercial sector in the United States. Japanese basic research results may thus be right where they ought to be: in the scientific community in both Japan and the United States. The production of Japanese basic research by industry notwithstanding, the dynamics of knowledge growth--and the increasing internationalization of that process--demand that research results be shared in order to advance the knowledge frontier. The location of basic research in industry does not mitigate this requirement.

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[10]See "Briefs" in *Research Management*, March-April 1987.

On the basis of the simple logic of the science paradigm, limited anecdotal evidence, and our understanding of the nature of the conduct of science, it seems more reasonable to presuppose the existence of Japanese basic research than its absence. The relationship between this science and and Japanese competitiveness remains to be seen in much the same way as the United States; however, given the strong emphasis on basic research by U.S. policymakers, comparisons are worthwhile.

Interestingly, quantitative comparisons of basic research efforts in Japan and the United States have been virtually non-existant;[11] policy-making has been guided more by conventional wisdom and anecdote than attempts to establish evidence for various positions or more accurate impressions of Japanese R&D.[12] For example, Brooks' conclusion that "it appears that the Japanese have hitherto drawn heavily on the open research system of the U.S., but they may well be forced to move toward greater dependence on their university system for public research" is based on no evidence whatsoever--anecdotal or otherwise (Brooks, 1988, p. 54). His sole justification for such a statement is that 1) since the Japanese university system is so weak, 2) the Japanese R&D system so dominated by industrial interests, and 3) Japanese technological capabilities so strong, then 4) they must have gotten their scientific knowledge from the U.S.

The findings presented here suggest that Japan has been engaged much more extensively in basic research than typically given credit for, particularly because its efforts have been in fields of research or industrial sectors most strongly identified with "applied" science or "technology" (e.g., medical science, engineering, industrial machinery). Moreover, while clearly lagging in some areas, especially the physical sciences, Japanese basic research expenditures match or exceed those in the U.S. for several industries and academic disciplines, even with substantial reductions or qualifications to the Japanese data. Available qualitative

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[11]The only known publications with even limited data on U.S. and Japanese basic research data are Papadakis (1988, 1989) and NSF (1988).

[12]The methodological issues at hand are not insignificant. The guiding premise of Japan's lack of contribution to basic science is its seeming absence of "pioneering" basic research. How does one actually define and determine this? There are typically two approaches to analyzing the contributions of basic science to innovation; the econometric rate of return studies and case studies on the sources of innovation (the standard science-push/demand-pull approaches). The rate of return studies for Japan are inconclusive and the findings counter-intuitive; the methods and analytical approaches in the case method are sufficiently contentious in the U.S. studies that cross-national comparisons seem unwarranted in the absence of better frameworks.

indicators, such as scientific publications, reflect the growing output and quality of Japanese basic research in those areas of greatest investment.

Data and Methodology

This chapter analyzes trends and levels of effort in U.S. and Japanese basic research expenditures over the years 1975-88. Although R&D expenditure data is technically not a measure of creativity or scientific discovery, it *is* a measure of the input into these processes. Since most basic research activity does occur as an R&D endeavor, expenditure data tend to capture the scope of the research process, although not in precise magnitude or character. For the advanced industrialized nations, definitions of basic research, R&D, and guidelines for measuring the R&D enterprise, are outlined in the *Frascati Manual* of the OECD (1981a).

The basic research expenditure data used here are derived from surveys of the National Science Foundation and from the Japanese annual *Report on the Survey of Research and Development*. Generally speaking, the data are highly comparable in both definition and collection methodology. Because of changes in methodologies and survey content, comparable basic research data for both countries may only be obtained back to the years 1974-75. However, when one begins to disaggregate the data, there are two methodological issues which are serious cause for concern. One is a measurement problem, the other a possible difference of national culture and conceptualization.

First, the Japanese include in their R&D data the full salaries of all faculty in the higher education sector, without regard to time actually spent on R&D (e.g. data are not in "full-time equivalents"). As a consequence, the salaries of faculty who spend all, or most of their time teaching, are included in the R&D data. This results in a rather serious overstatement of R&D performed in the higher education sector not only because of the inclusion of costs not associated with research, but because of the large proportion of non-PhD granting institutions included in the Japanese surveys. Additionally, these 4-year colleges and universities are also predominantly liberal arts institutions, which further inflates Japanese R&D relative to the U.S.: the Japanese include the arts, humanities, and education disciplines in their data, while the U.S. does not.

In order to correct for these comparability problems, only R&D in the natural sciences and engineering are analyzed here. Additionally, Japanese higher education R&D expenditures have been deflated by 35%. The exclusion of social science and humanities research is not an analytical issue, since basic research in the natural sciences and engineering is the R&D most likely to be relevant for economic and industrial purposes. Although some social science R&D should also be properly included, the volume of such research is small, would not make a difference statistically, and as a consequence it would not be time-effective to make the estimates.

With regard to the more serious reduction in the Japanese higher education data, there are two bases for the adjustment. Using a .50 full-time-equivalence ratio for research in the Japanese higher education sector (a ratio that is also used by the Japanese Ministry of Education), calculations show that a 50% reduction in the salary component of the higher education R&D expenditure data results in a 35% net reduction in total higher education-performed R&D. This figure is additionally quite consistent over time, although it does not take into account differences between fields of science, which may have varying ratios of salary and equipment costs. The 35% reduction using performer-based R&D data is consistent with a study conducted by the OECD which used source-of-funds data; The OECD also recommends a 35% reduction in the Japanese higher education R&D data for purposes of international comparisons.[13]

Secondly, it is frequently argued that the Japanese conceptualize basic research differently than we do in the United States (Kodama, 1985; Gerstenfeld, 1982). Most critics charge that the Japanese typically call basic,--or "fundamental"--research that which Americans would consider to be applied. However, in the U.S. and Japanese surveys which collect basic research data, basic research is defined as scientific research conducted without any specific application in mind; more implicitly, this research is for the purpose of uncovering and explaining natural phenomena and processes.[14]

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[13] See OECD, *Science and Technology Indicators No. 2: R&D, Invention, and Competitiveness* (OECD, Paris: 1986), p. 75.

[14]The U.S. definition is "research projects which represent original investigation for the advancement of scientific knowledge and which do not have specific commercial objectives, although they may be in the fields of present or potential interest to the reporting company." Note that this final phrase "although they may be ..." is a qualifier attached only to the (continued...)

Nevertheless, it is repeatedly asserted that in practice the Japanese conceptualization of basic research is more expansive than that of the United States and includes research which Americans would typically consider to be applied research. This basic/applied synthesis is called "fundamental" research in Japan, and includes an ambiguous area of research in which specific commercial needs require new scientific knowledge and understanding of natural phenomena. Such research is especially common in basic technology research, e.g., genetic engineering, laser technology, photovoltaic technology, and in some standard industries such as semiconductors, microelectronics, and pharmaceuticals. Kodoma (1985) calls this ambiguous area "applied basic research," and argues that most contemporary Japanese basic research is of this character. Owens (1984) finds (through interviews with Japanese R&D officials) that "some of the [officials] viewed directed studies of fundamental aspects of some phenomenon which might be helpful in solving a particular other-than-scientific problem to qualify as basic research. Many engineers and some scientists in Japanese universities would agree with this definition."

If these assertions are accurate in part or *in toto,* it would appear that Japanese basic research data may be seriously overstated relative to the U.S., but *only to the extent* that U.S. research comparable to "applied basic research" may be being report as applied research. As Brooks (1978) notes, "many industrial research directors stress the artificiality of the distinction between basic and applied research as far as industry is concerned"; clearly "applied basic" industrial research takes place in the U.S. as well. The question is merely one of research classification, and not content.

A recent survey of firms which participate in Japan's national survey of R&D (the survey from which the data presented here are obtained) affirms the popular understanding of the nature of Japanese conceptualizations of basic research. The National Institute of Science and Technology Policy (NISTEP) found that most respondents (71%) believed that goal-oriented basic research--research with a purpose in a broad sense but for which a specific commercial

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[14](...continued)
industrial R&D survey (see NSF, 1987). In the Japanese surveys (all of them) the definition is "theoretical or experimental research for the purpose of formulating new hypotheses or theories or for obtaining new knowledge related to phenomena or observable facts, where specific applications or uses are not directly sought" (this translation from the Japanese survey was provided by the NSF/Tokyo office in an effort to reconcile the English translations already provided in Japan's *Annual Survey of R&D*).

application is not clear--was a preferable conceptualization of basic research.[15] While this may be quite different from the strict definition of basic research, it is not clear that it is any different from the U.S. industrial survey for which basic research is explicitly understood to be within the commercial interests of the responding firm. Importantly, "fundamental" research in Japan is a concept distinct from applied research, which the Japanese understand the same way as Americans.

Thus, this limited empirical evidence suggests that any differences in U.S. and Japanese conceptualizations of basic research are not as severe as the popular impression, at least within the environment of industrial R&D. What the Japanese call fundamental basic research is, in many respects, comparable to what is referred to as strategic basic research in the United States. However, since there is no information to allow us to conclusively state that Japanese conceptualizations are the same as the U.S., or to what degreee they are different, the overall high level of Japanese industrial emphasis on basic research relative to the U.S. still must be treated with some slight caution. Nevertheless, as will be seen below, Japanese industrial basic research efforts cannot be dismissed entirely.

All expenditure data reported herein are in constant 1982 dollars, and all growth changes are therefore real, and not nominal. Yen have been converted to current U.S. dollars using OECD purchasing power parities, which provide a more accurate conversion of national price structures than that obtained using market exchange rates. Current dollars for both Japan and the United States have then been deflated using the GNP implicit price deflators reported by the Department of Commerce. Other than the reduction of the Japanese higher education statistics discussed above, all Japanese data are as actually reported in the *Survey of R&D*. However, due to the nature of U.S. data collection and reporting, some U.S. basic research expenditures are imputed or estimated.[16] Any other adjustments to the U.S. data or comparability problems are reported in the text.

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[15]Note that fewer than 5% of the respondents believed that the length of time of the research project was an appropriate guideline for determining whether research was basic or not (It is frequently argued that the Japanese also consider to be basic research that research which has a long time horizon).

[16]U.S. basic research data were provided by John Jankowski, Division of Science Resources Studies, the National Science Foundation. The U.S. academic and government sector basic research data have been estimated using federal funds obligations data; the industrial non-defense basic research figures have been imputed for the odd-numbered years beginning with 1979.

National Patterns of Basic Research

Japan and the United States have increased their expenditures on basic research substantially since 1976, to about $4 billion for Japan and $14 for the United States in 1987 (figure 6-1). Although the average annual rate of increase in Japan was somewhat higher than that of the United States for the 1976-87 period (7% versus 6%), U.S. expenditures on basic research as a percentage of GNP still exceed those of Japan at 0.34% and 0.30%, respectively. Nevertheless, Japanese expenditures on basic research have been quite high in the 1980s, increasing by an average annual rate of 8% and exceeding growth in both applied research and development. The U.S. is similarly in a period of high growth, with outlays for basic research increasing nearly 6% annually in the 1980s and likewise slightly outpacing growth in applied research and development.

Differentials in the rates of growth for basic and applied research and experimental development have not, however, been large enough to significantly alter the total distribution of R&D among these three types of research activity. From 1976 to 1985, basic research accounted for 12% of total U.S. R&D expenditures; appplied research, 23%, and development 65%. In Japan, basic research dropped quickly from 14% of total R&D in the early 1970s to 12% in 1980; the share has since stabilized at 11-12%. The net decline in Japanese basic research (just under 2 percentage points) was gained by development, which increased to 64% over the period. In 1987, basic research accounted for roughly the same share of total R&D in both Japan and the United States, 12% and 13%, respectively.

Although Japan still spends less on R&D as a proportion of GNP than the United States (2.5% v. 2.8%), this gap can be explained by the slightly lower intensity of Japanese investments in all areas of R&D, but especially in basic research (figure 6-2). This picture is altered considerably, however, when defense-related expenditures are excluded from the country totals.[17] Comparison of the non-defense components alone shows that Japan spends proportionately about the same amount on applied research as does the U.S., still slightly less

[17]For Japan, the non-defense R&D/GNP ratio is virtually the same as its total R&D/GNP ratio: Less than 2% of Japan's total R&D effort is directed towards defense. By comparison, defense-related expenditures accounted for 25%-30% of the U.S. R&D total throughout the period under review. Of that, about 90% is development and most of the rest is applied research.

Figure 6-1. Basic Research Expenditures
[constant 1982 dollars in millions]

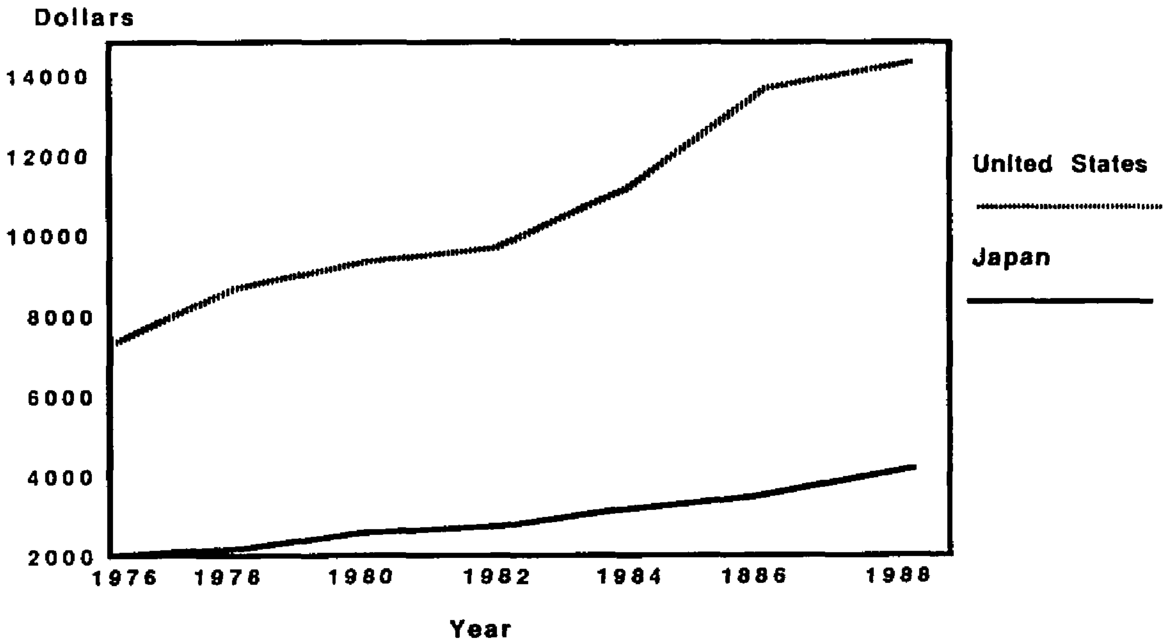


Figure 6-2. Japanese R&D as a Proportion of GNP Relative to that in the United States

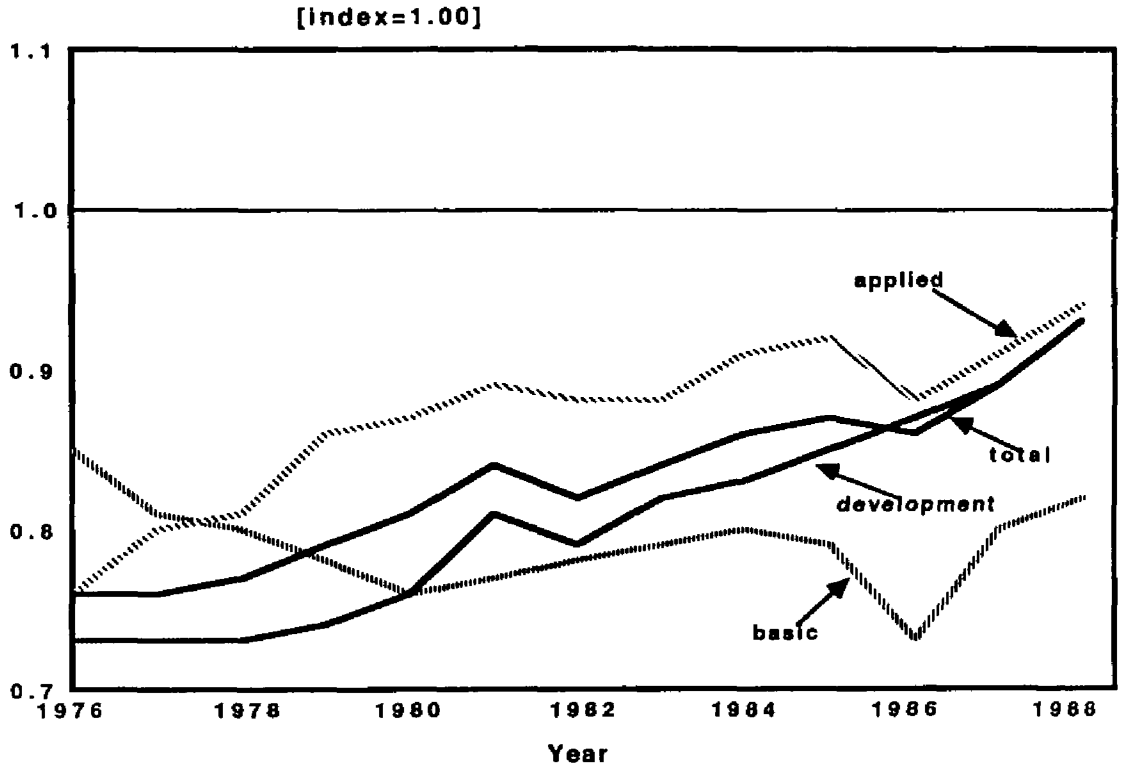


Figure 6-3. Japanese R&D as a Proportion of GNP relative to U.S. Nondefense R&D-to-GNP

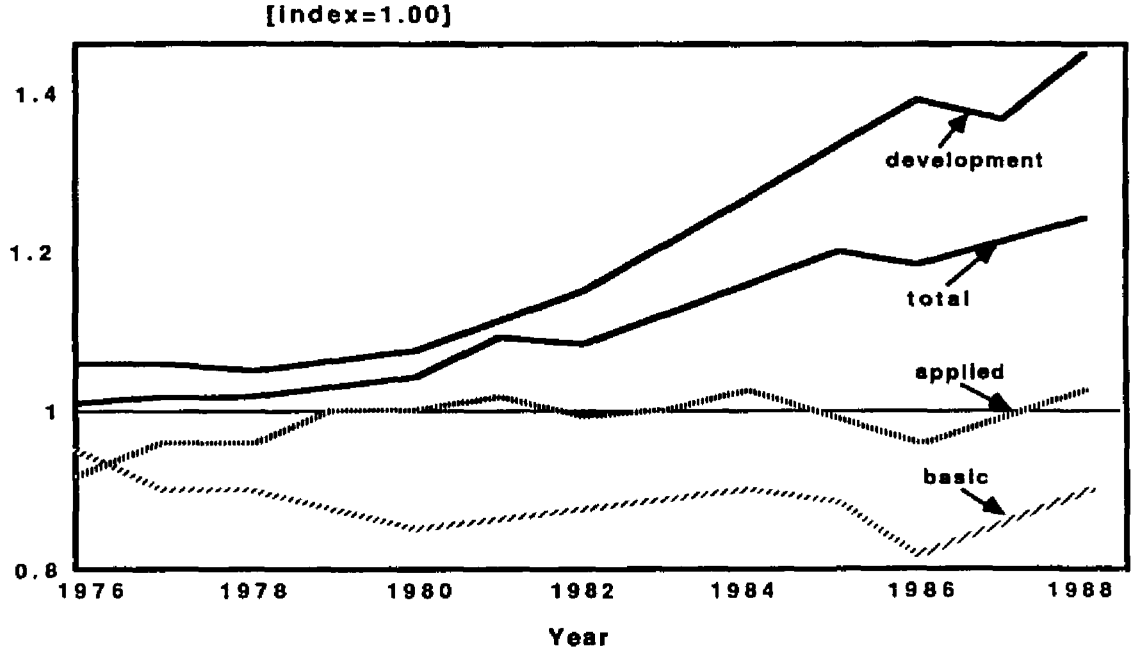


Figure 6-4. Japanese Basic Research By Performer

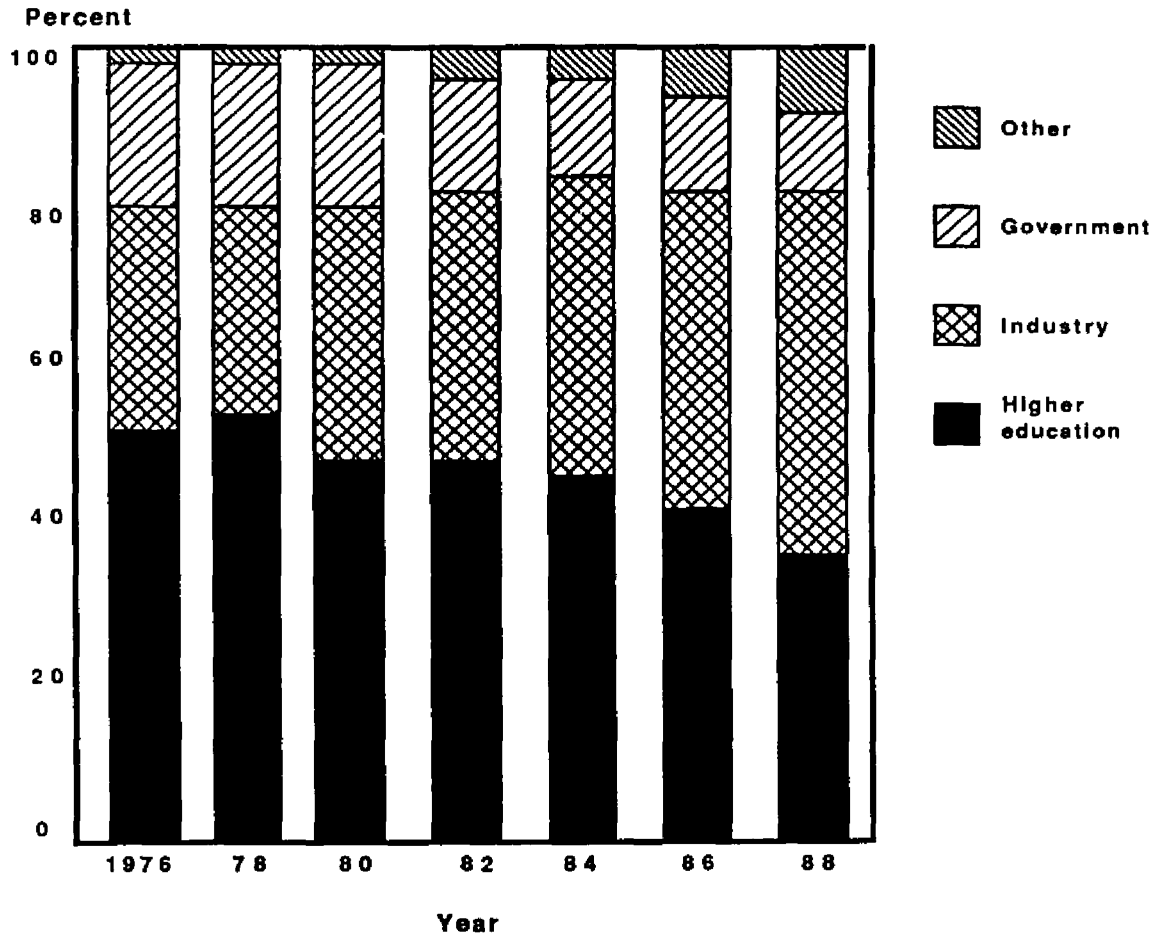


Figure 6-5. Japanese Performance of Basic Research As a Proportion of GNP Relative to the U.S.

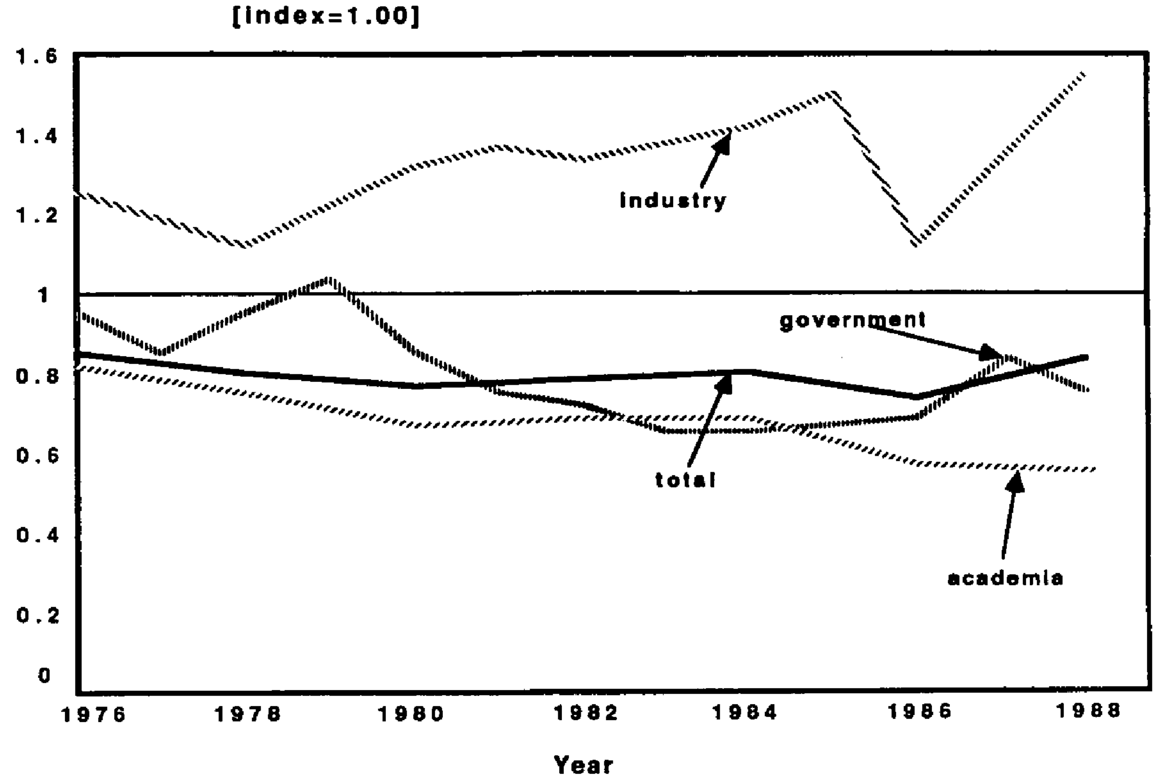
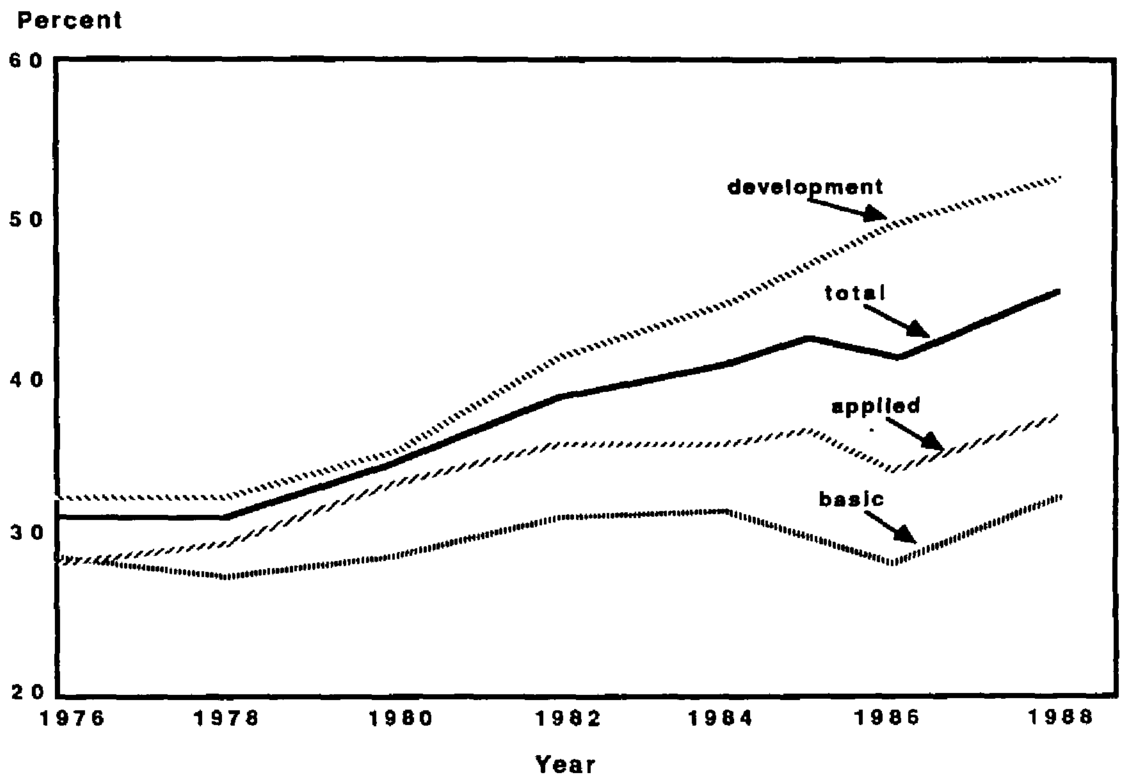


Figure 6-6. Japanese R&D Expenditures as a Percentage of U.S. Nondefense R&D Expenditures



on basic research, but substantially more on development (figure 6-3). In 1986, U.S. total non-defense R&D expenditures were equivalent to approximately 2.0% of GNP; the ratio for Japan is 2.4%.

The aggregate R&D expenditure data mask some important institutional differences in the conduct of basic research in Japan and the United States. As figure 6-4 shows, the higher education sector--the primary basic research performer in the United States--no longer accounts for the majority of expenditures on basic research in Japan. From 1976 to 1987, the share of basic research accounted for by the Japanese higher education sector declined from just over one-half to 42%. Industry's share increased from 26% to 41%, while that of the government declined from 19% to 12%. Although academic and governmental basic research expenditures kept pace with economic growth--these expenditures as a percentage of GNP remained fairly constant throughout the 11-year period--industrial basic research as a percentage of GNP doubled from .06% to .12% during the period. Clearly the growth of industrial basic research is the cause of the improvement in the Japanese basic research to GNP ratio over the 1976-87 period. Figure 6-5 dramatically reveals the Japanese reliance on industrially-performed basic research vis-a-vis the United States; in 1987, Japan's industrial expenditures on basic research as a proportion of GNP were nearly one-and-a-half times that of the United States, and has been higher than such U.S. ratios since at least 1976. On the other hand, the basic research expenditures of Japanese universities and government as a proportion of GNP have decreased steadily relative to the U.S. ratios since that time.

Japan and the United States thus possess several important similarities and differences in their structure and performance of basic research and total R&D. Both countries have increased their investments in basic research since the mid-1970s as evidenced by the steadily rising basic research-to-GNP ratios. However, while expenditures on basic research in the 1980s have grown slightly faster than those for applied research or development, there has not been any substantial shift in either country in the distribution of R&D among basic and applied research or development. They also have remarkably similar configurations of research balance in this regard, with 12-13% of the total accounted for by basic research.

These patterns are nonetheless dramatically changed when nondefense R&D is excluded; basic research then accounts for 16% of all U.S. R&D. Notably, the intensity of Japanese R&D expenditures relative to GNP become equivalent to the United States for applied research, still slightly less for basic research, *but one-and-a-half times* the intensity of U.S.

development expenditures. These differences are also reflected in total spending, with Japanese basic research expenditures equivalent to about one-third those of the United States, and development just over one-half (figure 6-6).

There is additionally a key difference between the two nations in terms of their institutional sources of basic research. In Japan, industry accounts for a much larger proportion of basic research expenditures (42%) than in the United States (19%), whereas the U.S. higher education sector dominates in the American basic research system. This may be the result of a relatively weak Japanese university research system, an inflation of the Japanese industrial data due to conceptual differences, a higher Japanese private sector priority on basic research, or still other factors.

Sector Patterns of Basic Research

Industry

In absolute terms, U.S. industrial expenditures on basic research are double that of Japan--$3.5 billion compared with $1.7 billion. However, the spending differential between U.S. and Japanese industry has narrowed by half over the past decade; in 1976, U.S. industry outspent Japanese industry by 3:1 in basic research. In terms of total R&D spending, Japan narrowed the gap in industrial R&D expenditures from a ratio of 1:4 in 1977 to 1:3 in 1987. Japan's industrial spending on basic research has grown from a low of about 40% of that in the U.S. to one-half of U.S. industrial basic research expenditures throughout the 1980s. When defense-related expenditures are netted out, the Japanese and U.S. levels of effort remain roughly the same, but as seen in table 6.1, Japanese industry invests more heavily in basic research as a proportion of GNP than the United States.

The higher levels of Japanese basic research as a proportion of GNP derive from the slightly greater share of total industrial R&D devoted to basic research. Since the late seventies, the basic research component of Japan's industrial R&D has risen from about 5% to almost 7% of the total; in comparison, since the mid-seventies approximately 4% of annual U.S. industrial R&D performance has been in basic research, or about 5% of industry's nondefense R&D spending. There are several plausible explanations for the disparate basic research emphases outlined above, including the earlier suggestion that Japanese industry cannot draw on

Table 6.1--Index of Japanese industrial R&D expenditures as a percentage of GNP relative to that in the United States

Year	Japanese R&D-to-GNP ratios relative to:					
	U.S. total R&D/GNP			U.S. nondefense R&D/GNP		
	Basic	Applied	Development	Basic	Applied	Development
1974	1.58	0.79	0.72	1.73	0.98	1.01
1975	1.29	0.76	0.73	1.40	0.91	0.99
1976	1.24	0.73	0.73	1.34	0.86	0.98
1977	1.16	0.79	0.74	1.26	0.92	1.00
1978	1.13	0.73	0.75	1.22	0.84	1.00
1979	1.20	0.81	0.77	1.29	0.91	1.00
1980	1.35	0.83	0.78	1.45	0.92	1.02
1981	1.39	0.88	0.80	1.49	0.96	1.05
1982	1.36	0.84	0.77	1.46	0.91	1.04
1983	1.42	0.87	0.82	1.52	0.94	1.12
1984	1.41	0.90	0.83	1.51	0.97	1.17
1985	1.55	0.90	0.86	1.68	0.96	1.25
1986	1.17	0.86	0.88	1.24	0.90	1.28
1987	1.35	0.89	0.88	1.43	0.94	1.25
1988	1.58	0.95	0.94	1.68	1.01	1.33

Source: Calculated by the author from unpublished data from the National Science Foundation and Government of Japan (1988).

Table 6.2--Distribution of U.S. and Japanese basic research among industries

	United States			Japan		
Industry	1975	1981	1988	1975	1981	1988
Total Manufacturing	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Food, drink, & tobacco	1.4%	1.8%	2.1%	3.8%	4.3%	4.3%
Textiles, footwear, & leather	0.3%	0.1%	0.6%	0.5%	1.8%	1.1%
Chemicals	25.8%	23.8%	10.6%	19.5%	17.7%	16.5%
Drugs & medicines	15.9%	11.9%	14.6%	13.9%	17.6%	18.4%
Petroleum refining	5.1%	8.8%	3.0%	0.5%	0.7%	2.3%
Rubber & plastic products	0.6%	1.5%	2.5%	0.3%	1.6%	1.1%
Stone, clay, & glass products	4.5%	NA	5.0%	2.3%	4.7%	3.6%
Primary metals	2.0%	3.0%	2.3%	9.9%	7.3%	6.8%
Fabricated metal products	0.7%	0.5%	2.4%	0.5%	2.1%	0.5%
Nonelectrical machinery	0.8%	NA	3.3%	2.9%	2.5%	4.6%
Electronic equipment & components	19.7%	NA	15.8%	9.8%	13.0%	17.1%
Electrical machinery	2.7%	NA	3.8%	16.0%	9.2%	7.8%
Motor vehicles	1.4%	1.4%	3.2%	10.2%	10.2%	12.0%
Instruments	2.3%	2.6%	15.4%	1.9%	2.4%	2.4%
Aerospace	7.7%	8.5%	11.0%	NA	NA	NA

NA: Not separately available.

Table 6.3--U.S. and Japanese manufacturing basic research expenditures

(Constant 1982 million dollars)

	United States			Japan			Japan/U.S Ratio		
	1975	1981	1988	1975	1981	1988	1975	1981	1988
Total Manufacturing................	1,189	1,608	2,726	442	753	1,688	37.2%	46.9%	61.9%
Food, drink, & tobacco.............	17	29	57	17	33	72	100.3%	113.5%	126.5%
Textiles, footwear, & leather.......	3	1	16	2	14	18	65.5%	1306.3%	114.1%
Chemicals...........................	307	382	289	86	133	279	28.0%	34.8%	96.5%
Drugs & medicines...................	189	192	398	62	133	310	32.6%	69.3%	78.0%
Petroleum refining..................	61	142	81	2	5	40	3.6%	3.7%	48.9%
Rubber & plastic products...........	7	24	69	1	12	19	22.1%	48.9%	27.8%
Stone, clay, & glass products.......	54	NA	138	10	35	60	19.0%	NA	43.6%
Primary metals......................	24	49	63	44	55	114	185.6%	112.3%	182.4%
Fabricated metal products...........	8	9	66	2	16	8	26.5%	187.0%	11.8%
Nonelectrical machinery.............	10	NA	97	13	19	78	128.0%	NA	80.9%
Electronic equipment & components...	235	NA	488	43	98	288	18.4%	NA	59.0%
Electrical machinery................	32	NA	103	71	69	132	220.6%	NA	128.6%
Motor vehicles......................	17	22	88	45	77	203	267.2%	345.3%	229.8%
Instruments.........................	27	43	419	9	18	40	31.6%	41.8%	9.5%
Aerospace...........................	91	136	301	NA	NA	NA	NA	NA	NA

Source: Calculated by the author from unpublished data of the NSF and Government of Japan (1988)

Table 6.4--U.S. and Japanese manufacturing basic research as a percentage of net sales

Industry	United States 1975	United States 1988	Japan 1975	Japan 1988	Japan/U.S 1975	Japan/U.S 1988
Total Manufacturing	0.09%	0.18%	0.08%	0.20%	0.89	1.12
Food, drink, & tobacco	0.01%	0.03%	0.03%	0.09%	2.73	3.05
Textiles, footwear, & leather	0.01%	0.03%	0.01%	0.09%	1.08	2.67
Chemicals 1/	0.40%	0.42%	0.20%	0.50%	0.51	1.18
Drugs & medicines	0.72%	0.92%	0.57%	1.30%	0.78	1.41
Petroleum refining	0.03%	0.05%	0.00%	0.11%	0.12	2.05
Rubber & plastic products	0.02%	0.21%	0.02%	0.15%	0.96	0.72
Stone, clay, & glass products	0.17%	0.45%	0.05%	0.21%	0.33	0.46
Primary metals	0.02%	0.10%	0.07%	0.16%	2.91	1.69
Fabricated metal products	0.02%	0.13%	0.01%	0.03%	0.83	0.25
Nonelectrical machinery 2/	0.01%	0.14%	0.03%	0.13%	3.44	0.93
Electronic equipment & components 2/	0.23%	0.27%	0.14%	0.25%	0.60	0.93
Electrical machinery 2/	0.05%	0.30%	0.25%	0.25%	4.63	0.83
Motor vehicles	0.01%	0.04%	0.07%	0.16%	4.90	3.49
Instruments	0.08%	0.70%	0.12%	0.20%	1.43	0.29
Aerospace	0.12%	0.22%	NA	NA	NA	NA

1/ Includes drugs and medicine.
2/ These figures are for 1987.

NOTE: Sales data for R&D-performing companies only.

university research the way the U.S. can, and thus invests in basic research more heavily than U.S. industry. Additionally, now that domestically-performed basic research is newly regarded as necessary to Japan's survival and development, industry could be increasing its investment in basic research as a reflection of a new industrial/national strategy.

Manufacturing industries.--The level and distribution of industrial basic research activity among the various manufacturing industries differs substantially in the United States and in Japan. A complete picture of such intercountry variations must take into consideration many factors, including differences in industrial size and structure as well as variations in research intensity. Consequently, tables 6.2, 6.3, and 6.4 present three measures for gaining perspective on the changing trends and patterns in industrial basic research activity in Japan and the U.S.: the distribution of basic research expenditures among manufacturing industries, basic research expenditures to net sales ratios, and Japanese basic research expenditures as a percentage of those in the U.S. The U.S. data *include* defense-related R&D; it is not possible to net defense-related R&D out at this level for basic research expenditures. Note, however, that the aerospace and electrical machinery industries receive just over 80% of U.S. government R&D transfers to industry. The Japanese figures represent, by and large, company-funded R&D. Additionally, Japanese R&D for office and computing machines are reported in the electronic equipment industry; therefore U.S. data have been adjusted by combining the office and computing machine and electronic equipment industries.

As seen in table 6.2, a handful of industries account for the majority of basic research expenditures in the manufacturing sector in both Japan and the United States. The chemical, drugs, electronic equipment, and aircraft and missile industries were the largest performers in the United States, accounting for 69% of the basic research conducted by the manufacturing sector in 1975. By 1988 expenditures had become somewhat less concentrated; the instruments industry surpassed chemicals, with the top four industries then accounting for 57% of the basic research total. In Japan, 60% of manufacturing basic research was undertaken by the chemical, drugs, electrical machinery, and motor vehicle industries in 1975; by 1988 electrical machinery had been replaced by electronic equipment as a major performer of basic research, which together with the other three industries accounted for 64% of the basic research expenditures in 1988. Motor vehicles represented 12% of Japan's industrial basic research effort, which dwarfs the 1% share of total that the auto industry held in the United States.

Over the 1975-86 period, there were some significant shifts in the overall distribution of basic research expenditures among industries in the United States and Japan. Most notable is the declining share of the chemical industry in the U.S., which went from 26% of the total in 1975 to 11% in 1988. The largest relative gain was made by the instruments industry, whose share of the basic research total grew from 2% to 15% during this period. (It is more than likely that this growth represents primarily improvements insurvey methodology rather than such a dramatic jump in research expenditure.) Other American industries that demonstrated strong increases include primary metals and rubber products, which more than tripled their share. The Japanese distribution was generally more stable than the U.S., with expenditure growth strongest in the drugs, petroleum, rubber, and nonelectrical machinery industries. Notably, the communications and electronic equipment industry (which produces computers and semiconductors) increased its share of total manufacturing basic research from 10% in 1975 to 17% in 1988.

Despite the size differences in their manufacturing sectors (Japan's is about half the size of the U.S. manufacturing sector), the absolute dollar amount of basic research expenditures in several industries do not differ substantially in the two countries. Japan's total basic research was the same as the U.S. in the chemical and textile industries in 1988, and Japan outspent the U.S. on industrial basic research in food, primary metals, electrical machinery, and motor vehhicles (table 6.3). This represents a considerable change from 1975 when Japanese basic research spending exceeded that of the U.S. in only the primary metals, machinery, and motor vehicle industries. With the exception of aircraft and missiles, industry by industry Japan's basic research spending has come to approach--or continued to exceed--U.S. expenditures during the past decade.

The basic research-to-net sales ratios (which control for variations in the amount of expenditure due to size) also reveal some important distinctions in research emphasis. On an industry-by-industry basis, the 1988 basic research intensity of all industries in both countries equal or exceeded the 1975 ratios (table 6.4). Overall, the basic research-to-manufacturing net sales ratio doubled in both countries, rising from 0.09% to 0.18% in the United States and from 0.08% to 0.20% in Japan. For most Japanese manufacturing industries, their basic research intensity now matches or exceeds that of the United States; by 1988, only the research-to-sales ratios of the rubber, ceramics, instruments, aerospace, electrical machinery, and fabricated metals were substantially lower in Japan. For most other industries, Japan moved from approximate parity in 1975 to a considerable lead.

Higher Education[18]

Universities in both Japan and the United States devote most of their research effort to basic research, yet academia's basic research share is higher in the United States than in Japan (table 6.5). Basic research as a share of Japanese higher education R&D expenditures has been in the 54-56% range throughout the 1980s, and in the U.S. this figure has stabilized around 60%.

In spite of the strong shift in the share of total Japanese basic research accounted for by the industrial sector, Japanese academic basic research has been increasing in real terms, and these expenditures have maintained a steady level relative to GNP since at least the early 1970s--the higher education basic research-to-GNP ratio has been quite stable at .11-.12%. Such U.S. expenditures increased rapidly in the latter 1980s, and the U.S. basic research-to-GNP ratio grew from .12% in the 1970s to .13% in the early 80s, then jumped to .16% in 1986, where it has since stabilized. As a consequence, the Japanese level of effort relative to the U.S. declined from parity through the 1970s, was 90% of the U.S. effort through 1984, and by 1988 was down to 69%. In absolute terms, Japanese higher education basic research expenditures fell off from about one-third those of the United States in the 1970s and early 1980s, and stood at about one-fourth of U.S. expenditures in 1988, at $1.6 billion and $6.4 billion, respectively.

Part of the explanation for the slightly lower proportion of Japanese higher education R&D that is devoted to basic research can be accounted for by differences between the two countries higher education structure. The engineering, agricultural, and medical sciences have a substantially greater presence in Japanese university teaching departments,[19] whereas the U.S. education system is concentrated heavily in the physical and life sciences relative to the other natural science and engineering disciplines. The net effect of these disciplinary variations

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[18]In this section, R&D expenditures at FFRDCs are excluded from U.S. totals. In 1987, FFRDCs spent $4.2 billion on R&D, of which $2.0 billion was on basic research. Other university performers spent $12.1 billion on total R&D, of which $8.3 billion was for basic research.

[19]For over a decade, Japanese universities have been producing as many or nearly as many bachelors degrees in engineering as the United States; consequently, the engineering faculty are relatively large. While it is not possible to compare the precise numbers of medical and health science students in the U.S. and Japanese higher education systems, such students are the second largest category of bachelors recipients in Japan and also account for nearly two-thirds of all Japanese doctorates. Both engineering and the medical sciences thus assume a preeminent place in Japanese higher education research and teaching.

Table 6.5--Higher education R&D expenditures by type of R&D

Country/type of R&D	1976	1980	1984	1988
United States				
Basic..................	58.8%	58.7%	60.4%	59.3%
Applied................	29.0%	28.8%	29.7%	27.3%
Development............	12.1%	12.5%	9.9%	13.4%
Japan				
Basic..................	56.4%	55.8%	54.9%	52.8%
Applied................	38.2%	37.0%	36.6%	38.5%
Development............	5.3%	7.2%	8.5%	8.7%

Source: Calculated by the author from unpublished data of the NSF and Government of Japan (1988)

Table 6.6--Basic research by academic field

	United States 1/			Japan			Japan/U.S.		
Field	1976	1980	1988	1976	1980	1988	1976	1980	1988
Total basic research...	3,341	3,997	6,427	1,042	1,143	1,609	31.2%	28.6%	27.7%
Engineering.........	306	390	636	402	438	576	131.4%	112.4%	90.1%
Sciences............	3,035	3,607	5,791	640	705	1,033	21.1%	19.5%	19.7%
Physical 2/......	NA	2,102	3,376	192	236	374	NA	11.2%	12.1%
Agricultural.....	NA	97	106	91	101	121	NA	104.1%	119.6%
Medical..........	545	695	1,371	357	368	538	65.5%	52.9%	50.8%

1/ Excludes FFRDCs. Distribution among fields based on Federal obligations to universities.
2/ Physical sciences include biological sciences.

Source: Calculated by the author from unpublished data of the NSF and Government of Japan (1988)

is that the fields which dominate the Japanese natural sciences and engineering tend to be more applied fields, and consequently the university sector registers slightly lower levels of basic research emphasis than found in the United States.

This structual difference shows up in the basic research expenditures as well. As indicated in table 6.6, whereas 10% of U.S. natural sciences and engineering basic research is in engineering and 90% in the natural sciences, these figures are 36% and 64%, respectively, for Japan. The net consequence of these disparate field concentrations appears to be that the absolute volume of Japanese higher education basic research expenditures is about equal to the United States in engineering and the agricultural sciences, about half of U.S. academic basic research in medical science, but only a fraction (12%) of U.S. expenditures in the physical sciences.

These field by field comparisons are, however, complicated by both slight differences in the disciplinary composition of the categories *and* by the nature of the Japanese higher education statistics. Even though these data have been deflated (and the social sciences and humanities excluded), they still reflect the underlying *education* structure, and not necessarily relative levels of emphasis on R&D. Because the salary data were uniformly deflated across fields (see the data and methodology section) the R&D data are still dominated by the relative distribution of faculty across disciplines.

A recent study by Irvine, Martin, and Isard (1990) is somewhat helpful in shedding some light on this problem. In an effort to compare government funding of academic and related R&D for several nations, they calculated highly comparable academic R&D data by detailed field of science. The calculations for Japan made a number of very fine adjustments to GUF, salaries, and a few other items that are commonly understood to "inflate" the Japanese R&D data. Since a substantial amount of Japanese and U.S. R&D come from government sources (and in the case of the U.S., two-thirds of university basic research is funded by the federal government), the field of science distributions calculated by the Irvine, Martin, and Isard study are a useful calibrator to the data reported here.

As seen in table 6.7 below, this study affirms the relatively high emphasis in Japan on engineering R&D, but provides data that are a more accurate representation of the differences between U.S. and Japan in the sciences. The very high proportion of U.S. basic research showing up as "physical" sciences in table 6.7 is predominantly biological research; once the biological and life sciences are broken out separately, it becomes more apparent that the differing concentrations in Japan and the United States in the natural sciences are not in the physical sciences (including math) but in all other fields (biological, other life, and environmental).

Table 6.7—Distributions of Japanese and U.S. Government-funded Natural Science and Engineering Academic R&D (1987)

Field of Science	Japan	United States
Engineering..................	29%	15%
Physical sciences 1/...	22%	23%
All other sciences 2/..	49%	63%

1/ Includes mathematics.
2/ Biological sciences, other life sciences, and environmental science.

The Japanese distribution by field revealed in the Irvine, Martin, and Isard study is not appreciably different than that reported here. The big adjustment is in the refinement of U.S. natural science distributions, which show a much higher emphasis in the U.S. on the biological and life sciences than in Japan (the environmental science component for both countries is quite small).

This study does, however, provide a very different picture in terms of total funding of R&D in Japan relative to the United States. Total Japanese funding of natural science and engineering R&D was found to be 22% of U.S. levels (compared to 28% in this report if the FFRDCs are included, 33% of U.S. levels without the FFRDCs). However, the Irvine, Martin, and Isard figures do also show high volumes of Japanese engineering research (41% of total engineering R&D in the U.S.), although other fields are more modest (22% of the U.S. in the physical sciences and 17% in the biological, life, and environmental sciences). Since that study was concerned with government-funded R&D, a fair amount of Japanese private university R&D was excluded; if it were included, the total R&D numbers for Japan would obviously increase, especially in engineering and life sciences, which are large teaching fields in private institutions.

While qualified, it is possible to make some reasonable conclusions about U.S. and Japanese higher education university basic research. Such research in Japan has been quite stable by Japanese standards (both as a share of total academic R&D and relative to GNP), and at least through 1988 this sector does not seem to be responding to the government's call for more basic research. Compared to the U.S. level of effort, which exhibited a burst of basic research from 1984-86, Japan continues to fall behind both absolutely and relative to GNP.

With regard to field of science efforts, if we account for the findings of Irvine, Martin, and Isard, it would seem that Japan puts an undeniably greater emphasis on engineering R&D, while the U.S. concentration is in the biological and life sciences. Notably, the two countries seem to focus on the physical sciences in relatively equal proportions. The absolute volume of engineering basic research relative to the United States is probably around 50% of U.S. levels, and could be even higher--many analysts argue that Japanese academic engineering research is extremely theoretical/basic.[20] The high levels of Japanese medical science research relative to the United States found in this study do seem to be mitigated by the preponderance of U.S. biological and life science research being reported in the "physical sciences" category. Nevertheless, agricultural and medical sciences are still key areas of basic research concentration for Japan.

Government research

The government R&D system in Japan, while smaller than that of the United States (e.g., there are roughly one-third the number of national R&D labs), accounts for the same amount of national R&D expenditures as does the government sector in the U.S.--roughly 10-11% of the total. However, if we examine nondefense R&D only, U.S. government performance of R&D declines to represent only 5% of the Nation's effort.

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[20]While many view engineering as largely applied research or technology, there are significant research themes within the discipline which explore natural phenomena, materials research being a case in point. Few would argue that there can be no basic research in engineering; more importantly still, Japanese engineering research is often criticized as being *too* theoretical. As early as the 1950s, the Japanese engineering discipline was evaluated by *U.S.* professionals as being too research and theory oriented, a sentiment frequently expressed in interviews with Japanese scholars and industrialists. See Sogo Okamura, "History of Engineering Education in Japan," in Edward E. David and Takahashi Mukaibo, eds., *Engineering Education: United States and Japan* (Washington, DC: National Science Foundation, Division of International Programs, 1988).

The high volume of defense-related R&D that takes place in the government sector does indeed mask some significant characteristics of R&D performed by the U.S. government laboratories. As seen in Table 6.8, until the early 1980s total R&D performed by the federal government was composed of about 52% development work, 33% applied research, and 16% basic research. This distribution shifted just slightly in the latter 1980s, as basic research expenditures grew in real terms from 1980-84, but then declined to pre-1980 levels in 1988. Nevertheless, at the end of the 1980s the distribution was not appreciably different from previous years, and basic research accounted for 14% of total R&D.

When defense-related R&D is excluded, this distribution shifts significantly: non-defense basic research has grown steadily in the 1980s from one-quarter of government-performed R&D to one-third; this strengthening emphasis on basic research is due to both real increases in nondefense basic research spending (a net increase of 29% from 1980 to 1988) and real declines in both applied research and development expenditures. Neither total or nondefense U.S. R&D spending has kept pace with the levels of investments of the 1970s; as a percentage of GNP, total government-performed R&D is still declining, while nondefense R&D expenditures appear to have stabilized right around .11% of GNP. The growth in nondefense basic research has simply allowed it to keep pace with the economy; as a share of GNP these expenditures have been at .04% since at least 1974.

While Japan's patterns of government R&D performance appear to be quite similar to those of the United States, again this is because of the nature of U.S. defense-related R&D, which is composed principally of development related expenditures. The volume of Japanese spending compared to total U.S. spending seems rather uniform, running just about one-third of U.S. levels in all categories of research—basic, applied, and development. Controlling for the size of the two contries economies, we find that Japanese investments compared to the United States are also uniform across types of research; in all categories Japanese research-to-GNP ratios are about three-quarters of U.S. levels (Japanese applied research investments are almost par with the U.S. on this measure).

Excluding U.S. defense-related R&D, we find that the comparison changes dramatically. Japanese government-performed basic research declined slightly from just over one-third of U.S. levels in the 1970s to 27% in the early 1980s; it is now right at one-third. Applied research expenditures have grown from one-third the volume of U.S. expenditures to one-half; Japanese government development expenditures, which have always been high (close to 100% of the U.S.

Table 6.8--Government R&D expenditures by type of R&D

Country/type of R&D	1976	1980	1984	1988
United States (total R&D)				
Basic......................	14%	16%	16%	14%
Applied....................	36%	33%	25%	23%
Development................	50%	52%	59%	63%
United States (nondefense R&D)				
Basic......................	26%	26%	36%	34%
Applied....................	49%	48%	45%	45%
Development................	25%	27%	19%	20%
Japan				
Basic......................	18%	16%	14%	14%
Applied....................	36%	39%	30%	27%
Development................	47%	45%	56%	60%

Source: Calculated by the author from unpublished data of the NSF and Government of Japan (1988)

Table 6.9--Basic research by government and field of science

	Japan					
	Constant 1982 $ million			Percent of total		
	1976	1980	1988	1976	1980	1988
Total basic research...	360	392	465	100%	100%	100%
Engineering..........	141	76	97	39%	19%	21%
Sciences.............	219	316	367	61%	81%	79%
Physical 1/........	62	117	149	17%	30%	32%
Agricultural.......	96	126	129	27%	32%	28%
Medical............	61	72	59	17%	18%	19%
	United States					
Total basic research...	1,246	1,379	1,690			
Engineering..........	141	171	226	11.3%	12.4%	13.4%
Sciences.............	1,105	1,207	1,464	88.7%	87.6%	86.6%
Physical 1/........	850	870	1,016	68.2%	63.1%	60.3%
Agricultural.......	NA	61	116	NA	5.9%	6.8%
Medical............	212	227	320	17.0%	16.4%	19.0%

Source: Calculated by the author from unpublished data of the NSF and Government of Japan (1988)

volume in the late 1970s), are now more than twice the volume of U.S. expenditures. Relative to GNP, Japanese goverment performance of basic research declined from parity with the U.S. in the 1970s to two-third U.S. levels, and by 1988 had risen back up to about 90% of the U.S. intensity. Applied research expenditures grew from parity to about a one-third greater intensity than the U.S.; most significantly, Japanese government-performed development is nearly seven times U.S. levels when controlling for the size of its economy.

The field of science distribution for basic scientific research is not distorted quite as much by defense-related expenditures as total U.S. R&D figures are, simply because defense-related basic research accounts for only about 15% of the government-performed basic research total. Table 6.9 indicates that the shares of basic research going to various fields of engineering and science have been stable, and that the biological and medical sciences together account for roughly half of government-performed basic research. In comparison, in Japan there has been a pronounced shift in government-performed R&D away from engineering to the physical sciences, which is continuing to gain an increasing share of the government's basic research performance total. The physical sciences and agricultural sciences account for 32% and 28% of the Japanese total, respectively. Notably, the volume of government-performed basic research in the United States dwarfs that in Japan in all fields except agriculture, for which Japanese expenditures are approximately three-quarters the U.S. volume.

In sum, the picture one gets of government-performed basic research, and R&D more generally, depends upon whether defense-related R&D is included or excluded from the U.S. data. U.S. nondefense basic research has clearly been responsive to changed government priorities in the 1980s, increasing in real terms, relative to GNP, and as a proportion of government-performed R&D. Much of the U.S. basic research is in biological and life sciences. Japan's government-performed basic research has been quite stable at .03-.04% of GNP, and has shown a shift in priorities away from engineering into the physical sciences. The real surprise of the comparisons--an indicator that was perhaps known qualitatively but masked by quantitative information--is the high volume of Japanese government-performed development relative to the United States, both absolutely and relative to GNP.

Productivity and Quality of Basic Research

A primary limitation of R&D expenditure data as an empirical indicator of scientific and technological creativity is that it doesn't reflect either the amount or quality of research output. For basic and applied research, bibliometric measures--data on the world's scientific literature--are a useful supplement to R&D data as an indicator of the scope, direction, and quality of a country's research effort. Although using these data as estimates of the absolute output of research is problematic, they do provide a useful indication of relative standing in the literature as well as long term performance trends.[21] Bibliometric databases typically record the articles published in defined sets of world-class journals, and thus tend to represent the most important scientific research results and the highest quality standards for scholarly journals.

The United States accounts for the vast majority of the world's scientific literature, about 30-35% depending on the database one is using.[22] This share has been relatively stable since 1973, the first year such data were compiled (table 6.10). According to the NSF-preferred database, Japan's share has increased from about 5% to 8% of the total,[23] a figure consistent with the 6% estimate by Barre but lower than the 13% estimated by a Japanese study.[24] Japan's share of literature is now higher than that of France and West Germany, but still slightly behind the United Kingdom.

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[21]There are a number of reasons why bibliometric data should be treated with some caution as measures of absolute output, including 1) differing propensities to publish in various countries, 2) the bias of most bibliometric databases against non-roman languages (an important point for Japan), and 3) database bias against engineering and technology journals (also an important factor for Japan).

[22]Three independent studies and databases have all come up with comparable measures--the database used for the biannual *Science and Engineering Indicators* publication of the National Science Foundation, the French Pascal database, and a database created by the Mitsubishi Research Institute in Japan (see NSF op. cit. fn. # and Remi Barre, "A Strategic Assessment of the Scientific Performance of Five Countries," *Science and Technology Studies*, vol. 5, no. 1 (1987): 32-38.

[23]Using the Computer Horizons, Inc. (CHI) data commissioned by NSF.

[24]The higher Japanese share in this latter study is probably due to the fact that it 1) included more Japanese journals, and 2) included more science and technology-related journals, both of which tend to be understated in the American and European databases.

Table 6.10--Shares of world scientific literature

Field	United States 1973	United States 1980	United States 1986	Japan 1973	Japan 1980	Japan 1986	% change 1973-86 U.S.	% change 1973-86 Japan
Share of literature (%)								
All fields..................	38.2	36.5	35.6	5.3	6.8	7.7	-6.8	45.3
Clinical medicine...........	42.8	43.0	40.0	3.5	5.0	6.4	-6.5	82.9
Biomedical research.........	39.2	39.7	38.4	4.0	5.9	7.1	-2.0	77.5
Biology.....................	46.4	42.0	38.1	5.3	6.5	6.5	-17.9	22.6
Chemistry...................	23.3	20.8	22.2	9.4	10.9	10.7	-4.7	13.8
Physics.....................	32.7	30.1	30.3	6.5	8.6	8.6	-7.3	32.3
Earth and space.............	46.7	42.4	42.6	2.0	2.4	3.7	-8.8	85.0
Engineering & technology....	41.8	39.4	37.3	5.4	7.2	12.7	-10.8	135.2
Mathematics.................	47.9	39.7	40.3	3.9	4.8	3.4	-15.9	-12.8
Field specialization index 1/								
All fields..................	1.00	1.00	1.00	1.00	1.00	1.00		
Clinical medicine...........	1.12	1.18	1.12	0.66	0.74	0.83		
Biomedical research.........	1.03	1.09	1.08	0.75	0.87	0.92		
Biology.....................	1.21	1.15	1.07	1.00	0.96	0.84		
Chemistry...................	0.61	0.57	0.62	1.77	1.60	1.39		
Physics.....................	0.86	0.82	0.85	1.23	1.26	1.12		
Earth and space.............	1.22	1.16	1.20	0.38	0.35	0.48		
Engineering & technology....	1.09	1.08	1.05	1.02	1.06	1.65		
Mathematics.................	1.25	1.09	1.13	0.74	0.71	0.44		

1/ Share of field relative to country share of total literature.

Source: Papadakis (1989)

Table 6.11--U.S. citations to Japanese scientific literature as a percentage of all foreign citations

	1977	1980	1986	% change
All fields.................	7.2	8.6	12.0	66.2
Clinical medicine..........	5.6	7.1	9.5	70.0
Biomedical research........	7.2	8.3	13.7	92.0
Biology....................	7.0	6.5	7.8	10.7
Chemistry..................	11.5	13.4	17.7	54.0
Physics....................	8.1	10.1	11.7	43.8
Earth and space............	3.9	4.4	5.5	40.5
Engineering & technology...	8.4	13.4	15.5	84.7
Mathematics................	6.5	6.0	6.0	-7.1

Source: National Science Foundation (1989)

Table 6.12--Scientific literature citation ratios by field: 1982

Field	France	West Germany	Japan	United Kingdom	United States
All fields................	0.85	1.00	0.86	1.08	1.37
Clinical medicine..........	0.62	0.67	0.76	1.10	1.32
Biomedical research........	0.78	0.95	0.89	1.06	1.34
Biology....................	1.03	1.17	0.94	1.19	1.12
Chemistry..................	1.01	1.34	0.99	1.23	1.63
Physics....................	1.04	1.33	0.83	0.98	1.50
Earth and space............	0.83	0.92	0.69	0.94	1.49
Engineering & technology...	1.06	0.94	1.25	1.01	1.18
Mathematics................	1.03	0.93	0.91	1.23	1.23

Source: National Science Foundation (1989)

Table 6.13--Macro-specialization indexes for basic research publications, by field

	Macro Profile Field	United States	Japan	France	West Germany	United Kingdom
I.	Theoretical physics and chemistry	100	119	93	110	97
II.	Life sciences, basic research	147	143	98	101	107
III.	Semiconductors; analytic and electro-chemistry; catalysis; condensed matter	68	166	94	95	81
IV.	Materials science, applied and organic chemistry	59	126	57	127	80
V.	Physics and technology of electronic components, integrated circuits, Group III-IV semiconductors, photochemistry	116	255	74	91	86
VI.	Computer science and imaging technology	106	84	78	102	101
VII.	Technnology for pollution treatment, energy storage, civil engineering, machine tool research	72	59	71	136	74
VIII.	Earth sciences	77	52	98	62	83
IX.	Environmental sciences, space sciences	114	55	68	84	88
X.	Renewable resources	83	45	129	78	97
XI.	Agronomy, food production, biotechnology for agriculture	90	67	98	69	97
XII.	Life sciences: health and drugs	121	69	155	114	130
XIII.	Other applied sciences	143	70	109	99	142

Note: The macro specialization index is the mean for each field of the relative specialization index of its subfields. The relative specialization index is the country's share of the literature in the macro profile field relative to its shareof the total literature. A value of 100 reflects no over- or under-specialization; that is, a nation is publishing at a level commensurate with its total share of world literature.

Source: Barre (1987)

While Japan's production of scientific literature is less than one might expect given the relative wealth and size of the country, it is also (as indicated) growing and not inconsistent with the amount of money it spends on basic research. For example, if Japan had the same research "bibliometric productivity" as the United States (the amount of national basic research expenditures per published article), Japan's share of the world's literature in 1986 would have been 11% instead of the current 8%.[25] These data suggest that Japan is publishing *somewhat* commensurate with its financial effort in a body of literature that is, if anything, biased against both the Japanese language and research strengths in engineering and technology.

Moreover, a detailed examination of publication fields indicates that Japanese and U.S. shares of the scientific literature are highest in fields comparable to their basic research emphasis. Japan's largest share of the world literature in 1986 was in engineering and technology (13% of the total number of engineering and technology publications), what one might expect given both the university basic research emphasis in engineering and industrial basic research efforts in metals and machinery (table 6.10). As recently as 1981, this category lagged both chemistry and physics in terms of Japan's share of the world literature, which is somewhat surprising given the relatively low level of university research in the physical sciences. However, much research in applied physics that would typically be conducted in physics departments in the U.S. and other countries is conducted in engineering departments in Japan; thus, the high level of emphasis of basic research in engineering is also possibly reflected in the physics literature. Notably, the largest increases in Japan's shares of literature occurred in the engineering and technology, clinical medicine, and biomedical research fields--those fields that receive the highest level of Japanese academic investments in basic research.

The U.S. bibliometric data are a little harder to interpret given the high overall shares of the world's scientific literature accounted for by U.S. authors. In general, however, it seems that the physical sciences, especially mathematics and earth and space sciences, reflect the largest U.S. shares, as do clinical medicine and biomedical research (these latter two fields also account for just over half of all U.S. scientific publications). As with Japan, the U.S. publication patterns are consistent with U.S. patterns of R&D funding; biological and life science basic research is clearly dominant in both the university and government sectors, and the U.S. has been preeminent in physics and space research throughout the post-war era.

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[25]These share estimates are calculated after making adjustments for changes in total world literature.

References by U.S. scholars to Japanese articles is an instructive gauge of the *quality* of Japanese publications, although the total numbers could simply reflect decreasing parochialism in the U.S. scientific community and the growing number of Japanese articles available to cite. Nevertheless, U.S. citations to Japanese literature as a proportion of all U.S. citations to foreign publications reveals the growing stature of Japanese scientific literature, especially in engineering and technology, chemistry, and biomedical research (table 6.11). Not only do these three fields have the largest of the shares of foreign citations, but they generally were the fields with the most rapidly growing number of citations as well. Finally, as shown in table 6.12, these three fields are also the most highly cited Japanese fields by all countries, not just the United States.

A bibliometric study by Barre (1987) focused on basic research publications of the United States, Japan, France, West Germany, and the United Kingdom in more refined fields of science, and with special attention to "strategic basic research fields." Barre notes that "Part of basic research is sometimes labelled 'strategic' as opposed to 'curiosity-oriented,' in that it can relate directly to innovations in the scientifically-driven 'core technologies,' which in turn can affect a broader spectrum of activities" (p. 32). This kind of basic research is thus especially relevant to economic competitiveness issues and is more likely to acount for the high levels of Japanese industrial basic research, which is presumably strategic in nature.

Barre studied patterns of performance in 103 scientific subfields which, because of the nature of the database, covered primarily basic research publications, and to a lesser extent, applied sciences. In this data set, the U.S. had by far the largest proportion of publications (29% of the total) whereas Japan and the European nations held roughly equal shares (6-7%). A calculation of the relative specialization index[26] for 13 fields of basic research identified the rather dramatic differences in the fields of specialization for Japan and the United States, with the Japanese specialization ratios reflecting a greater overall level of publishing concentration in strategic basic research fields.

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[26]The relative specialization index is the country's share of the literature in the macro-profile field relative to its share of the total literature (all fields combined). A value of 1 (or in this case, 100) reflects no over- or under-specialization; a nation would be publishing in that field at a level commensurate with its total share of the world literature.

The fields of publication strength for Japan found in the Barre study are: physics and integrated circuit and semiconductor technology, electro- and photo-chemistry, basic life science research, materials science and applied and organic chemistry (table 6.13). These fields are somewhat consistent with the patterns of basic research expenditure found in Japanese industry; based on the industrial expenditure data we would expect to find an emphasis in metallury and materials research; the electronics-related basic science is a bit surprising given expenditure patterns but quite consistent with Japan's economic strength in electronics and computer-related industries. In comparison, the U.S. specialization ratios were more evenly distributed, and specializations were most intense in the life sciences--which is consistent with the preponderance of U.S. basic research expenditures.

The Barre study also indicates that the absolute number of publications reflect similar patterns of emphasis. While the U.S. publishes considerably more than any other country in each category, Japan is by far the second largest source of articles in the strategic basic research fields--and especially applied physics. However, the volume of its publications fall off substantially in the other more purely scientific fields. Generally speaking, the U.S. publication level is exceptionally preponderant in basic research in the life sciences, environmental and space science, and other applied life sciences.

Basic Research and Competitiveness

The foregoing analysis reveals some startling findings in three particular respects: the undeniable presence of a productive basic research system in Japan, the overwhelmingly commercial nature of this system, and the economic irrelevance of the U.S. basic research system. If we can suspend for the moment the American tendency to see basic research as unmotivated by anything other than pure scientific curiosity, then it is possible to see that a number of our pet assertions about Japan simply do not hold up under scrutiny.

It is important to appreciate the role of definitional bias in the way we have traditionally evaluated basic research. Kruytbosch (1990) argues that basic research the way we currently understand it--research into the causes of natural phenomena without any application in mind--did not enter our lexicon until Vannevar Bush put it there.[27] From all appearances, basic research is as contrived as the linear model of innovation. What is missing in our picture of basic research is any evidence or theory which can support the fundamental assumption that new knowledge derived from scientific purity is *intrinsically more valuable* than new knowledge responding to social need. This bit of wisdom may turn out to be one of the most brilliant pieces of propaganda ever advanced by science.

This issue is not trivial, especially with respect to our understanding of Japanese science. Is basic research to be defined by its quest to understand and explain nature, or to understand and explain nature as long as there is no practical use in mind? The rejection of science as a response to social need is a peculiarly recent--and American--phenomenon, since the history of science doesn't really support this stringent separation of discovery from motivation. Indeed, one brand of science historiography (one frequently rejected in the United States), argues that science is the product of society, not vice-versa.

Having said this, what may we now say about Japan, basic research, and competitiveness? First and foremost, it seems rather undeniable that Japan is conducting a fair amount of basic research, and at a level that is essentially commensurate with the size of its economy. Additionally, the rather crude comparison of patterns in basic research expenditure with bibliometric trends supports this finding: publications are showing up in fields comparable to areas of expenditure, the most intensive areas of investment (e.g., in engineering and technology) are of apparently high quality given both their presence in the world's leading literature and the citation rates, and the volume of publication is not out of line with what we might expect given expenditure levels and the roman-language biases of the bibliometric databases.

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[27]Kruytbosch conducted a content analysis of leading scientific publications both before and after World War II. He found that the term "basic research" was used rarely prior to publication of *Science--The Endless Frontier*. This document systematically developed the concept of basic research as essentially the purest form of science, research unmotivated by anything other than curiosity and the quest for knowledge. After this document was published and the National Science Foundation established, the concept was used repeatedly--in its Bush connotation--in policymaking. From the discussion in chapter 2, it should become apparent why Bush created this notion of science: to assure funding for university-based research and to prevent government meddling of the research agenda and methods.

Is this a surprise? Yes, but only for those with strong paradigm blinders. The copycat image of Japan is dying hard, and for a variety of reasons (too complicated to detail here) it is much easier to deny Japan's innovativeness than acknowledge it. Additionally, because we typically look to the universities for basic research, the picture from Japan reinforces our institutional stereotypes: only universities (or comparable "scientifically" motivated organizations) do basic research, Japanese research universities are woefully underfunded, facility poor, and suffer from extraordinary cultural and institutional rigidities; therefore, they do little basic research. However, leading historians of Japanese science offer revisionist interpretations of this image, and argue that Japan's academic scientists are highly creative and have long traditions of world-class scientific excellence (see Bartholomew, 1990). This would certainly explain Japan's "disproportionate" presence in some publication fields (e.g., chemistry, physics) relative to the low volume of university basic research expenditures in these areas.

In spite of hidden academic excellence, the university research system is relatively small because of rather low pressures for graduate education. Demand by the education system for PhDs (for undergraduate teaching) is constrained because of relatively stable enrollments (the big era of unversity expansion was in the 1970s); additionally, there is little industrial demand for for PhD researchers. As a consequence, neither the labor market or the education system provide the means to sustain a large-scale, intensive university research system. Notably, the commercial demand for bachelors and masters in engineering is considerable, with the result that a significant amount of basic research in engineering is conducted.

Perhaps as a result of this, Japan's basic research system appears to be primarily a commercial one. Industry is responsible for the substantial improvement in Japan's basic research-to-GNP ratios, and now accounts for a share of total basic research expenditures equal to that of academia. Although it seems to be a commercial system, this does not preclude the publication of knowledge in the public domain. As the Barre study illustrates, Japanese basic research publications are principally of a strategic character and again in fields strongly associated with industrial basic research expenditures or commercial excellence. Far from freeloading on the West, Japan seems to be in the enviable position of having a great deal of its basic research emanating from the institutions most likely to use it and without the added complication of inter-sector technology transfer.

How does this compare with the United States? As demonstrated in the previous data analysis, most basic research in the U.S. is conducted in universities, and is largely in the biological, life, and physical sciences. Bibliometric analyses confirm the expenditure patterns and accentuate the predominantly "pure science" nature of U.S. basic research efforts. It is hard to imagine research less connected to commerce or more economically irrelevant than such science. This is not to argue that these efforts are not useful or desirable, but that they seems far less efficacious for competitiveness than the Japanese system.

If we can accept that most of what Japanese industry reports as "basic" research is indeed fundamental research of some sort or another, then it provides an interesting contrast to U.S. industry, which spends less intensively on basic research than Japan and suffers from an unwillingness to invest in relatively inappropriable knowledge. While different national approaches to the economic exploitation of science and technology will be addressed in the concluding chapter, this does suggest that market failure theories cannot be taken for granted and that inappropriability is not an absolute determinant of levels of research investment.

Can we explain patterns of U.S. and Japanese competitiveness on the basis of their patterns in scientific effort? The answer is a somewhat surprising yes and no. For the U.S., the preponderant amount of basic research activity takes place in government and academia, and dwarves comparable Japanese expenditures in both absolute magnitude and on a field by field basis. However, the fields of research are somewhat removed from U.S. competitive strength, and patterns of U.S. competitiveness vis-a-vis Japan simply cannot be explained by U.S. basic research efforts. The singular exception to this is the aerospace industry, which benefits from direct and indirect government support of basic aerospace research. It is also probable that the pharmaceutical industry benefits from the considerable U.S. investments in life science research; molecular biology and the nature of disease are quite naturally important to commercial pharmacology.

However, as table 6.14 illustrates, what might better explain U.S. and Japanse patterns of competitiveness are Japanese industrial investments in basic research. As can be seen, in the industries for which Japan is more competitive than the United States, their basic research investments prior to the onset of U.S. competitive problems (in 1978 and/or 1982) were on the order of 2-3 times that of the U.S. *on a dollar per dollar basis*. This represents an investment intensity two, three, or four times greater than U.S. efforts. The exceptions to this are instruments and electronics, which had expenditures of less than half their U.S. counterparts (but with approximately the same level of investment intensity). To the extent that the competitive prowess in both of these industries derives from their manufacturing abilities, they

Table 6.14--Basic research performance and industrial competitiveness

Competitive status of industry	Japan's Basic Research Status in 1975 and 1981
Industries in which Japan is more competitive relative to the U.S.	
Instruments	Expenditures < 50% of U.S.; intensity index = 1.4
Electronic equipment & components (inc. computers 1/)	Expenditures < 50% of U.S.; intensity = .66-.75
Electrical machinery	Expenditures approx. 300% of U.S.; intensity = 4.0
Motor vehicles & equipment	Expenditures approx. 300% of U.S.; intensity = 4.9-3.0
Nonelectrical machinery	Expenditures approx. 200% of U.S.; intensity = 3.0-4.0
Primary metals	Expenditures 100-200% of U.S.; intensity = 2.0-3.0
Industries in which the U.S. is more competitive relative to Japan	
Chemicals	Expenditures < 30% of U.S.; intensity = .5
Stone, clay, & glass products	Expenditures < 30% of U.S.; intensity < .5
Food, drink, & tobacco	Expenditures > 100% of U.S.; intensity = 3.0
Petroleum refining	Expenditures < 5% of U.S.; intensity < .50
Drugs & medicines	Expenditures 33-66% of U.S.; intensity = 1.0
Aerospace	Not separately available for Japan
Industries in which Japanese strength is increasing 2/	
Rubber & plastic products	Expenditures 25-33% of U.S.; intensity = .75-1.0
Fabricated metal products	Expenditures 25-100% of U.S.; intensity = 1.0

1/ It is not possible to separate R&D data for the electronics and computer industries.
2/ Japan accounts for approximately 20% of imports in these industries.

Note: See table 5-9 for classification criteria.

Intensity index=Japanese basic research-to-net sales ratio relative to that in the U.S.

may have benefited from spillovers from the machinery industries. Notably, Japan's R&D investments were in industries with the greatest manufacturing spillover capacities--electrical machinery, nonelectrical machinery, motor vehicles, and primary metals.

In contrast, Japanese basic research activity is somewhat negligible relative to the U.S. in those industries for which the United States is more competitive. Can we conclude from this that basic research in industry (and its associated discovery) are the critical determinants of industrial competitiveness? Yes and no. First, there is still a fair amount of variation that needs to be accounted for in the basic research/competitiveness patterns, and this variation is best explained by the "demand" factors discussed in chapter 4. For example, the industries in which the U.S. is competitive are still largely the nondurable goods industries, industries that are isolated from international competition. Additionally, the aerospace and drug industries have sufficiently unique histories and/or market structures that discourage widespread international competition. For the set of competitive U.S. industries, R&D may be irrelevant to competitive advantage unless a nation has a substantial industrial capacity to begin with or until buffered markets become globalized.

Similarly, it is important to understand the particular economic context of Japan's industrial activity in the mid-to-late 1970s. Japan spend much of the 1974-78 period restructuring its economy in response to the first oil shock and to make it much more energy efficient. It should come as no surprise that there was significant, and intense, basic research investment *in the most energy intensive industries.* Heavy industry is notorious for its energy consumption, energy which is consumed (or generated) through machinery. The concentration of Japan's basic research investments in the machinery, motor vehicles, and primary metals industries is testimony to this nation's commitment to perpetually rationalize its industrial base and reduce energy dependence. However, it also reflects the changing competitive strategy of the Japanse manufacturing sector. It is at this time that we begin to see the emergence of flexible manufacturing systems, the integration of product design with manufacturing process, and built-in quality control.

The interactive effect of research investments and new business strategies more than likely created the core of Japan's competitive advantage. Greater economy, streamlined and flexible mass production, computer and IC technology, and low scrap and reprocessing rates all yield better and more innovative products that can be bought and sold, but also considerably higher total factor productivity. It is not the basic research expenditures *per se* that are the determinants of competitiveness, but the patterns of *industrial* activity that they are capturing. What these basic research data suggest is that Japan's well known manufacturing strength derives not from tedious incremental engineering, but from substantial efforts in pioneering research. It would be Western arrogance to argue that this research was not basic or did not involve deeper understanding of the laws of nature, but detailed exploration of Japan's research endeavors is certainly called for. In any event, it is to Japan's misfortune that Nobel prizes are not awarded for fundamental insights into the nature of production.

CHAPTER 7

Patterns of Industrial R&D

Perhaps more than any other kind of R&D, we would expect industrial R&D to have the closest association with competitiveness. Because research and development within the firm responds to its competitive needs, it seems reasonable to assume that company-funded R&D best captures the mix of technological opportunity and market pressure. Such R&D represents the efforts of the "second stage" of technical change (commercial innovation), and thus is located--both literally and figuratively--closer to private sector institutions and markets. If basic research provides the basis for radical change and new opportunities, then industrial R&D should capture the innovation reactive to "real time" competition.

This chapter analyzes patterns in U.S. and Japanese industrial R&D expenditures attempts to relate these patterns to U.S. and Japanese industrial competitiveness. As discussed in chapters 4 and 6, R&D expenditures are considered to be the best quantitative measure for innovative activity in industry, largely because much innovation, especially in high tech industry, derives from R&D activity. Since one of the principal limitations of R&D data is their inability to reflect the "quality" of R&D, U.S. patent data are evaluated as a supplement to R&D expenditures. Because patents in the U.S. system must reflect minimum standards of novelty, utility, and advancement of prior art, there is a qualitative dimension to these data that is absent from the R&D figures.

R&D data are analyzed for the years 1970-86 and represent company-funded R&D expenditures for the 2- and 3-digit SIC manufacturing industries.[1] Japanese figures are those as reported in the annual *Report on the Survey of Research and Development* (Government of Japan, 1988); the U.S. data are from the annual *National Patterns of Science and Technology Resources* (National Science Foundation, 1988). Because some U.S. company-funded data were

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[1]Note that the manufacturing sector accounts for 97-98% of all U.S. industrial R&D expenditures; in Japan, the proportion is 92-94%. Total U.S. manufacturing R&D (as opposed to company-funded) is not analyzed here for the following reasons: 1) the vast majority (98%) of Japanese manufacturing R&D is company-funded, 2) the expenditure differential between total and company-funded R&D for the United States is predominantly defense-related, and 3) most (90%) defense-related R&D is product development and consequently has little or no spillover effect into the "civilian" economy. Thus, U.S. company-funded R&D is a better measure of U.S. industry's self-initiated commercial innovation activities.

not reported for the years 1975-80 (for business confidential reasons), the data have been estimated using patterns of total R&D funding. The R&D data for Japan and the United States are highly comparable, with two major exceptions: the Japanese do not report office and computing machines separately (they are included with electronic and communication equipment) and radio and television R&D is included in electrical machinery, not electronics. The U.S. data have therefore been adjusted to reflect these differences. As with the basic research data, yen have been deflated using OECD purchasing power parities and all R&D data have been converted to constant 1982 dollars using the GNP implicit price deflator.

The patent data analyzed here are patents actually granted by the U.S. patent office, by year of patent application (as opposed to the year the patent was actually granted). Since the patent office does not process patents in a uniform time frame, the date of patent application provides a better trend line for inventive activity, since it contains no institutional "noise". Patents are analyzed for the years 1975-85 for the same industries as reported for R&D data; SIC-level patent data are not readily available prior to 1975, and because of the lag involved in application processing, 1985 is the latest year for which one may confidently assume that all patent applications of that year have completely processed.[2] Data were obtained from the U.S. Patent and Trademark Office (1989).

Research and Development Expenditures

General trends in R&D expenditures

U.S. manufacturing R&D is dominated by a handful of industries, due in large part to both the size of these industries and the role of R&D in their innovation dynamics. The chemicals, electronics (inclusive of computers), motor vehicles, instruments, and other transportation (of which 97% of the R&D is in aerospace)[3] industries have consistently

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[2]This is unfortunate, since Japanese patenting activity increased markedly during 1970-75, and analysis of patent trends for these five years could provide critical information on Japanese competitiveness. However, the year 1975 does provide a useful benchmark for subsequent patent activity.

[3]Two-thirds of *total* aerospace R&D is funded by the federal government. When total (instead of company-funded) R&D is considered, the aerospace industry accounts for the single-largest share of U.S. manufacturing R&D, about 21% of the total.

accounted for roughly two-thirds of total U.S. manufacturing R&D (table 7.1); the remaining manufacturing industries possess rather nominal shares of the U.S. R&D effort.

Change in the distribution of total R&D among industries is a useful indicator of R&D effort, since it reflects the degree to which expenditures are growing at differential rates and it identifies those industries emphasizing R&D most heavily. As table 7.1 shows, the paper, pharmaceuticals, nonelectrical machinery, electronic equipment, motor vehicles, and instruments industries were the only industries to increase their share of total R&D during 1970-86; expenditures in these industries outpaced all others. The most rapidly growing industry (in terms of R&D investments) was the instruments industry--real average annual growth was 7.3% over the 1970-86 period.

Generally speaking, industries demonstrated either consistently high or consistently sluggish growth in most of the four, 4-year subperiods of 1970 to 1986 (table 7.1). There are a few exceptions, however. Since 1978 R&D in the food industry has been growing at a slightly faster rate than that for the manufacturing sector as a whole, while that of the nonelectrical machinery industry has slowed appreciably.

As in the United States, Japanese manufacturing R&D is dominated by five industries: chemicals, nonelectrical machinery, electrical machinery, electronics, and motor vehicles. From 1970-86 these industries accounted for about 73% of total manufacturing R&D (table 7.2); however, a slightly different set of Japanese industries comprised the "high growth" sector when compared to the United States. The pharmaceuticals, rubber, stone and glass, electronic equipment, motor vehicles, other transportation[4], and instruments industries maintained or significantly increased their share of total manufacturing R&D during 1970-86 (table 7.2); of these industries, stone and glass, electronic equipment, motor vehicles, and instruments increased their R&D expenditures by 10% or more annually in real terms. Growth in this set of industries was substantially larger than all others in the manufacturing sector, which still registered healthy 5-7% real average annual increases in R&D expenditures.

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[4]The "other transportation" industry in Japan is an agglomeration of aircraft, railroads, and shipbuilding. Most (two-thirds) of the R&D conducted by this "industry", however, is concentrated in the nonelectrical machinery product field, probably indicating extensive research in production technology, although it is not clear for which mode of transportation. The next largest product area of research is aircraft, which accounts for about 16% of the industry's total R&D.

Table 7.1--U.S. company-funded research and development

Industry	R&D, constant 1982 million dollars					Average annual rate of change				
	1970	1974	1978	1982	1986	1970-86	1970-74	1974-78	1978-82	82-86
Total Manufacturing............	$23,942	$26,616	$29,650	$38,411	$45,465	4.1%	2.7%	2.7%	6.7%	4.3%
Food, drink, and tobacco........	$540	$550	$526	$762	$952	3.6%	0.5%	-1.1%	9.7%	5.7%
Textiles, footwear, & leather...	$133	$128	$111	$124	$138	0.2%	-1.0%	-3.5%	2.9%	2.7%
Wood, cork, & furniture.........	$124	$145	$174	$162	$154	1.4%	4.0%	4.8%	-1.8%	-1.3%
Paper & printing...............	$343	$423	$439	$626	$779	5.3%	5.4%	1.0%	9.3%	5.6%
Chemicals......................	$2,670	$2,674	$2,695	$3,736	$4,382	3.1%	0.0%	0.2%	8.5%	4.1%
Drugs & medicines..............	$1,121	$1,470	$1,806	$2,490	$3,325	7.0%	7.0%	5.3%	8.4%	7.5%
Petroleum refining.............	$1,173	$1,117	$1,300	$1,981	$1,640	2.1%	-1.2%	3.9%	11.1%	-4.6%
Rubber & plastic products.......	$488	$569	$521	$665	$682	2.1%	3.9%	-2.2%	6.3%	0.6%
Stone, clay, & glass products...	$443	$376	$356	$414	$430	-0.2%	-4.0%	-1.4%	3.9%	0.9%
Ferrous metals..................	$352	$328	$375	$436	$341	-0.2%	-1.8%	3.4%	3.8%	-6.0%
Nonferrous metals..............	$278	$321	$313	$285	$370	1.8%	3.6%	-0.6%	-2.3%	6.7%
Fabricated metal products.......	$478	$554	$482	$510	$478	0.0%	3.8%	-3.4%	1.4%	-1.6%
Nonelectrical machinery.........	$1,047	$1,355	$1,862	$2,255	$2,077	4.4%	6.7%	8.3%	4.9%	-2.0%
Electrical machinery...........	$1,963	$2,059	$1,916	$2,211	$2,433	1.4%	1.2%	-1.8%	3.6%	2.4%
Electronic equipment & components....................	$5,310	$6,181	$6,803	$9,559	$12,799	5.7%	3.9%	2.4%	8.9%	7.6%
Motor vehicles.................	$2,993	$3,894	$4,682	$4,329	$6,372	4.8%	6.8%	4.7%	-1.9%	10.1%
Other transport equipment.......	$2,934	$2,443	$2,611	$3,978	$3,759	1.6%	-4.5%	1.7%	11.1%	-1.4%
Instruments....................	$1,309	$1,683	$2,310	$3,396	$4,020	7.3%	6.5%	8.2%	10.1%	4.3%
Other manufacturing............	$245	$348	$368	$493	$335	2.0%	9.2%	1.4%	7.6%	-9.2%

Source: the National Science Foundation and author's estimates

Table 7.2--Japanese research and development expenditures

Industry	R&D, constant 1982 million dollars					Average annual rate of change				
	1970	1974	1978	1982	1986	1970-86	1970-74	1974-78	1978-82	1982-86
Total Manufacturing............	$6,984	$8,815	$9,905	$15,766	$22,880	7.7%	6.0%	3.0%	12.3%	9.8%
Food, drink, and tobacco........	$213	$257	$316	$478	$587	6.6%	4.8%	5.3%	10.9%	5.3%
Textiles, footwear, & leather...	$132	$126	$115	$218	$249	4.1%	-1.0%	-2.4%	17.4%	3.4%
Wood, cork, & furniture.........	$24	$34	$37	$54	NA	NA	9.7%	2.2%	9.6%	NA
Paper & printing...............	$83	$109	$93	$116	$201	5.7%	7.1%	-4.0%	5.8%	14.6%
Chemicals......................	$1,191	$1,360	$1,272	$1,879	$2,558	4.9%	3.4%	-1.7%	10.3%	8.0%
Drugs & medicines..............	$417	$478	$636	$1,007	$1,363	7.7%	3.5%	7.4%	12.2%	7.9%
Petroleum refining.............	$69	$94	$117	$183	$273	7.3%	1.4%	5.7%	11.7%	10.6%
Rubber & plastic products.......	$88	$153	$203	$234	$320	8.4%	15.0%	7.2%	3.7%	8.1%
Stone, clay, & glass products...	$162	$230	$276	$393	$748	10.0%	9.1%	4.6%	9.3%	17.5%
Ferrous metals..................	$336	$486	$509	$767	$1,018	7.2%	9.7%	1.2%	10.8%	7.3%
Nonferrous metals...............	$164	$162	$162	$302	$439	6.4%	-0.3%	0.0%	16.8%	9.8%
Fabricated metal products.......	$129	$141	$189	$272	$377	7.0%	2.2%	7.6%	9.6%	8.5%
Nonelectrical machinery.........	$664	$883	$758	$1,180	$1,511	5.3%	7.4%	-3.8%	11.7%	6.4%
Electrical machinery............	$899	$964	$1,260	$1,620	$2,470	6.5%	1.7%	6.9%	6.5%	11.1%
Electronic equipment & components....................	$1,192	$1,437	$1,480	$3,319	$5,423	9.9%	4.8%	0.7%	22.4%	13.1%
Motor vehicles..................	$721	$1,112	$1,571	$2,391	$3,350	10.1%	11.5%	9.0%	11.1%	8.8%
Other transport equipment.......	$150	$351	$336	$430	$595	9.0%	23.7%	-1.1%	6.4%	8.5%
Instruments.....................	$175	$209	$327	$564	$794	9.9%	4.6%	11.8%	14.6%	8.9%
Other manufacturing.............	$158	$229	$249	$360	$603	8.7%	9.7%	2.2%	9.6%	13.8%

Source: Government of Japan (1988)

Unlike the U.S. industries for which high or low rates of growth relative to the whole manufacturing sector were fairly consistent, several Japanese industries manifested quite distinct growth trends. The rubber and motor vehicles industries experienced above average R&D growth only from 1970-78, while rapid, above average growth for nonferrous metals and electronics occurred only after 1978. In comparison, the instruments industry had its high growth from 1974-82, and other transportation during 1970-74 and 1982-86.

These trends in U.S. and Japanese industrial R&D expenditures do not seem, however, to act as strong predictors of competitive performance. The U.S. is non-competitive in four of the six most rapidly (R&D) growing industries (nonelectrical machinery, electronics, motor vehicles, instruments), as are three of Japan's seven high-growth industries (drugs, stone and glass, and other transportation). However, of the eight Japanese industries which have the greatest differential in R&D growth rates with their U.S counterparts (rubber, stone and glass, steel, fabricated metals, other transportation, nonferrous metals, electrical machinery, and motor vehicles), all but stone and glass, nonferrous metals, and other transportation are existing or emerging international competitors.[5] This suggests that disparities in the rates of change of R&D expenditures may be a reasonable indicator of a linkage between R&D and competitiveness; nevertheless, this approach cannot explain the successful performance of the non-electrical machinery, instruments, or electronics industries--for which the Japanese growth advantage has been quite nominal--or the lack of international stature of the Japanese stone and glass and nonferrous metals industries, which have had a substantial growth advantage.

While rates of growth reflect relative levels of effort within and between the U.S. and Japanese manufacturing sectors, absolute volumes of spending may be more indicative of the competitive strength of industries, since proximate levels of R&D expenditures could reflect more "equal" innovative capacities. As will be seen below, there is considerable variation among the Japanese manufacturing industries in their total volumes of R&D spending relative to the United States.

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[5]Note that the rubber and fabricated metals industries, for which the U.S. is still considered to be competitive, are approaching the seemingly critical threshold for non-competitive status. As discussed in chapter 5, a major distinguishing characteristic of non-competitive U.S. industries is that 25% or more of foreign imports are Japanese. Since both the rubber and fabricated metals industries are approaching this threshhold, I consider them to be emerging Japanese competitors.

Absolute levels of R&D expenditures

The differentials in the real average annual rates of growth between the U.S. and Japan (as shown in tables 7.1 and 7.2) have enabled Japan to match–indeed exceed–U.S. R&D expenditures in several industries. From 1970-80, Japanese R&D expenditures were greater than those of the United States for only the steel and textile industries, since most growth relative to the U.S. has occurred after 1978. Modest R&D gains during 1970-74 were almost completely offset during Japan's recession of 1974-78, but by 1986, Japan's manufacturing R&D surpassed that of the United States in the electrical machinery, nonferrous metals, textiles, stone and glass, and steel industries (table 7.3). Indeed, in the steel industry, Japanese R&D exceeds U.S. levels by 3-to-1.

There does not appear to be any consistent relationship between the levels of R&D spending by Japanese and U.S. industries and their competitive status as discussed in chapter 5. For the industries in which the U.S. is noncompetitive and Japan constitutes a significant foreign competitor, Japanese R&D as a percentage of U.S. ranges from 20% for instruments to 300% for steel. Moreover, with the exception of steel and electrical machinery, in 1978 the industries in which Japan is competitive had R&D expenditures that were still only about a third or less of those in the United States, hardly spending levels one would expect given assertions about the significance of science and technology to competitiveness and the presumed role of R&D in generating innovation. With the similar exception of steel and electrical machinery, those Japanese industries with the highest levels of R&D relative to the United States (e.g., 60% or more, textiles and stone and glass prior to 1978, together with nonferrous metals and food after 1978) are undistinguished as international competitors. Since improvement relative to the United States is a function of the comparative rates of growth, the Japanese industries that show the best and worst gains in narrowing the R&D expenditure gap with the U.S. are those with the highest and lowest differential growth rates as discussed in the previous section.

Another means of explaining competitive performance may be the technological intensity of an industry; the greater the embodied technology of a good, the more competitive it is likely to be either through novelty, quality, or lesser production cost. One way of measuring this intensity is through the R&D-to-sales ratios of products and industries. Although these ratios are generally used as an indicator of high, medium, and low technology

Table 7.3--Total Japanese R&D expenditures as a percentage of U.S.

Industry	Ratio of Japanese to U.S. R&D, in percent					Percentage change during period				
	1970	1974	1978	1982	1986	1970-86	1970-74	1974-78	1978-82	1982-86
Total Manufacturing............	29.2%	33.1%	33.4%	41.0%	50.3%	72.5%	13.5%	0.9%	22.9%	22.6%
Food, drink, and tobacco........	39.3%	46.7%	60.0%	62.7%	61.7%	56.7%	18.6%	28.7%	4.4%	-1.6%
Textiles, footwear, & leather...	98.8%	98.7%	103.4%	175.6%	180.3%	82.4%	-0.1%	4.7%	69.8%	2.6%
Wood, cork, & furniture.........	19.1%	23.8%	21.5%	33.4%	NA	NA	24.1%	-9.7%	55.6%	NA
Paper & printing...............	24.2%	25.9%	21.1%	18.6%	25.7%	6.3%	6.9%	-18.3%	-12.1%	38.6%
Chemicals......................	44.6%	50.8%	47.2%	50.3%	58.4%	30.8%	14.0%	-7.2%	6.6%	16.0%
Drugs & medicines..............	37.2%	32.5%	35.2%	40.4%	41.0%	10.2%	-12.5%	8.2%	14.9%	1.4%
Petroleum refining.............	7.6%	8.4%	9.0%	9.2%	16.7%	120.1%	11.0%	7.4%	2.2%	80.5%
Rubber & plastic products.......	18.0%	27.0%	39.0%	35.2%	46.9%	160.9%	50.0%	44.5%	-9.6%	33.1%
Stone, clay, & glass products...	36.7%	61.2%	77.5%	94.9%	174.1%	374.2%	66.6%	26.7%	22.5%	83.4%
Ferrous metals..................	95.3%	148.1%	135.7%	176.0%	298.5%	213.2%	55.4%	-8.4%	29.7%	69.6%
Nonferrous metals..............	58.9%	50.6%	51.9%	106.1%	118.8%	101.6%	-14.1%	2.5%	104.5%	11.9%
Fabricated metal products.......	26.9%	25.4%	39.1%	53.4%	79.0%	193.4%	-5.8%	54.3%	36.4%	47.9%
Nonelectrical machinery.........	63.4%	65.2%	40.7%	52.3%	72.8%	14.7%	2.8%	-37.6%	28.6%	39.1%
Electrical machinery...........	45.8%	46.8%	65.7%	73.2%	101.5%	121.6%	2.2%	40.4%	11.4%	38.6%
Electronic equipment & components..................	22.4%	23.2%	21.8%	34.7%	42.4%	88.8%	3.6%	-6.4%	59.6%	22.0%
Motor vehicles.................	24.1%	28.6%	33.6%	55.2%	52.6%	118.3%	18.6%	17.5%	64.5%	-4.8%
Other transport equipment.......	5.1%	14.4%	12.9%	10.8%	15.8%	209.6%	180.9%	-10.5%	-16.0%	46.6%
Instruments....................	13.3%	12.4%	14.1%	16.6%	19.7%	48.0%	-6.8%	13.7%	17.4%	19.0%
Other manufacturing............	64.3%	65.6%	67.6%	73.0%	180.0%	180.0%	2.0%	3.0%	7.9%	146.7%

Source: Tables 7.1 and 7.2

Table 7.4--Japanese R&D-to-sales ratios

	Ratio, in percent					Net change during period				
Industry	1970	1974	1978	1982	1986	1970-86	1970-74	1974-78	1978-82	1982-86
Total Manufacturing.............	1.1%	1.2%	1.3%	1.7%	2.1%	83.9%	4.3%	12.0%	30.0%	21.1%
Food, drink, and tobacco........	0.3%	0.3%	0.3%	0.4%	0.4%	46.9%	2.0%	6.3%	30.4%	3.9%
Textiles, footwear, & leather...	0.3%	0.3%	0.3%	0.5%	0.5%	80.5%	-7.2%	-3.1%	87.6%	7.0%
Wood, cork, & furniture.........	0.1%	0.1%	0.1%	0.3%	NA	NA	20.0%	22.8%	177.4%	NA
Paper & printing................	0.2%	0.2%	0.2%	0.2%	0.3%	36.3%	-3.3%	-6.3%	-2.5%	54.3%
Chemicals.......................	2.9%	2.7%	2.6%	2.9%	3.4%	19.4%	-4.5%	-5.0%	13.6%	15.9%
Drugs & medicines...............	5.0%	5.3%	6.0%	7.3%	8.8%	77.8%	6.7%	12.5%	21.7%	21.7%
Petroleum refining..............	0.5%	0.2%	0.3%	0.3%	0.3%	-41.7%	-54.8%	30.5%	-13.3%	14.0%
Rubber & plastic products.......	0.4%	0.5%	0.7%	0.6%	0.7%	61.4%	22.1%	25.3%	-6.3%	12.5%
Stone, clay, & glass products...	0.7%	0.8%	0.9%	1.1%	1.9%	162.7%	9.7%	15.6%	23.4%	67.8%
Ferrous metals..................	0.6%	0.7%	0.9%	1.3%	1.5%	163.4%	19.7%	24.6%	51.8%	16.4%
Nonferrous metals...............	0.9%	0.9%	1.2%	1.7%	2.1%	122.9%	-4.8%	32.0%	40.9%	26.0%
Fabricated metal products.......	0.3%	0.2%	0.4%	0.4%	0.6%	117.5%	-6.8%	45.7%	23.0%	30.2%
Nonelectrical machinery.........	1.1%	1.3%	1.3%	1.6%	1.9%	67.8%	17.3%	-3.2%	24.3%	18.8%
Electrical machinery............	3.1%	2.9%	3.7%	3.9%	5.1%	62.6%	-7.9%	28.5%	6.9%	28.5%
Electronic equipment & components....................	3.1%	3.6%	3.3%	4.5%	4.6%	48.9%	18.0%	-9.1%	35.5%	2.5%
Motor vehicles..................	1.6%	2.1%	2.2%	2.6%	3.0%	88.7%	36.1%	1.8%	17.2%	16.3%
Other transport equipment.......	0.8%	1.4%	1.6%	1.8%	3.0%	274.4%	72.5%	13.3%	13.1%	69.3%
Instruments.....................	1.5%	1.4%	1.9%	2.3%	2.7%	81.5%	-3.5%	32.6%	24.7%	13.8%
Other manufacturing.............	1.3%	1.5%	1.4%	1.5%	2.0%	52.7%	16.8%	-7.5%	4.4%	35.3%

Source: Government of Japan (1989) and OECD (1988)

Table 7.5--U.S. R&D-to-sales ratios

Industry	Ratio, in percent					Net change during period				
	1970	1974	1978	1982	1986	1970-86	1970-74	1974-78	1978-82	1982-86
Total Manufacturing............	1.7%	1.5%	1.5%	2.1%	2.2%	28.8%	-11.0%	-0.7%	39.3%	4.6%
Food, drink, and tobacco........	0.2%	0.2%	0.2%	0.3%	0.3%	37.3%	-19.4%	-2.5%	50.5%	16.1%
Textiles, footwear, & leather...	0.1%	0.1%	0.1%	0.1%	0.1%	14.0%	-8.2%	-14.4%	31.7%	10.2%
Wood, cork, & furniture.........	0.3%	0.3%	0.3%	0.4%	0.3%	-12.4%	-12.3%	-1.0%	35.2%	-25.4%
Paper & printing................	0.3%	0.3%	0.3%	0.4%	0.4%	36.3%	3.5%	-5.6%	35.6%	2.8%
Chemicals.......................	2.7%	2.0%	1.8%	2.6%	2.6%	-3.5%	-26.9%	-12.7%	46.4%	3.2%
Drugs & medicines...............	7.2%	8.2%	9.1%	10.9%	11.9%	64.8%	13.9%	10.3%	19.8%	9.4%
Petroleum refining..............	2.0%	1.1%	0.9%	1.0%	0.8%	-62.3%	-47.1%	-13.0%	6.0%	-22.7%
Rubber & plastic products.......	1.3%	1.1%	0.9%	1.2%	1.0%	-24.9%	-16.1%	-21.1%	36.4%	-16.9%
Stone, clay, & glass products...	1.2%	0.8%	0.7%	1.0%	0.9%	-25.7%	-27.9%	-21.9%	50.1%	-12.1%
Ferrous metals..................	0.5%	0.3%	0.4%	0.8%	0.6%	10.8%	-37.3%	20.6%	100.1%	-26.8%
Nonferrous metals...............	0.7%	0.6%	0.6%	0.7%	0.9%	22.2%	-13.7%	-2.6%	24.2%	17.1%
Fabricated metal products.......	0.5%	0.5%	0.4%	0.5%	0.4%	-27.5%	-8.6%	-20.7%	20.1%	-16.7%
Nonelectrical machinery.........	0.9%	0.9%	1.1%	1.6%	1.4%	50.7%	-2.3%	21.5%	40.7%	-9.7%
Electrical machinery............	3.9%	3.5%	3.1%	4.1%	4.2%	8.8%	-9.8%	-11.7%	33.4%	2.4%
Electronic equipment & components....................	7.8%	8.0%	7.0%	7.5%	7.9%	1.4%	2.2%	-11.6%	6.5%	5.3%
Motor vehicles..................	2.1%	2.7%	2.3%	3.4%	3.9%	85.8%	27.0%	-14.2%	47.4%	15.6%
Other transport equipment.......	5.2%	3.7%	3.8%	5.2%	4.2%	-19.1%	-28.3%	1.0%	36.9%	-18.4%
Instruments.....................	5.6%	5.6%	6.3%	8.4%	8.6%	54.4%	0.4%	13.2%	32.1%	2.8%
Other manufacturing.............	1.3%	1.7%	1.5%	2.2%	1.6%	19.8%	28.5%	-8.2%	46.8%	-30.8%

Source: Table 7.1 and OECD (1988)

Table 7.6--Japanese R&D-to-sales ratios indexed to those of the U.S.

Industry	Index					Net change during period				
	1970	1974	1978	1982	1986	1970-86	1970-74	1974-78	1978-82	1982-86
Total Manufacturing............	0.66	0.78	0.88	0.82	0.95	42.8%	17.2%	12.8%	-6.7%	15.8%
Food, drink, and tobacco........	1.24	1.57	1.71	1.48	1.33	7.0%	26.6%	8.9%	-13.3%	-10.5%
Textiles, footwear, & leather...	2.50	2.52	2.86	4.07	3.95	58.3%	1.1%	13.2%	42.5%	-3.0%
Wood, cork, & furniture.........	0.28	0.38	0.47	0.97	NA	NA	36.8%	24.0%	105.2%	NA
Paper & printing...............	0.81	0.75	0.75	0.54	0.81	0.0%	-6.6%	-0.8%	-28.1%	50.1%
Chemicals......................	1.04	1.36	1.48	1.15	1.29	23.7%	30.6%	8.7%	-22.4%	12.3%
Drugs & medicines..............	0.69	0.64	0.66	0.67	0.74	7.9%	-6.3%	2.0%	1.5%	11.2%
Petroleum refining.............	0.27	0.23	0.34	0.28	0.41	54.6%	-14.5%	50.0%	-18.2%	47.5%
Rubber & plastic products.......	0.34	0.50	0.79	0.54	0.74	115.0%	45.5%	58.9%	-31.3%	35.4%
Stone, clay, & glass products...	0.62	0.94	1.40	1.15	2.19	253.6%	52.3%	48.0%	-17.8%	90.9%
Ferrous metals.................	1.15	2.19	2.26	1.71	2.72	137.7%	90.9%	3.2%	-24.1%	59.0%
Nonferrous metals..............	1.33	1.47	1.99	2.26	2.43	82.4%	10.3%	35.5%	13.4%	7.6%
Fabricated metal products.......	0.50	0.50	0.93	0.95	1.49	199.9%	1.9%	83.7%	2.4%	56.4%
Nonelectrical machinery.........	1.19	1.43	1.14	1.01	1.33	11.3%	20.1%	-20.3%	-11.6%	31.6%
Electrical machinery...........	0.80	0.82	1.19	0.96	1.20	49.5%	2.1%	45.5%	-19.9%	25.6%
Electronic equipment & components....................	0.40	0.46	0.47	0.60	0.58	46.9%	15.4%	2.8%	27.2%	-2.7%
Motor vehicles.................	0.75	0.80	0.95	0.76	0.76	1.5%	7.1%	18.5%	-20.5%	0.6%
Other transport equipment.......	0.15	0.37	0.41	0.34	0.71	363.0%	140.7%	12.2%	-17.4%	107.5%
Instruments....................	0.26	0.25	0.30	0.28	0.31	17.5%	-3.9%	17.1%	-5.6%	10.7%
Other manufacturing............	1.02	0.93	0.94	0.67	1.31	27.4%	-9.0%	0.8%	-28.9%	95.4%

Source: Tables 7.4 and 7.5

goods/industries, variations in the ratios may reflect growing or declining technological/innovative activity.

R&D to sales ratios

In addition to controlling for the effect of size on trends and patterns of R&D spending, R&D-to-sales ratios also serve as a rough measure of embodied technology in manufactured goods. By and large, Japan and the United States share the same most R&D intensive sectors, which additionally correspond to the OECD's group of high technology industries (tables 7.4 and 7.5). In Japan, however, the chemical and motor vehicles industries are also relatively R&D intensive, while instruments--a high tech industry--is not.

There are few distinctive patterns and trends in the Japanese and U.S. R&D-to-sales ratios. R&D intensities for Japanese manufacturing industries generally increased steadily during 1970-86, with most of the increase occurring after 1978 when real increases in R&D growth were largest, running about 10% or more per annum. There were a few exceptions to this trend; the electronics and motor vehicles industries experienced large increases in their R&D-to-sales ratios during 1970-74 and the fabricated metals and instruments industries demonstrated steadily large increases in R&D investments relative to sales after 1974. Above average improvements in the R&D-to-sales ratios occurred in the other transportation, steel, stone and glass, nonferrous metals, fabricated metals, and motor vehicles industries, and to a lesser extent in instruments, textiles, and drugs.

In comparison, the U.S. R&D intensity for manufacturing industries declined rather uniformly throughout the 1970s; pharmaceuticals and instruments were the only two industries which increased their ratios during this period. For the other industries, it wasn't until 1979-80 that the 1970 level was again attained and growth in R&D investments began. From 1978-82 the R&D-to-sales ratio jumped appreciably, not only because R&D expenditures increased in real terms during this period, but also because there was a real decline in U.S. manufacturing sales, thus also improving the overall ratio. However, the high ratio has been maintained with the onset of macroeconomic recovery in 1982, reflecting an appreciably higher level of R&D investments in the 1980s than in the 1970s. The industries which experienced the largest increases in R&D investments relative to sales over the 1970-86 period were motor vehicles, drugs, instruments, nonelectrical machinery, food, and paper and printing. For several other industries—including rubber, stone and glass, and fabricated metals—the R&D intensities of the early 70s have never been recovered.

All of the Japanese manufacturing industries increased their R&D-to-sales ratios relative to those of the United States during 1970-86. Table 7.6 presents indexes of the Japanese ratios to those of the U.S.; even in 1970 Japanese investments were comparable to U.S. levels in several industries including chemicals, the primary metals, and nonelectrical machinery. By 1986 this list had expanded to include the stone and glass, fabricated metals, and electrical machinery industries. In 1986, the R&D intensities of the Japanese primary metals industries were more than double levels in the United States (almost triple for steel), while the R&D intensity of the Japanese textile industry was quadruple the intensity of the U.S.

In spite of this superior performance, Japanese investments were lagging those of the U.S. in several of the most competitive Japanese industries, including motor vehicles, electronics, and instruments. In fact, R&D investments by the Japanese instruments industry were barely one-third of the R&D intensity of the U.S. industry. Similarly, of the nine Japanese industries which had comparable or higher R&D-to-sales ratios as those in the United States (table 7.6), only steel, the machinery industries, and fabricated metals could in any way be considered international competitors. As in the general trends in R&D growth, the Japanese materials and fabricated metals industries did best relative to the United States, while the more competitive motor vehicles, nonelectrical machinery, and instruments industries were among the worst relative to the United States.

R&D and competitiveness

There is little in the patterns of Japanese and U.S. R&D expenditures that would allow one to reasonably predict which industries are competitive and those which are not. The Japanese instruments and electronics industries (inclusive of computers) present some of the most vigorous international competition, yet Japanese R&D investments in these industries are appreciably less than U.S. levels of expenditure in absolute terms, and continue to seriously lag U.S. intensities of R&D investments (R&D-to-sales).[6] While Japanese R&D expenditures

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[6]Jeffrey Hart has pointed out the the official Japanese R&D statistics for electronics and instruments seem grossly underreported compared to the data available from industry sources. While these discrepancies are being explored, it would nonetheless be wise to treat such data here with some caution.

in these two industries grew fastest relative to the U.S. in the post-1982 period--the time during which the U.S. industries became non-competitive--this is in all liklihood due to the fact that R&D expenditures and sales volumes tend to be highly correlated, and this increase in Japanese R&D corresponds to rapid growth in industrial sales. In contrast, patterns of Japanese investments in the pharmaceuticals industry are quite comparable to those for electronics and instruments, yet this industry in not a major international competitor.

There do seem to be some systematic trends in the R&D activities of the Japanese machinery industries and their competitive performance. The absolute levels of Japanese R&D expenditures in the electrical and nonelectrical machinery industries relative to their U.S. counterparts were stable throughout the 1970s, but began growing signficantly after 1980, at the same time their R&D-to-sales ratios were rising appreciably both absolutely and relative to the U.S. Nevertheless, identical R&D trends may be observed for both the Japanese nonferrous metals and stone and glass industries, yet neither one of them are major international competitors.

The motor vehicles industry is similarly perplexing. The absolute levels of R&D spending were quite low relative to the U.S. in the years preceding the 1978 onslaught, although the R&D-to-sales ratio did increase from 75% of the U.S. level to 95% of the U.S. effort during this period. The Japanese ratio has since waivered between 75% and 100% of U.S. ratios, but about half of U.S. absolute levels of spending.[7] In contrast, however, the Japanese chemical industry has patterns of R&D comparable to motor vehicles (e.g., half of U.S. absolute levels, but a higher R&D intensity), yet the U.S. remains quite competitive in this industry and Japanese imports are not a significant domestic threat.

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[7]There are several explanations for these statistical relationships, which seem counter-intuitive given the fact that Japan now produces more cars than the United States. First, the sales value of the Japanese cars is somewhat lower than the United States, which would explain why the Japanese R&D-to-sales ratio is comparable to the U.S. even though absolute spending is so much lower. Additionally, U.S. R&D data is not collected at the establishment level--this means that all non-automotive R&D conducted by the U.S. automakers' subsidiaries are included as motor vehicle R&D. As a case in point, the acquisition of Hughes Aircraft by General Motors caused a significant increase in the amount of R&D reported by the auto industry the year after the acquisition. Although Japanese figures are also not establishment level, Japanese industries tend to be less diversified than those in the United States. Note that sales data are establishment based, however.

Figure 7-1. Typology of Japanese Industrial R&D Performance Relative to the United States, by Industry and Competitive Status

TYPE OF R&D PERFORMANCE	COMPETITIVE STATUS OF THE INDUSTRY: Competitive	Non-Competitive
TYPE I. SUPERIOR PERFORMANCE (above average on 3 or 4 R&D dimensions)	Steel Electrical Machinery **Fabricated Metals	Textiles Stone and Glass Non-ferrous Metals
TYPE II. MIXED PERFORMANCE (combination of good, poor, and/or average on R&D)	**Rubber Nonelectrical Machinery Motor Vehicles	Food Other Transportation Chemicals
TYPE III. INFERIOR PERFORMANCE (well below average on 3 or 4 R&D dimensions)	Instruments Electronics	Paper and printing Pharmaceuticals

** These industries appear to be emerging competitors.

In sum, there does not appear to be any systematic relationship between an industry's R&D activity and its international competitive stature. However, it would be misleading to claim that there are no distinctive patterns with regard to R&D and competitiveness. The R&D data reviewed here reflect four major dimensions of R&D activity, which are:

- differences in U.S. and Japanese rates of R&D investment,
- differences in absolute levels of U.S. and Japanese R&D expenditures,
- differences in U.S. and Japanese rates of change in industrial R&D intensity, and
- differences in the actual R&D intensity of U.S. and Japanese industries.

Japanese industrial R&D progress compared to the United States does tend to fall out into three separate categories of performance: those industries that do very well along three or all four of the R&D "variables", those that do quite poorly along three or all four dimensions, and those whose performance is a combination of good, bad, and/or unremarkable. Importantly, when one considers the competitiveness of these industries vis-a-vis the United States, for every competitive industry in each category, there is a non-competitive one as well (figure 7-1).

Figure 7-1 illustrates the limitations of associating R&D performance with competitive performance for any number of reasons, but three in particular stand out. First, as mentioned above, for every instance of a competitive industry for a particular R&D type, there is a non-competitive one as well. Second, and as a corollary to this first observation, a superior record of R&D activity relative to the United States does not guarantee the industry competitive status: there are not only non-competitive "superior" industries, but there are also highly competitive industries which manifest quite poor performance on three or all four of the R&D variables. Finally, the inability to decisively determine a clear R&D advantage or disadvantage for the rubber, motor vehicles, and nonelectrical machinery industries suggests—as in the first two cases—that any number of factors may be either alternative causes of competitiveness, R&D "enhancers" (e.g., connect R&D more directly to innovation), or R&D "inhibitors" (e.g., weaken the innovation potential of R&D).

A detailed comparison of the competitiveness and R&D trends for the four competitive Japanese industries/non-competitive U.S. industries for which more extensive competitiveness data were available (see chapter 5) does not really shed any more light on the relationship between R&D and competitiveness. The motor vehicles, electronics, instruments, and electrical machinery industries share a common competitiveness trend, which is that Japanese competitiveness relative to the United States strengthened dramatically right around 1978-79 and again in 1983/84. (The electrical machinery industry was running about a two year lag, however, improving in 1980-81 and again in 1985/86.) The fact that these dates coincide first with the end of a Japanese recession and oil-shock restructuring suggests that macroeconomic phenomena may be more at play than science and technology; however, as noted in the previous chapter, the restructuring involved highly innovative improvements in manufacutring technologies and machinery.

The R&D data additionally show that a significant improvement in the Japanese R&D-to-sales ratios relative to the U.S. occurred for all four industries during at least one of the two 4-year sub-periods *prior* to 1978-79. Additionally, the second best period of overall R&D improvement for all four industries (except electronics) occurred in the period *coincident* with the onset of the 1983-84 competitive challenge.[8] Since this pattern is also evident for virtually all Japanese industries, competitive and non-competitive alike, it would seem that the pattern derives more from broader macroeconomic activity than anything to do with R&D directly. Clues to causality are therefore still missing (e.g., does R&D lead to competitiveness, or does competitiveness allow industries to invest more heavily in R&D?) and any systematic relationship between the two phenomena is--as discussed above--far from apparent.

There are several possible explanations for this lack of clear association between industrial R&D and competitiveness. The first most obvious one is limitations of the data themselves. The industrial level of aggregation is still quite high, and may mask considerable relationships at sub-industry, firm, or product line levels. Additionally, the R&D data are not "perfectly" industrial: for diversified firms, R&D is allocated *in toto* to one industry class on the basis of the majority of firm sales. Thus, there could be a considerable amount of R&D "misclassification." Disjunctures in industry-level data for R&D and competitiveness may create just enough noise to hide associations. Similarly, the R&D data do not capture spillover effects,

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[8]The Japanese electronics industry does not quite fit this pattern because of the unparalleled increase in R&D activity during the years 1978-82. During this four year period R&D and R&D-to-sales increased dramatically both within the industry and relative to the United States. This focus is clearly reflective of Japan's explicit industrial policy with regard to semiconductors and information technologies. Not only were there several government-sponsored R&D programs in place at the time (including the first VLSI program), but industry itself was extremely aggressive in advancing its technological position.

so that competitive gain by one industry from R&D performed by another will not show up in this analysis.

Another possible explanation may be that the competitive Japanese industries benefit either from an inordinate amount of government support or purchase an inordinate amount of foreign technology. This would explain why industries with comparable R&D profiles may have different competitive stature, and why industries with clearly inferior R&D profiles manage to be highly competitive. In the case of government support, industries could be benefitting from more comprehensive industrial policies, and in the case of technology imports, they could be closing technology gaps far more rapidly than others. Data relating to these issues will be explored below.

External supplements to Japanese industrial R&D

Since R&D supplements are one tool of Japanese industrial policy, an analysis of government-funded R&D could indicate industries for which there was a larger "package" of policy support, enabling the targeted industries to be more competitive. The Japanese industrial R&D data reveal that government funding has been highly concentrated among a handful of industries; throughout the 1970s four manufacturing industries accounted for roughly 80-90% of government R&D transfers to the manufacturing sector (table 7.7). Nonelectrical and electrical machinery, electronics, and other transportation equipment consistently garnered the vast majority of government support throughout the decade, although the other transportation industry clearly acquired these government R&D resources at the expense of the others: from 1970-78 the total share of the machinery industries and electronics declined, while that of other transportation increased from 12% to 54% of total government R&D support. After 1980 government R&D transfers became slightly less concentrated, and the steel industry replaced nonelectrical machinery as one of the "group of four". Throughout the 1980s this new combination of industries accounted for 75% of government R&D transfers.

The presence of substantial government R&D attention does appear to associate with an industry's competitiveness. Although a number of competitive industries have never accounted for a significant proportion of government R&D funds, including steel, motor

Table 7.7--Japanese government R&D funding

Industry	Distribution of Japanese govt R&D funding 1970	1974	1978	1982	1986	Funding as a percentage of total R&D 1970	1974	1978	1982	1986
Total Manufacturing............	100.0%	100.0%	100.0%	100.0%	100.0%	0.8%	1.5%	1.3%	1.9%	1.7%
Food, drink, and tobacco........	0.0%	0.1%	0.2%	0.5%	0.9%	0.0%	0.0%	0.1%	0.3%	0.6%
Textiles, footwear, & leather...	0.1%	0.2%	0.1%	0.7%	1.9%	0.0%	0.2%	0.1%	0.9%	3.1%
Wood, cork, & furniture.........	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Paper & printing...............	1.3%	1.6%	0.2%	0.0%	0.1%	0.9%	1.9%	0.2%	0.0%	0.2%
Chemicals......................	5.7%	2.3%	3.6%	8.6%	5.5%	0.3%	0.2%	0.4%	1.3%	0.9%
Drugs & medicines..............	0.0%	0.1%	0.0%	0.2%	0.3%	0.0%	0.0%	0.0%	0.1%	0.1%
Petroleum refining.............	1.5%	0.0%	0.3%	2.5%	6.3%	1.0%	0.1%	0.4%	4.1%	9.2%
Rubber & plastic products.......	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Stone, clay, & glass products...	4.3%	1.0%	0.8%	2.2%	1.3%	1.6%	0.6%	0.4%	1.6%	0.7%
Ferrous metals.................	0.4%	0.9%	4.2%	9.8%	7.0%	0.1%	0.3%	1.1%	3.8%	2.8%
Nonferrous metals..............	4.6%	0.7%	3.1%	2.5%	2.5%	1.6%	0.6%	2.5%	2.4%	2.3%
Fabricated metal products.......	0.1%	0.4%	0.2%	0.1%	0.3%	0.1%	0.4%	0.1%	0.2%	0.4%
Nonelectrical machinery.........	28.1%	15.3%	9.5%	6.1%	5.3%	2.5%	2.3%	1.7%	1.5%	1.4%
Electrical machinery...........	29.9%	29.4%	13.7%	10.0%	11.0%	2.0%	4.1%	1.4%	1.8%	1.8%
Electronic equipment & components....................	9.0%	18.0%	6.7%	18.3%	13.3%	0.4%	1.7%	0.6%	1.6%	1.0%
Motor vehicles.................	0.9%	3.0%	1.2%	0.4%	0.4%	0.1%	0.4%	0.1%	0.1%	0.1%
Other transport equipment.......	11.7%	24.9%	54.1%	36.6%	43.2%	4.6%	9.6%	21.4%	25.0%	28.9%
Instruments....................	2.3%	1.5%	1.4%	0.8%	0.2%	0.8%	0.9%	0.6%	0.4%	0.1%
Other manufacturing............	0.0%	0.6%	0.8%	0.4%	0.1%					

Source: Government of Japan (1988)

Table 7.8--Japanese imports of foreign technology 1/

Industry	Distribution of technology imports					Technology imports as a percentage of total R&D				
	1971	1974	1978	1982	1986	1971	1974	1978	1982	1986
Total Manufacturing............	100.0%	100.0%	100.0%	100.0%	100.0%	16.3%	10.6%	9.0%	7.4%	4.5%
Food, drink, and tobacco........	1.4%	1.8%	5.8%	4.1%	4.2%	6.3%	6.5%	16.2%	9.9%	7.3%
Textiles, footwear, & leather...	1.3%	1.2%	1.1%	1.0%	1.3%	9.6%	8.7%	8.9%	5.4%	5.2%
Wood, cork, & furniture.........	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Paper & printing................	0.7%	1.2%	1.1%	0.8%	0.5%	10.2%	9.9%	10.2%	8.3%	2.4%
Chemicals.......................	17.9%	14.1%	11.1%	11.8%	10.8%	17.2%	9.7%	7.8%	7.3%	4.4%
Drugs & medicines...............	2.1%	3.4%	3.8%	4.7%	4.9%	5.1%	6.6%	5.3%	5.4%	3.7%
Petroleum refining..............	1.7%	1.7%	0.8%	1.0%	1.2%	19.0%	17.2%	6.3%	6.7%	4.6%
Rubber & plastic products.......	1.7%	2.4%	2.4%	1.2%	2.1%	21.4%	14.7%	10.4%	6.2%	6.7%
Stone, clay, & glass products...	4.4%	5.4%	3.5%	3.9%	2.5%	34.6%	21.9%	11.3%	11.5%	3.5%
Ferrous metals..................	3.7%	4.3%	3.9%	2.8%	2.2%	12.1%	8.3%	6.8%	4.3%	2.3%
Nonferrous metals...............	1.9%	2.7%	1.8%	1.2%	1.6%	14.9%	15.8%	10.1%	4.7%	3.8%
Fabricated metal products.......	1.0%	1.4%	1.2%	1.1%	1.2%	12.2%	9.0%	5.7%	4.7%	3.3%
Nonelectrical machinery.........	17.6%	13.4%	11.8%	9.9%	9.8%	30.9%	14.1%	13.8%	9.8%	6.7%
Electrical machinery............	18.6%	14.8%	13.1%	10.7%	11.8%	25.1%	14.3%	9.3%	7.7%	4.9%
Electronic equipment & components..................	12.9%	10.7%	11.9%	21.4%	23.5%	12.9%	6.9%	7.2%	7.5%	4.5%
Motor vehicles..................	3.3%	3.8%	4.3%	5.6%	4.4%	4.7%	3.2%	2.5%	2.8%	1.3%
Other transport equipment.......	7.3%	13.5%	17.9%	14.5%	14.6%	47.4%	36.0%	47.4%	39.4%	25.3%
Instruments.....................	1.8%	2.0%	2.2%	1.3%	1.6%	11.4%	8.8%	5.9%	2.6%	2.1%
Other manufacturing.............	0.8%	2.3%	2.2%	2.9%	1.8%	7.2%	9.2%	7.8%	9.3%	3.0%

1/ Payments of royalties and fees for licenses and equipment for which there is "embodied" technology.

Source: Government of Japan (1989)

vehicles, instruments, rubber, and fabricated metals,[9] with the exception of the other transportation industry, and to a lesser extent the chemicals industry, no industry that has received major government R&D attention has failed to become an international market presence.

However, it may be that rather than "causing" competitiveness, the government is responding to industrial commercial strengths: government R&D funds are a fraction of total manufacturing R&D. With the exception of the "other transportation" industry, for which government-funded R&D accounts for about one-fourth of the industry's total R&D expenditures, government R&D contributions represent--on average--less that 2% of manufacturing R&D (table 7.7).[10] Even in electronics, for which MITI has been a major funder of R&D since 1966, government funds are the equivalent of only 1-2% of total research and development in the industry.[11]

This conjecture is reinforced by a very interesting association between government R&D funding and trends in the industrial R&D-to-sales ratios. With the exception of the machinery industries, increases in an industry's share of government R&D funding coincide with periods of large increases in it's R&D-to-sales ratios. While government's share of R&D funding also increased during these periods, the increases and shares generally appear to be too low to account for the overall improvement in the R&D intensity of the industry.[12] This relationship suggests that government funds act as supplements to--not directives of--industrial goals. Such a conclusion is consistent with many of the case studies and qualitative analyses of Japanese industrial policy (e.g., Okimoto, 1988), which argue that the government is far more

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[9] The steel industry has in fact received a fair amount of government R&D funds, but after the industry had already established itself as a world-class competitor (e.g. after 1978).

[10]This is in dramatic contrast to the United States, where government funding constitutes one-third of total manufacturing R&D. Estimates of indirect Japanese R&D assistance--through tax credits and concessional loans--indicate that total Japanese government support would still only represent 4% of total industrial R&D (Goto, 1988).

[11]Note that Nippon Telephone and Telegraph (NTT) has been a major performer of telecommunications and electronics R&D. R&D data for NTT are reported under "special corporations" in the Japanese government R&D data, since NTT was technically a state enterprise prior to its privatization.

[12] These relationships will be explored more fully in the future using regression analysis.

responsive to specific industrial needs rather than determining industrial goals. Government funds thus appear to either leverage or catalyze the R&D programs of the private sector.

Imports of foreign technology by Japanese manufacturing industries have been equally concentrated among a handful of industries, but these imports represent a far more important supplement to the technological base of the manufacturing sector than government R&D transfers.[13] Imports of foreign technology by the Japanese chemical, nonelectrical machinery, electrical machinery, electronics, and other transportation equipment industries have consistently accounted for two-thirds to three-fourths of total such imports by the manufacturing sector (table 7.8). As with government R&D transfers, the other transportation sector and electronics industries account for the largest shares of total imports.

Relative to manufacturing R&D expenditures, technology imports represented a significant addition to the technical resource base of Japanese manufacturing industries. From 1971 to about 1973, imports of foreign technology were the equivalent of nearly 20% of manufacturing R&D, and from 1974-79 about 10% (table 7.8). The yen value of R&D imports dropped sharply between 1973 and 1974, increased slowly until 1981, and has since stabilized at about 28 billion yen (approximately $131 million). In order, the food, drugs, electronics, nonferrous metals, and other transportation industries have been the "heaviest" importers of new technology; their rate of importation has been far more rapid than the rest of the manufacturing sector.[14]

As in the previous analyses, data on imports of foreign technology do not inform us as to the competitiveness of Japanese industries relative to the United States. Competitive and non-competitive industries alike account for the largest shares of technology imports, while competitive industries also represent the range of high to low ratios of imports to indigenous

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[13]The data discussed here for imports of technology include payments of royalties and fees for patent and know-how licenses as well as imports of production equipment and facilities which embody technology, e.g., "turn-key" plants.

[14]Note that both the R&D data *and* the technology transfer data (see footnote 13) do not capture reverse engineering. Engineering and design-related activities are not considered to be R&D, and technology transfer payments represent actually commercial transactions. As a consequence, reverse engineering is a statistically invisible form of technology transfer and innovation.

R&D.[15] Moreover, both competitive and non-competitive industries represent the most rapidly importing industries, and industries from all six of the japanese R&D performers/competitive types may be considered aggressive technology importers. There are no readily apparent associations in the patterns of technology imports with those of R&D spending.

In a final attempt to relate R&D to competitiveness, the patent data for the United States and Japan will be compared to assess both the relative "quality" of their R&D efforts and trends in their inventiveness. While there are limitations to patent data as well, when analyzed in conjunction with R&D they can serve as useful indicators of the productivity and quality of an industry's research effort.

U.S. and Japanese Patenting Activity

The most frequently remarked upon trend in the U.S. patent system is "the steady relentless rise in Japanese share from less than nine percent in 1975 to almost 19% by 1986" (Narin and Olivastro, 1988). In comparison, the U.S. share declined from almost two-thirds in 1975 to about half in 1986 (Papadakis, 1989). However, as seen in table 7.9, this rise in the number of Japanese patents granted in the U.S. patent system stems most directly from the increase in Japan's R&D and economic growth; over the 1975-85 period the R&D productivity of Japanese industry remain almost absolutely constant. That is, for every $10 million (real) of R&D expenditure, the Japanese received approximately seven patents (table 7.9). There has been a pronounced downward trend in this productivity since 1982, although the decline does not appear to be substantial except for the chemicals, drugs, steel, and nonferrous metals industries.

In contrast, the patent productivity of U.S. R&D declined by just over 50% during 1975-85, from 15 patents per $10 million to seven. Although many industrialists claim that this declining productivity is not a serious concern, principally because of a growing irrelevance of the patent system for the intellectual property protection of high tech goods, one would presume that the same disincentives would apply to the Japanese as well. Thus, these variations

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[15]Note that the net balance of technology transfer flows, or trends in technology exports, may be able to distinguish between competitive and non-competitive Japanese industries. The data are being explored further. However, the intent here is to evaluate whether or not technology imports act as a supplement (or substitute) to R&D as a determinant of competitiveness.

Table 7.9--Patent productivity of Japanese R&D 1/

Industry	Patents per $10 million of R&D				Net change in productivity			
	1975	1978	1982	1985	1975-85	1975-78	1978-82	1982-85
Total Manufacturing 2/..........	7	7	7	6	-13.6%	7.4%	-4.8%	-15.4%
Food, drink, and tobacco........	1	2	1	1	-9.8%	30.6%	-46.8%	29.8%
Textiles, footwear, & leather...	4	5	4	4	1.7%	25.5%	-30.4%	16.5%
Chemicals and allied products...	6	6	5	4	-34.7%	-3.9%	-17.1%	-18.0%
Industrial chemicals..........	8	9	7	6	-29.4%	7.0%	-22.7%	-14.7%
Drugs and medicines...........	2	2	2	2	-35.9%	0.3%	-10.6%	-28.5%
Other chemicals...............	10	9	8	7	-30.3%	-11.2%	-5.1%	-17.3%
Petroleum refining..............	2	2	3	2	-19.3%	12.7%	17.3%	-39.0%
Rubber & plastic products.......	18	14	20	18	1.3%	-19.4%	39.0%	-9.6%
Stone, clay, & glass products...	4	5	5	4	0.7%	27.3%	-1.9%	-19.3%
Ferrous metals..................	1	1	1	1	-37.0%	-8.6%	17.7%	-41.5%
Nonferrous metals...............	4	3	3	2	-51.4%	-29.9%	-11.9%	-21.4%
Fabricated metal products.......	18	19	18	17	-3.7%	7.5%	-2.6%	-8.0%
Nonelectrical machinery.........	16	15	14	13	-18.4%	-2.4%	-6.8%	-10.3%
Electrical machinery............	5	5	6	4	-5.8%	3.4%	19.3%	-23.6%
Electronic equipment & components....................	8	10	8	6	-23.2%	24.2%	-19.3%	-23.4%
Motor vehicles..................	2	2	3	2	20.8%	-9.6%	40.5%	-5.0%
Other transport equipment.......	10	6	10	8	-12.9%	-39.8%	70.4%	-15.1%
Instruments.....................	55	66	60	44	-21.5%	19.8%	-9.9%	-27.3%

1/ Patents obtained in the U.S. patent system per constant 1982 $10 million of R&D expenditures.
2/ Sum of industries listed only. It was not possible to obtain patent data at the appropriate SIC level for all other industries.

Table 7.10--Patent productivity of Japanese R&D indexed to that of the U.S. 1/

Industry	Index 1975	Index 1978	Index 1982	Index 1985	Net change in index 1975-85	Net change in index 1975-78	Net change in index 1978-82	Net change in index 1982-85
Total Manufacturing 2/..........	0.45	0.60	0.79	0.81	81.4%	32.8%	32.9%	2.8%
Food, drink, and tobacco........	0.17	0.26	0.23	0.32	85.4%	49.9%	-13.4%	42.9%
Textiles, footwear, & leather...	0.19	0.25	0.20	0.25	33.1%	35.2%	-21.1%	24.8%
Chemicals and allied products...	0.41	0.46	0.53	0.58	42.6%	12.7%	16.0%	9.2%
Industrial chemicals..........	0.41	0.51	0.59	0.66	58.5%	23.5%	15.4%	11.3%
Drugs and medicines...........	0.57	0.66	0.69	0.65	14.5%	15.9%	4.9%	-5.8%
Other chemicals...............	0.22	0.23	0.29	0.32	41.6%	3.2%	25.3%	9.5%
Petroleum refining.............	0.42	0.42	0.84	0.54	29.2%	1.7%	98.1%	-35.8%
Rubber & plastic products.......	0.53	0.45	0.83	0.78	47.3%	-14.8%	83.6%	-5.8%
Stone, clay, & glass products...	0.19	0.24	0.27	0.26	39.5%	27.9%	14.5%	-4.7%
Ferrous metals.................	0.22	0.23	0.39	0.23	4.5%	5.9%	72.0%	-42.6%
Nonferrous metals..............	0.69	0.53	0.43	0.47	-31.2%	-23.1%	-18.9%	10.3%
Fabricated metal products.......	0.23	0.24	0.30	0.29	29.0%	4.5%	29.2%	-4.4%
Nonelectrical machinery.........	0.29	0.36	0.50	0.40	40.1%	26.7%	37.6%	-19.6%
Electrical machinery............	0.29	0.32	0.48	0.40	36.4%	9.0%	51.2%	-17.2%
Electronic equipment & components....................	0.83	1.28	1.36	1.52	83.0%	54.2%	5.9%	12.0%
Motor vehicles.................	0.79	1.12	2.01	2.40	204.3%	42.8%	78.9%	19.1%
Other transport equipment.......	2.09	1.72	5.38	4.40	110.2%	-17.8%	212.6%	-18.2%
Instruments.....................	2.01	3.42	4.39	3.82	89.8%	69.8%	28.4%	-12.9%

1/ Patents obtained in the U.S. patent system per constant 1982 $10 million of R&D expenditures.
2/ Sum of industries listed only. It was not possible to obtain patent data at the appropriate SIC level for all other industries.

Table 7.11--Japanese patents as a percentage of U.S. 1/

Industry	Ratio, in percent				Net change in ratio			
	1975	1978	1982	1985	1975-85	1975-78	1978-82	1982-85
Total Manufacturing............	15.1%	19.9%	32.5%	40.6%	168.4%	31.5%	63.2%	25.0%
Food, drink, and tobacco........	9.4%	15.6%	14.1%	20.3%	117.2%	67.2%	-9.6%	43.7%
Textiles, footwear, & leather...	21.4%	25.9%	34.7%	45.7%	113.5%	20.9%	34.0%	31.8%
Chemicals and Allied Prod	17.5%	19.4%	24.6%	25.2%	66.6%	11.0%	26.8%	18.4%
Industrial chems	18.0%	19.5%	23.6%	30.9%	71.4%	8.0%	20.6%	31.3%
Drugs & Medicine	18.7%	23.3%	28.1%	28.1%	50.5%	24.8%	20.4%	0.2%
Other chems	15.6%	17.4%	24.6%	25.8%	65.4%	11.5%	41.5%	4.8%
Petroleum refining.............	3.5%	3.8%	7.7%	7.9%	122.5%	8.0%	102.5%	1.7%
Rubber & plastic products.......	16.3%	17.6%	29.1%	35.0%	115.0%	8.0%	65.9%	20.0%
Stone, clay, & glass products...	12.3%	18.6%	26.1%	42.1%	240.9%	50.6%	40.3%	61.4%
Ferrous metals..................	30.3%	31.0%	69.1%	66.7%	119.9%	2.2%	123.0%	-3.5%
Nonferrous metals...............	28.2%	27.5%	45.6%	55.4%	96.5%	-2.6%	65.6%	21.6%
Fabricated metal products.......	7.4%	9.2%	16.2%	23.0%	209.6%	24.1%	76.2%	41.6%
Nonelectrical machinery.........	11.6%	14.8%	25.2%	31.4%	171.2%	27.8%	76.9%	20.0%
Office & computing machines.....	19.2%	30.1%	56.0%	91.8%	377.2%	56.3%	92.8%	58.3%
Electrical machinery............	14.4%	20.8%	35.0%	43.2%	200.5%	44.6%	68.4%	23.4%
Electronic equipment & components....................	18.8%	27.4%	44.0%	55.5%	194.6%	45.1%	60.9%	26.2%
Motor vehicles..................	18.6%	26.7%	73.0%	95.9%	414.6%	43.3%	173.4%	31.3%
Aerospace.......................	20.6%	32.7%	57.5%	70.6%	242.5%	58.4%	76.1%	22.7%
Other transport equipment.......	13.1%	15.3%	32.8%	32.2%	145.2%	16.6%	113.9%	-1.9%
Instruments.....................	21.4%	31.0%	42.2%	50.9%	138.2%	44.9%	36.3%	20.6%

1/ Patents granted in the U.S. patent system.

in patent productivity could be due to 1) a real decline in the inventive output of U.S. R&D, or 2) the decreasing utility of patents generally but a greater propensity on the part of the Japanese to obtain patents anyway. This higher propensity by Japan to obtain U.S. patents could in turn result from the fact that they are patenting in industries where patents are still a significant form of protection or in industries where, because of their growing market presence, they have a greater need to ensure maximum intellectual property protection.

The patent data do not shed much light on this question. Indexes of the patent productivity of Japanese R&D relative to the United States show differentials in the two countries' productivity to be somewhat below average for all but five of Japan's industries--rubber, electronics, motor vehicles, other transportation and instruments (table 7.10). In all of these industries, the rate of Japanese patent productivity nearly doubled or more from 1975 to 1984-85; this extraordinary improvement in inventiveness may help explain why at least motor vehicles, instruments, and electronics are competitive in spite of their generally inferior R&D performance.

In addition to this high rate of productivity, a study by Narin and Olivastro shows that Japanese automotive, semiconductor, and photocopying and photography patents during 1975-84 have had some of the greatest technological impact (1988, p. 145).[16] Their analysis of U.S. patent citations--references by patent examiners to the "prior art" of a new patent--indicate that these Japanese patents are the most highly cited in the entire U.S. patent system, and the authors conclude, "The implication of this is that the Japanese position in patented technology is strong, growing steadily, and based on high quality, high impact technology" (1988, p. 5). Even more specifically, highly-cited patents represent breakthrough technologies which in turn stimulate future rounds of inventive activity.

Nevertheless, it is still difficult to find a systematic relationship between patenting trends and competitiveness, both in terms of the volume of patenting activity and time periods of greatest relative inventiveness. Table 7.11 presents the numbers of Japanese patents in the U.S. system expressed as a percentage of U.S. patents. As can be seen, there was a doubling--even tripling--in the number of Japanese patents relative to the U.S. during 1978-82 for most manufacturing industries. Because so much of the improvement in individual Japanese

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[16]Note that photography is appropriate to the instruments industry, while photocopying relates to office and computing machinery (part of the electronics industry for the R&D data).

industries' patent activity is coincident with the onset of competitiveness, it is quite possible that the patenting rate is a function of the greater need for intellectual property protection that goes with a greater market presence. The causation mechanism is therefore not clear; the rates of Japanese patenting may be driven more by market necessity than any substantial changes in inventiveness.

In the case of motor vehicles, instruments, semiconductors, and photo technologies, the patent citation research suggests that the leading edge quality of these industries' inventions is what is driving their competitive stature. However, in spite of the fact that Japanese pharmaceuticals patents are also among the most highly cited, and this industry has an R&D performance profile comparable to that of electronics and instruments, it is not, however, a major U.S. competitor. One characteristic which does distinguish the drug industry from instruments and electronics is its relatively low number of patents compared to the U.S.: in 1985, Japanese drug patents were the equivalent of 28% of those of the U.S., while the number of patents for office and computing machines, electronics, and instruments were equivalent to one-half or more of the U.S.-owned patents. Thus, while the pharmaceuticals patents are of relatively high quality, the inventions which they represent may be of insufficient "critical masss" to create a highly competitive, international industry.[17]

In sum, one may conclude from the patent data that for the motor vehicles, instruments, and electronics industries, R&D and technology may have played a substantial role in their competitiveness. For the remaining manufacturing industries, the patent data are as inconclusive as R&D data for linking science and technology to an industry's competitive position. For example, the patenting trends of the non-competitive textile, stone and glass, chemicals, and nonferrous metals industries are not appreciably different than those for the more competitive nonelectrical machinery, rubber, or fabricated metals industries.

Nevertheless, the most competitive Japanese industries do seem to have a much high number of patents relative to the United States than the non-competitive ones; the principal difficulty is determining whether this is a cause of, or response to, competitiveness. Since

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[17]As mentioned in previous chapters, it is also possible that the industrial structure of the pharmaceuticals industry prevents intensive international competition along a wide range of pharmaceuticals. Global competition is thus concentrated in particular drug "niches", and doesn't show up as an erosion of competitive strength, but rather as balanced inter-industry comparative advantage.

patents do reflect some minimum standard of technical novelty, it is reasonable to assume that the products of competitive Japanese industries do embody technology that is somehow different from thath in the United States. Nonetheless, since competitive advantage can derive from factors other than technological novelty (e.g., lower cost, better quality control), more detailed study is necessary to determine the direct linkages between patent activity and competitiveness.

Industrial R&D and Competitiveness

This analysis of industrial R&D and patenting data demonstrated that we cannot predict the competitive performance of Japanese and U.S. industries on the basis of their relative trends in R&D expenditures and patenting activity. In fact, it is probably safe to say that there is a total absence of any sort of systematic relationship between these data, with the R&D figures quite incapable of distinguishing competitive industries from non-competitive ones. Not only are Japanese industries with identical R&D profiles equally split between competitive and non-competitive status, but some industries with absolutely inferior (or ambiguous) R&D efforts relative to the U.S. are highly competitive. The patent data do, however, indicate that the productivity and quality of Japanese motor vehicles, instruments, and electronics R&D may be quite superior to the U.S. This suggests that the much lower level of R&D expenditure by these industries is, "dollar for dollar" far more effective than the comparable expenditures of the United States.

An understanding of the two countries basic research efforts does help us discriminate competitive from non-competitive industries. To the extent that such a large proportion of Japanese basic research is performed in the industrial sector, one would expect that it would have a somewhat powerful effect in terms of distinguishing competitive industries from non-competitive ones. In fact, the volume of Japan's basic research expenditures (and expenditures as a percentage of sales) in autos, steel, electrical and non-electrical machinery has been greater than such expenditures in the United States since at least 1975; this pattern, when combined with the indications of the technical quality and volume of Japan's patents in instruments and electronics, can essentially account for all of Japan's competitive industries vis-avis the United States. Thus, while the aggregate R&D data are not terribly effective in discriminating the competitive status of Japan's industries (or vice-versa, that of the U.S.), the basic research data combined with the qualitative dimensions of the patent data do seem to do so.

Observing these coincidences is not, however, the same thing as explaining their causal relationship. To confound the issue somewhat, a recent study by Jorgenson and Kuroda[18] on Japanese and U.S. productivity during 1960-85 find clear patterns of industrial productivity advantages for both Japan and the U.S. A sorting of the industries studied into two groups--one for Japanese industries which have higher levels of productivity than the U.S., and one for U.S. industries which have higher levels of productivity than Japan--essentially mirrors the list of competitive and non-competitive Japanese industries presented in figure 7-1.

Jorgenson and Kuroda found that the United States has had a clear and continuing productivity advantage in the food, textile and apparel, printing, rubber, fabricated metal, and stone and glass industries, while Japan has had a significant advantage in the motor vehicles, chemicals, primary metals, electrical and non-electrical machinery, and instruments industries. Moreover, for those industries in which each country had higher levels of productivity, they have also had a relative price advantage. That is, industry by industry, prices were lower in the country with the productivity advantage.

One could make the rather reasonable (and obvious) assumption that higher rates of productivity lead to lower prices, which in turn lead to enhanced market competitiveness. Significantly, the patterns of R&D expenditure also (obviously) fail to distinguish the relative *productivity* of Japanese and U.S. industries, since their productivity advantages also coincide with their competitive status. Since R&D is frequently alleged to have a more immediate impact on productivity than other economic performance indicators, this is an important finding. Econometric studies have consistently found comparable productivity rates of return for both Japanese and U.S. R&D expenditures (Griliches and Mairesse, 1985; Mohnen, et al., 1986; Suzuki, 1985; Odagiri and Iwata, 1986; Goto and Suzuki, 1989), payoffs which are frequently interpreted as a validation of the relationship between R&D and competitiveness.

We are thus left with an interesting puzzle. The competitive status of U.S. and Japanese industries seems to be most closely associated with productivity indicators, but neither productivity or competitiveness may be systematically associated with patterns of R&D and patenting. The preponderance of basic research expenditures in the motor vehicles, electrical

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[18]Dale W. Jorgenson (Harvard University) and Masahiro Kuroda (Keio University), "Productivity and International Competitiveness in Japan and the United States, 1960-85," paper prepared for the Social Science Research Council Conference on International Productivity and Competitiveness, Stanford University, Oct. 28-30, 1988.

machinery, and steel industries may be a helpful clue, but other Japanese industries (most notably textiles) also have extraordinarily high volumes of basic research expenditures relative to the U.S., but have neither productivity or competitive advantages. Additionally, econometric studies have failed to turn up any association between Japanese basic research and productivity (Mansfield, 1978; Goto and Wakasugi, 1988), unlike the case for the United States.

The apparent high quality of R&D in the Japanese instruments and electronics industries is similarly perplexing. Not only has it been received wisdom that Japan has not been, and cannot do, basic research, but chapter 5 revealed that Japan does seem to have a rather impressive record of publications in the scientific fields of relevance to these two industries—in spite of their relatively low level of investments in R&D compared with the United States. Additionally, its patent record in these industries is superior to that of the U.S., again in spite of far fewer expenditures on R&D. The innovative effectiveness of Japan's R&D expenditures in these industries (as well as the accuracy of the data) therefore requires more exploration, as does the economic competitiveness which coincides with it.

Part IV
Bringing Science to Market

The myths of human "progress" have been killed by the progress of science itself; the "scientistic illusion" regards technology as a substitute for social and political choices.

Jean-Jacques Salomon, *Science and Politics*

CHAPTER 8

Bringing Science to Market Through Public Policy

The competitiveness crisis and its associated policies represent a significant departure for the United States. For the first time in U.S. history, science policy was used proactively for *economic* purposes. Unlike space, health, energy, and defense, economic welfare does not enjoy mission-related R&D. The federal custodians of American commerce--the Departments of Treasury and Commerce, the International and Federal Trade Commissions--have no R&D laboratories to foster and promote private enterprise. The rather singular exception is the National Institute of Science and Technology (the old Bureau of Standards), an agency that has performed yeoman service in the formulation of standards and which is now charged with supporting research in manufacturing technologies. But as is often the case with new initiatives, adequate funding has not been forthcoming.

Although mission-related R&D policy is included under the rubric of science policy, *policies for science* form the core of this arena. Our government's involvement in the scientific establishment was predicated on the assumption that a nation's power could be enhanced and radically improved through concerted scientific action. As Salomon observed about science and government, "seen from its cultural aspect aas an end in itself, pure science has no greater claim to state support than any other cultural activity; it must have the backing of national goals before it becomes a collective adventure" (1973, p. 66). Historical events from World War I through and including World War II certainly demonstrated the reasonableness of state interest in science, and provided the national goals to mandate state support.

But it took clever political manipulation to turn popular understandings of science into a myth of scientific munificence, an establishment whose gifts could be bestowed only when science was left to its own devices. The painful need of the scientific community for stable and reasonable levels of research funding was wedded to new national expectations about the power of science. In the process of securing federal money Vannevar Bush also secured federal abstinence: by advancing a model of science as fountainhead, Bush both overpromised the role of science and guaranteed that its sociology would remain insulated from direct federal management.

In the stroke of a pen, government lost the capacity for strategic control over science, the very control which had so rewarded the country during World War II and which was the catalytic force behind the creation of a science policy arena. The "pretext" of scientific utility (to borrow D'Alembert's words) was exploited to a level in which scientific knowledge generated by the purity of curiosity was regarded as intrinsically more valuable than any other kind.

The price our country may be paying for this fantasy is considerable. Not only are we constrained by false fears about directed science, but it has mutated in the political arena to the point that science and technology have become substitutes for social and political choices. Schmandt thus echoes Salomon's concern by noting that "a strategy of technological fixes has been advanced on the grounds that technological solutions to social problems are often easier to effect than political or economic solutions" (1975, p. 198). At a time when there is a demonstrable need for revisionist approaches to science and technology, the nation is burdened by a policy heuristic which cannot be adequately diagnostic and which absolves the political system of its responsibilities.

The conclusions to follow all revolve around a central theme: that the U.S. science policy legacy has left us with a critical void in our science and technology system. By virtue of both *laissez-fairism* and the science policy paradigm, the government has developed neither the mandate nor institutional infrastructure to direct science and technology for economic gain. There is no mission system for economic R&D, and in many ways the competitiveness policies of the past decade represent efforts to create national mechanisms for sponsoring commercially useful science and technology. But because the appropriate infrastructure is lacking, economic mandates threaten to undermine the strength of our science base, and defense-sponsored technology policies threaten to distort civilian needs.

Overview of the Findings

Before the policy implications of this research are fully explored, it is useful to highlight the key questions, conjectures, and findings. I began this dissertation with concerns over the likely effectiveness and impacts of U.S. competitiveness policies. The theme and content of these policies are concertedly supply-of-science in nature, in spite of ample evidence that the crisis may not have been of a scientific or technical nature. Recent theory and research in the policy analysis literature suggest that the fundamental determinants of effective public policy may not be at the implementation stage--where it has traditionally been thought to be--but at the design stages, where policy ideation and formulation take place. The counterfactual nature of policy is thus of considerable concern, since it may reflect the "wrong" solutions at the outset.

It is argued here that science policy is guided by a funding paradigm which powerfully influences the way social and economic problems are diagnosed. A certain logical reductionism to the paradigm provides a core set of "ideas" about the role of the *supply* of science in national welfare. These ideas interacted with the political "interests" of science policy to create a policymaking environment overwhelmingly sympathetic to science as the cure to competitive ills. We can label the resultant policies as *laissez-faire technoscience,* since they are by and large void of research content and direction. If we can envision science and technology as a marketplace of knowledge generation, then these policies act as the equivalent of generic, macroeconomic stimulants of production. Basic research, relaxation of anti-trust, tax credits, technology transfer--these are all supply-sided policies in the best macroeconomic tradition. The notable exception to *laissez faire technoscience* are the technology-specific engineering research centers of the NSF.

Significantly enough, once outside the realm of "pure science," policies become appreciably more strategic in nature. Almost without exception, attempts at technology policy have reflected efforts to provide R&D support to specific industries and technologies. Such policies typically resulted from intense industrial lobbying for protection. Since there is no institutional home for commercially-specific R&D, the Department of Defense has become the shelter for semiconductor, HDTV, and manufacturing R&D. It is not clear to what extent defense-related priorities will affect the research agenda for these technologies. In any event, we can characterize industry- and technology-specific R&D policies as *strategic technoscience,* for they attempt to target specific needs and research items. Even so, these strategic policies are still very much at the "supply" end of the R&D spectrum, concentrating by and large on precommercial research.

The *strategic technoscience* approach is far from systematic, however. Competing industrial interests have created more of a pork barrel approach to technology policy than any more rigorously pluralistic process of agenda setting. This is not an area of policymaking where there is a routinized body of actors and interests and an identifiable corpus of resources. Institutionalized programs for commercial R&D do not exist; there is no government formula (even loosely defined) for determining the "best" areas of such investments. Indeed, integral to our economic *laissez-faire* tradition is an aversion to "picking the winners." To do so would favor one industry over another, and thus violate a cardinal principle of economic policy. We decided long ago that markets were the best arbiters of technological investment, since market failure allegedly occurs only at the level of science.

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The nation has hence evolved a set of competitiveness policies which are largely *laissez-faire technoscience* in nature. *Strategic technoscience* in a formalistic sense is absent; ad hoc *strategic technoscience* is present, but limited, unsystematic, and highly unstable. To what extent are these policies likely to be effective in redressing the competitiveness crisis?

First, we have to consider the nature of the crisis itself. Prior to this study, our understanding of the crisis was somewhat confused. Appropriate, multi-dimensional indicators of competitiveness were absent; our knowledge about the crisis--its character and causes--was formulated from measures of the determinants of competitiveness (e.g., productivity, R&D) and its consequences (e.g., trade, growth). The fact that each of these phenomena have their own independent set of dynamics confounded the trends and illuminated numerous paradox in our conventional explanation of crisis. So much so that a few prominent scholars argued there was no crisis at all.

The analysis here detected three discrete patterns of non-competitiveness: a systematic decline in the balance of trade due to the economic recovery and aggravated by faulty exchange rates, a heavy concentration of the trade decline (and rising import penetration) in the durable goods industries, and acute non-competitiveness in a half-dozen industries. As discussed in earlier chapters, the first two patterns are largely attributable to macroeconomic problems. R&D is an irrelevant remedy in instances of exchange rate distortion, premature business cycle contraction, and expensive capital. Price sensitive industries are almost surely doomed in their short-term competitive abilities under such circumstances. Based on the data trends from chapter 5, it seems that these macroeconomic difficulties accounted for at least one-third of the trade deficit over 1982-86/87.

What is of greater concern however, is the long-term debilitating effects of extrinsically-induced non-competitiveness. The loss of markets and profits that result from cyclic contraction are perpetuated by the inability to invest (and modernize) and by international price distortions. In quick succession, the external environment created a series of market stresses in the 1970s, then essentially denied the private sector the ability to regroup during the recessions of 1978-82 and rebound with the recovery in 1983. At no time was American commerce presented with the necessary opportunities and inducements to break the downward spiral of its competitive strength. The capital investments needed for appropriate "reindustrialization" could not be generated internally during the recessions and were not "externally" possible given the interest rates of the late 1970s and early 1980s. By the time of the recovery--when profits should have normally resumed and competitive adjustment proceeded--exchange rate factors conspired to further deny requisite sales and profits. The American durable goods industries have been faced with nearly a decade of counterproductive macroeconomic policies, which can only act to weaken future competitive strength.

But as indicated, a handful of industries were really driving the crisis, and moreover, it was essentially bilateral in nature. Competitive decline vis-a-vis Japan in autos, electronics, office and computing machines, instruments, and electrical and nonelectrical machinery account for the substantial majority of the decline in the U.S. trade position and the growing foreign market share in the United States. High tech was of little salvation. Although running a minute net surplus, key high tech sectors with comparative advantage in trade were largely uncompetitive on balance and in market share. The high-end niches filled by U.S. electronics, office and computing machines, instruments, and electrical machinery are simply not big enough to offset the vast consumer and industrial markets for high quality, mass produced merchandise.

To what extent can we explain U.S. and Japanese competitive strengths and weaknesses on the basis of their efforts at scientific and technical innovation? The answer to this is a bit fuzzy, but a shape does suggest itself. In spite of the limitations of the data, it would appear that industrial R&D--the *proxy for* technical innovation--is poorly associated with patterns of competitive performance, and this is true even for the high tech industries. This in itself is not surprising given the discussion in chapter 4 on the contingencies of the innovation process. It would have been far more surprising to have uncovered clear patterns.

Where the findings are truly shocking--and ultimately liberating--is in the ability to predict competitive performance on the basis of *Japan's industrial expenditures on basic research and the quality of its inventiveness.* The analysis of basic research expenditures and scientific publications showed both countries to be highly active and productive in scientific research, but the fields of government and academic-performed basic research did not appear to be appreciably related to industrial competitive strengths. This is not to deny a connection, but only to point out that at the level of aggregation being studied, the research of these sectors seems commercially remote. (The exception to this is the concentration of Japanese basic research in engineering.) Differentials in the two countries efforts in industrial basic research do rather nicely explain their relative competitiveness. In the several years preceding the onset of their global strength, all of the competitive Japanese industries had equal (or vastly greater) basic research expenditures and basic research-to-net sales ratios compared to their U.S. counterparts. The marginal exceptions to this characteristic are the instruments and electronics industries; but these are the two industries for which there is some concern over the *understatement* of the Japanese data. If we supplement the basic research and publication data with the remarkably superior Japanese patent performance in electronics and instruments, then we have essentially accounted for patterns of U.S. and Japanese competitiveness.

What do these findings mean? On their face they certainly demand serious reconsideration of the way Japan has used science and technology for competitive advantage, and this will be addressed below. But can we interpret them as a ringing endorsement of U.S. competitiveness policies? After all, basic research and associated innovations are the cornerstone of U.S. policies, and here we have firm evidence of the role of basic research in competitiveness. Caution is advised in two regards. First, we have to realize that what these data are capturing is by and large *strategic* basic research; that is, research directed undoubtedly to the commercial use of new or advanced technology. Second, Japan rarely, if ever, has taken a *laissez-faire* approach to technology. To understand just what the implications of these findings are for U.S. policy we thus have to understand the context in which this research took place in Japan.

Japan: Getting Beyond Incrementalism

In spite of our messy understanding of the Japanese miracle, a certain consensus is emerging in the industrial political economy literature. An extremely condensed version of the new line of thinking is as follows. Japanese miraculous performance has not been evenly distributed throughout its manufacturing sector. Inter-industry comparisons have repeatedly shown Japan's industrial superexcellence to be in autos, consumer electronics, consumer precision instruments (watches and cameras), copying equipment, semiconductor memory and production, and industrial production equipment. This is the case in both productivity and international trade, and the additional competitiveness data developed and analyzed here reinforce these conclusions. Moreover, Jorgenson and Kuroda's U.S. and Japanese productivity study show this superexcellence to hold not just within Japan, but between Japan and the United States as well.

These industries are characterized by mass-produced goods of inordinate quality and highly integrated sequential production processes. As Stowsky observes:

> In relatively simple assembly industries such as clothing and textiles, Japanese productivity growth has been comparable to U.S. rates; this is also true in highly capital-intensive process industries such as chemicals and paper and in areas such as petroleum refining and petrochemicals where most producers have already achieved continuous flow operation. (Stowksy, 1989, ch. 3)

As was revealed by the R&D data, Japan's R&D advantage (or parity) in several of these industries (notably textiles and chemicals) was to naught in terms of productivity and competitive advantage. In short, Japan's productivity and competitive advantage is derivative of a mastery of a particular form of manufacturing, not from forces common to the entire manufacturing sector.

Explaining Japan's strength in these particular industries has evolved over time, and now rests upon a 3-factor model in which government, the social organization of production, and imitative (or incremental) technical innovation play decisive roles. The state has figured monolithically in many traditional explanations of Japan's political economy, and to be sure there has been explicit targeting, protection, and direct assistant for several industries. But what has now emerged is a more sophisticated appreciation of what national guidance is all about. In most cases, especially in the technology-intensive industries, the government devised a set of policies designed to maximize the diffusion of foreign technology and intensify domestic competition. For a variety of reasons not entirely clear--but which probably lie in the history of Japanese economic thought--the Japanese government developed a set of macroeconomic tools concerned with long term efficiency and growth.

Unlike neoclassical approaches to macroeconomic welfare, Japanese political economy does not presume that static efficiencies will lead inexorably to long term maximized welfare. Policymakers have been far more sensitive to both the externalities and endogenous market imperfections which can disrupt and weaken the growth dynamic. Capital formation and technology diffusion have hence became central features of macroeconomic management. During the initial stages of industrial reconstruction, importations of foreign technology were carefully regulated, and the Japanese patent system (modelled after Germany's) was designed to be a weak intellectual property regime. Moreover, MITI established a system of collaborative pre-commercial industrial R&D as part of the technology importation and adaptation process. The widespread sharing and diffusion of technology that resulted ensured rapid technological catch up with the West; capital formation assured the necessary investments in plant and equipment.

To accelerate reconstruction, Japan thus developed a system designed to enhance the diffusion of technology in the manufacturing sector. This system left an important legacy in terms of economic development, because it institutionalized a peculiar sort of growth dynamic. Technology advance became not a source of competitive advantage, but a shared base of minimum performance. The diffusion aspect of Japanese industrial policy formalized the dynamics through which new technology is systematically spread throughout industries to establish a guaranteed base of efficiency. Market aspects of industrial policy fostered either intensely vicious or carefully regulated competition to correct for the competition-suppressing effects of shared technology bases.

Foreign technology and the social organization of production figure prominently in this framework. The technology base upon which Japan built--and continues to build--is understood to be the advanced technology of the West. Japan's excellence emanates from imitation, and its ability to more effectively link the stages of production and product design.

Moreover, an elaborate network of suppliers, relational contracting, quality circles, worker rotation, *keiretsu* financiers, and management practices has enabled rapid incremental innovation and improvements on this technology. Precommercial or precompetitive (often foreign) technology is widely spread to uniformly advance the production art; incremental improvements are held closely within the firm and form the basis of inter-firm rivalry. Competition in the domestic setting derives from manufacturing quality, product variety, and relentless pressures to reduce production costs at the core and at the margins. Competition in the international setting derives from the extraordinary productivity advantages that this technology strategy generates. It is not surprising that Mansfield (1989) found that two-thirds of Japanese R&D is directed toward process, and not product, innovation.

The new political economy portrays industries using serial manufacturing technology as masters of production, mastery aided and amplified by artful environmental manipulation by the state. The image one gets is of cybernetic organization, a system in which mechanical and human constituents are fully integrated into loops of instantaneous organizational learning and adjustment. The organization's interface with its environment is buffered by complex corporate structures (*zaibatsu, keiretsu*), and the environment itself is carefully altered to induce the desired states of competitive and productive response.

Not to naysay, but this image is somewhat troubling. In the oversimplification presented here, we do lose the compelling and credible nature of these new accounts of Japan. They are far more satisfying than the old, and taken together give us a more accurate picture of the complexities and interactive nature of the Japanese system. But it highlights the considerable emphasis on production, market, and industrial structures in these revisionist treatments. Technology is imported from abroad, and carefully--but innovatively--repackaged and diffused for exploitation. The system of manufacturing incrementalism kicks in, and Japanese competitiveness advances to the next stage.

The data analyzed here absolutely support this understanding of the industrial concentration of Japan's competitive strengths. But what they also suggest is that Japan's innovativeness in these industries may be far more radical than presumed. In many ways, this makes more sense. Japan's prowess is far beyond what convention would hold, even allowing for auspicious incremental innovation and carefully leveraged, "radical" government-sponsored R&D. Although MITI orchestrated several "large scale" R&D projects in the 1970s directed toward generic technology, company-funded efforts toward the same surpassed state funding. If we want to place technology in a central role in economic performance yet cling to images of Japan as modest innovator, then we must be able to explain this nation's almost superhuman organizational and system capacities. While contemporary accounts are credible, they leave no margin for error.

An alternative explanation--one suggested by the industrial basic research, publication, and patent data analyzed here--is that significant technological innovation is taking place in Japan, and together with other dimensions of its political economy, serves as the roots of its competitive strengths in key industrial sectors. Far from successfully leveraging small amounts of R&D with foreign technology, it would appear that Japan is balancing considerable investments in strategic basic research with its longstanding abilities in engineering and incremental innovation. How close this research is to science remains to be seen, but as is explored below, it is also not the issue.

The United States: Getting Beyond *Laissez-faire*

The competitiveness policy problems for the United States are relatively simple to diagnose, but more complex in effecting change. Better traditional macroeconomic management is called for, or else some form of programs that can help industries weather the effects of recession better. This is not as simple as it seems, since it also requires that the private sector change the way it views competition. A special feature of the Japanese system is the ability of industrialists to recognize the duality of their competitive environment: sectors compete together against foreigners, but also rather intensely against each other. As indicated earlier, international competition derives from baseline structural commonalities in industry, and domestic competition from both process and product innovation.

Japan's system of "controlled competition" does provide insights into alternative macroeconomic tools. This is not to advocate a wholesale copying of Japan, but to illustrate that there are alternative ways of managing business cycles and stimulating long term growth at the same time. Japan has managed to put in place an industrial system that restructures itself on a fairly regular basis. Constant rejuvination of part of the industrial base is accompanied by intense competition and associated microeconomic rationalizations; structural adjustment is--in many respects--built in to the system.

With regard to science and technology, the United States has a *laissez-faire technoscience* system, but needs a *strategic technoscience* capacity. Because there is no provision for the systematic evaluation and funding of "mission-oriented" economic R&D in the U.S., the entire science base has been activated to respond to the crisis. The void in our system undoubtedly derived from the liberal tradition in America which insistently keeps government at arm's length from certain (but not all) kinds of business activity. There were vested interests on all sides to keep the government, university, and industry research systems relatively independent of one another. The science paradigm reinforced the political interests by creating parallel funding structures and promising the economic fecundity of science.

There is nothing particularly "wrong" about a *laissez-faire* science system, but it simply isn't designed to provide economically strategic science and technology. It is designed to generate free-flow science and technology and to compensate for market failures in "national interest" areas of basic research. It is important to note that with the singular exception of NASA, the Bureau of Standards, and some of the DOD labs, at no time were the government or university performers of basic research *expected to deliver strategic science,* strategic meaning the *a priori* identification of specific economic need and associated research requirements. We have a *laissez-faire* science system with the expectation that should a discovery or new knowledge be economically useful, the *laissez-faire* economic system will take advantage of it. We thus have a "free market" supply of knowledge, and a "free market" demand for that knowledge.

The architecture and rationale of federal involvement in science was based on the need to fund science. The political debate of the 1940s resolved for us the issue of whether or not government would, or could, manage the scientific enterprise. The answer was no, and by and large this was the right decision. Science should direct itself, and is a sufficiently cultural product that it is responsive to larger social dynamics. On this matter Frank Press was absolutely right. Our system has not failed us, it delivered exactly what we wanted it to and what it was designed to do. It is unfortunate that the rhetoric of paradigm promises far more than the capacity of science to deliver, because it does neglect the demand-side of the equation.

The only assumption to really take issue with is the presumption that unmanaged science is the only way to acquire economically useful technology. A careful examination of the U.S. competitiveness crisis reveals that the *intrinsic* crisis is principally of a particular bilateral nature; that is, with Japan and in industries of a specific manufacturing and industrial structure. The competitive advantage that these industries enjoy does not derive from pure, or curiosity-driven science, but from a concerted effort throughout the 1970s to create second and third generation manufacturing technologies. This was no mean feat, and the analysis here suggests the R&D devoted to this goal was far more fundamental and voluminous than suspected. It was also the result of careful coordination and consensus building among industry, government, and academia, and leveraged by the organizational and industrial structures in Japan. The basic research data reviewed in chapter 6 demonstrate that Japan has a small (but nevertheless high quality) *laissez-faire* science base. It also demonstrated that in Japan and the United States, this science base may not be particularly relevant to competitiveness the way it has been defined and explored here. What Japan has that we do not have is a strategic capacity.

Oddly enough, these words echo the wizard in *The Wizard of Oz*. But unlike the tin man, cowardly lion, and scarecrow, we do not already possess the virtues that we so desperately want. There is no wizard to give us symbolically what has been in our power all along. Science is not a substitute for the lack of political will to take more responsibility for our economic welfare. Nor is pork barrel *strategic technoscience* a substitute for the national coordination and commitment necessary to commercially exploit emerging technologies.

The Cathartic Powers of Crisis

To what likely effect, then, are our competitiveness policies? In the short term, none at all. In the long term, they are likely to effect long term change, some good, some bad, and in some cases our competitive position will not be altered. We have to consider recent policies in terms of their impact on the science base, competitiveness, *and* economic development. Economic development is added here because there has been a persistent confusion between competitiveness and long-term economic development in the policy rhetoric. The ability to prevail in existing markets is often substituted with market preparedness in emerging technologies.

As mentioned above, because a strategic technoscience infrastructure is missing in the U.S. R&D system, the entire system has been activitated to respond to the crisis. More money for basic research and calls for more technology transfer from public to private organizations carry with them subtle, but important, distorting effects. New funding criteria for research--whether or not it can contribute to competitiveness--and new mandates for labs detract from the very strengths of the American science base. The scope of our leadership in science continues to be unparalleled, and this science does pay off. A continued insistence on economic payoff and relevance as a *system* characteristic is unwarranted and likely to erode the strengths of our institutions charged with scientific research.

The unrelenting supply-sidedness of our approach to science, technology, and welfare clouds our capacity to see what strategic technoscience is about. A careful examination of the Japanese (and to lesser extent, West German) approaches to strategic technoscience shows that there are two particular forms. The identification of economic needs and the establishment of research agendas designed to meet the needs is one. A good example of this is Japan's generic manufacturing technology efforts. Manufacturing needs of the future are envisioned, gaps in the knowledge base identified, technical problems explored, and a research agenda set and pursued. The other form is "opportunity scanning," in which new discoveries or emerging technologies are identified, their commercial potential evaluated, and a reseach program designed to bring these opportunities to market developed.

Both cases involve fundamental research (these are not simple matters of application), consensus between government and industry, government R&D and capital investment support, and a careful division of research labor, coordination, and sharing of results. Moreover, they are not a matter of agitating the entire science base. In the first instance, there are specific technoscience "pressure points". In the second, the science base generates a set of opportunities that are then separately pursued (typically in special programs and dedicated research facilities) for commercial purposes. The state isn't necessarily involved in these endeavors, and in Japan, research consortia dealing with relatively less complex technical challenges are a way of life.

This suggests that it is not necessary for the United States to appreciably change the nature of its research system, but begin building in mechanisms for true strategic technoscience coordination, and develop an institutional niche within the system that can deal deal with technoscience research needs. Given the nature of our political system it is unlikely that this will happen in any formalistic way. Change may nonetheless already been taking hold because of the cathartic effects of the crisis itself. The tenor of the science and technology rhetoric did serve to refocus attention on the critical role of science and technology in economic performance and identify critical weaknesses in our system, namely in education and research in manufacturing technologies.

A number of coordinating networks are now developing, largely through the incessant task forces of the decade, but also through institutionalized committees of the National Academies of Science and Engineering. Anti-trust revision has paved the way for industry research consortia, and there are a tremendous number of these now registered with the Department of Commerce. Business has taken a new view toward technology-based competition strategies, and both NIST and NSF have set up research centers devoted to manufacturing technologies. In short, economic awareness of science and technology has probably never been greater, appropriate agendas have been set, and linkages created between key actors.

The question is to what degree this can be self-sustaining, and whether it can have any real impact. What the United States may be evolving is the technological equivalent of its science base, a system which generates world class basic technologies but which is still relatively remote from its commercial users. Such a system will be useful for economic development, since it does provide the basis for growth industries, namely high tech. But the United States already excels at this; its critical weakness--as demonstrated by the crisis--is in cerating the successive generations of technological advance as a new technology proceeds through its product and innovation cycles. Differential holdings in technology may breathe new life temporarily into comparative advantage, but transforming comparative advantage into sustained competitive advantage is another strategy entirely.

In this task, science and technology become equal partners with the contingencies of innovation. Both organizational and extrinsic factors become critical in using science and technology to competitive advantage. Unlike emergent industries and technologies where the supply of new knowledge is the critical determinant of the pace of change and the final nature of commercial application, sustained economic development and welfare from such emergent industries requires a much stronger partnership between the supply and utilization forces of technoscience.

This is where Japan has excelled, and where the United States is particularly weak. It is likely that the U.S. may develop a first-rate strategic technoscience R&D subsystem, but be quite incapable of using this knowledge for sustained competitive advantage. In the absence of widespread change in industry, and new macroeconomic tools and commitments by government, it is unlikely that the requirements of successful technology-based competition will be satisfied. In its own constrained way, the science policy arena has shown signs of appropriate technoscience response. So has some of the private sector, where there is far greater awareness of the organizational demands of successful innovation and flexible manufacturing strategies. The weak link in the chain is in federal macroeconomic policies. Providing adequate capital and the willingness to systematically identify and support basic technologies are the prerogatives and functions of the state. So far, it has proved remarkably unwilling to take on these tasks.

Suggestions for Future Research

There are many critical issues and problems still to be explored with respect to bringing science to market. One basic one is to continue to collect and refine competitiveness indicators, and begin systemically linking competitiveness to both its determinants and its consequences. The methodological challenges here are considerable, not only for the non-quantifiable nature of many factors but for the general explanatory bankruptcy of many of the technical change econometric models. Obviously the findings here need to be modelled in some statistical fashion that will provide significance tests and verify the associations, confirmed from other sources, and explored further both qualitatively and quantitatively.

The Japanese political economy literature is a good place to start, but we also need some very basic knowledge about the Japanese R&D system, too. We have been burdened with myths, paradigms, and received wisdom for far too long, and it is time to give a fresh look at Japan and how it uses science and technology for economic gain. In this respect, the role of science and technology must be weighted with other factors in the Japanese system. While we are getting a better sense of such issues as industrial policy, the organization of production, and industrial structure, we still can't weight these variables very well. What are their degrees of relative necessity, sufficiency, and importance in driving the Japanese economy?

Evaluating the impact of recent U.S. policy changes on the R&D and science and technology systems is additionally important. What effect are the technology transfer provisions having on both competitiveness and the scientific vitality of the research system? What are the trade-offs and consequences? Similarly, is there a strategic technoscience system forming within the larger system, what does it look like, and what likely impact will it have?

More theorizing and research on the role of technical change in all dimensions of economic welfare is also called for. "Old" ways of thinking have essentially exhausted themselves, and we are at least headed in a new direction of understanding the economic functions of science and technology. However, competitiveness has generally been neglected; attention is still focused on growth, development, trade, and productivity, undoubtedly because these are also the phenomena that dominate the field of economics and are best suited to standard econometrics. Competitiveness encompasses more complex theory, modelling, and measurement problems.

In sum, future research should follow at least four paths. The first is to pursue empirical studies of competitiveness, and as an ancillary to that, try to validate the findings reported here. The second is to approach Japan afresh, not only to put its political economy in a new perspective, but also because it will provide insights into how science and technology are used for competitive advantage. Third, the impact of the competitiveness crisis and associated policies on the U.S must be evaluated. The primary reason for this is to establish the need for "damage control" in the science base, but also because there are signs that the structure of the system may be changing for the first time in decades. Underlying system or sub-system changes would be expected to have consequences for system performance. Finally, we still need to get a much better handle on the role of science and technology in competitiveness, and how it weighs with other determinants. Even more specifically, more theoretical and empirical care needs to be taken with the kinds of "technoscience" induced competitiveness. The competitive dynamics and associated science and technology issues in emerging industries are likely to be substantially different from maintaining the technical and competitive vitality of maturing industries.

Epilogue

Since the time this data was compiled and analyzed, the U.S. trade position has improved considerably.[1] After exchange rate adjustments went into effect in 1985, the manufactures trade deficit improved from its trough of roughly $125 billion in 1987 to an estimated $73 billion for 1990. This dramatic improvement resulted from a rebound of U.S. exports and a considerable slowing of imports. From all appearances, several sorts of classic macroeconomic adjustment mechanisms kicked in to create the expected improvements; the sharp improvement in the deficit in 1990 is most likely attributable to the U.S. recession.

Notably, trade with Japan has been relatively unresponsive to macroeconomic adjustment. Modest improvements in U.S. exports were offset with modest increases in Japanese imports. From 1986-89 the U.S. deficit with Japan has remained an intractable $64-68 billion; in 1990 it is estimated to be just under $60 billion. At the time of the economic recovery in 1982, the U.S. deficit with Japan was $27 billion, and represented 57% of the total trade deficit. That share was down to 48% in 1989 (the most recent year for which detailed data are available) as the United States has increased the number of bilateral trade deficits it is running. The NICs continue to account for about one-quarter of the total deficit.[2] Leading imports from the Pacific Rim continue to be autos, integrated circuits, a variety of data processing components and machines, textiles, and consumer electronics. The first quarter auto data for 1991 show foreign imports accounting for just over one-third of the U.S. auto market; a full one-half if U.S. fleet sales are excluded.

Although we do not have additional data to allow us to follow the competitiveness profile of Japan and the United States for the years after 1986, using trends in the trade data it is probably reasonable to suspect there has been no improvement in the U.S. market position vis-a-vis Japan in the non-competitive core. It is critical that we come to a more complete

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[1]See *Survey of Current Business;* U.S. Department of Commerce, *U.S. Foreign Trade Highlights 1989;* and U.S. International Trade Commission *International Economic Review Chartbook, Composition of U.S. Merchandise Trade 1986-90.*

[2]Note that the total deficit is *not* equivalent to the net balance of trade. The total deficit represents the summation of all bilateral trade deficits; the net balance of trade reflects the balance of the total deficit *plus* the total surplus.

understanding of these trade patterns. Multinational globalization may be one clue, intrinsic and protracted non-competitiveness another. Additionally, Japan's trading patterns show it to have a much lower volume of intra-industry trade in its leading export industries, thus diminishing U.S. opportunities to have more refined intra-industry comparative advantage. The concentration of U.S. trade/competitiveness problems with Japan dictate that the resolution be effected on a bilateral basis.

While consumers may benefit from higher quality, lower priced imports (although this is not always the case) the loss of long-term welfare to the United States economy and society may be considerable. The deficit in effect represents the real loss of income in the present, and net loss of future earnings. Dynamic growth and qualitative development simply are not possible in industrial sectors that are consistently crippled competitors. Science and technology may be significant economic weapons, but the character of the U.S.-Japan bilateral relationship suggests something far more complex is taking place, and only partially remediable through a technoscience strategy.

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