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The delicate task of linking industrial R&D to national competitiveness

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Abstract

The question posed in this research is whether US R&D-oriented competitiveness policies are likely to be effective in light of a number of concerns about the deterministic role R&D is presumed to play in competitiveness. Three relationships are explored: (1) R&D intensity and comparative advantage; (2) R&D intensity and competitive performance; and (3) US and Japanese relative R&D efforts and competitive performance. Although R&D was found to have a direct association with comparative advantage, it was not a systematic predictor of US industrial competitiveness. Relative to Japan, R&D was found to be a necessary but not a sufficient condition for competitive ability. Critical additional determinants are total factor productivity and levels of industrial basic research spending. The findings suggest that US R&D policies may enhance US technological innovation, but not necessarily the transformation of that skill into competitive strength.

Introduction

Linking industrial R&D to national competitiveness is a delicate analytical task to which this research admittedly brings crude empiricism. The intention is to shed some light on US R&D-based competitiveness policies by (a) questioning the presumptive accuracy of the core public policy assumptions about the role of R&D in international competitiveness, (b) making the point that both methodologically and empirically the task is difficult, and (c) exploring the extent to which R&D efforts by the United States and Japan can account for their patterns of bilateral competitiveness over the years 1970–86. The research findings are themselves both startling and not — R&D in general seems to have no predictive ability concerning US and Japanese competitive performance, but *industrial basic research* does.

After reviewing the public policy focus in Section 1 and the theoretical and research issues in Section 2, this paper presents the core of the analysis in Section 3, followed by a set of conclusions and policy implications.

1. The policy framework

Beginning with the productivity slowdown of the 1970s and culminating in the ‘competitiveness crisis’ of the 1980s, economic duress has served to sharply focus US public policy attention on the role of R&D in industrial competitiveness. Federal promotion of R&D as a solution to economic

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malaise has enjoyed widespread nonpartisan support, and has sustained itself through several presidential administrations (from Carter onward) and roughly two dozen sessions of Congress. R&D tax credits (including a new one for basic research), relaxed antitrust restrictions, revisions in intellectual property law and the encouragement of intersectoral cooperative R&D (university–industry–government partnerships) from the core of US policy initiatives which attempt to stimulate the volume of industrial R&D and its associated commercial innovations.

There are many reasons to suspect the likely effectiveness of US R&D policies. First, the slowdown in growth and productivity defies attribution to R&D trends [1], and the US has been running substantial trade deficits or net export declines in several R&D-intensive industries for which it also has structural comparative advantage [2]. Second, innovation theorists have long acknowledged the institutional and market determinants of innovation, so much so that R&D and technological change are themselves viewed as necessary but not sufficient conditions for successful innovation and associated economic impacts [3–7]. Third, a growing body of management literature suggests that it is precisely these latter factors, and not R&D or the supply of technical innovations, that are wanting in US competitive performance [8–11]. For these and other reasons that are detailed below, a nation's R&D efforts and its international competitiveness are hard to link, both theoretically and empirically.

2. R&D and economic performance

A paradox exists in current R&D policy research. Although R&D can be identified as a positive determinant of economic performance, it cannot be isolated as a cause of economic decline. Attributing the US competitiveness crisis to inadequate R&D is problematic, not only because of this dilemma, but because the empirical models that currently exist do not isolate the effects of R&D or precisely capture competitive ability. Each of these points is explored below.

2.1 The paradox

A body of production function research establishes positive economic payoffs from R&D. Proceeding from Cobb–Douglas production functions, this scholarship calculates the marginal product of industrial R&D to national, industry, and firm level total factor productivity growth. In almost all instances, high rates of return to R&D are found, in the range of 25–36%, and returns to basic research alone are typically higher than that for aggregate R&D [12–16]. There is basically a preponderance of econometric evidence that national income/productivity growth can be meaningfully associated with returns to R&D.

An analogous line of inquiry is found in the international trade scholarship. Beginning with the Leontieff paradox in which the composition of US exports was found to be the inverse of that predicted by Heckscher–Ohlin orthodoxy, research has since demonstrated that, with respect to international trade, "all roads lead to R&D" [17]. An abundance of qualitative and empirical research on technology gap, product cycle, and technology-modified Heckscher–Ohlin equations has found support for the presumption that technology (as measured by industrial R&D) is a significant determinant of comparative advantage. Statistical significance is established in a variety of ways, either by stabilizing or by augmenting H–O vintage trade models [18–21] or by revealing the technical composition of exports through factor ranking-techniques [22–24].

While it is clear that the effects of industrial R&D on growth, productivity, and trade are observable, they have not yet been isolated. It is, in fact, extremely difficult to associate current US competitive distress with movements in R&D spending or technical innovation. The US spends substantially more on R&D than any of the major industrialized countries individually and almost as much as they do collectively, even when defense-related expenditures are excluded [25]. Declining rates of technical change and associated payoffs are also hard to establish empirically; Denison [26] reviewed the arguments about declines in

American innovative activity and diminishing returns to R&D and decided there was no conclusive evidence, at least at the aggregate level, that creativity or its economic returns were waning.

Likewise, Griliches [14] and Mansfield *et al.* [27] find little evidence that slowing productivity is the result of declines in R&D. Griliches and Lichtenberg conclude 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 ... what cannot be found in the data is strong evidence of the differential effects of the slowdown in R&D itself" [28 (pp. 465–466)]. Evidence that the output of R&D is declining is scanty, and is accounted for most strongly by industry-specific variables [29]. With regard to international trade, high technology trade is under stress and waning in spite of substantial innovative efforts on the part of US manufacturers [2].

It appears that, slowdowns in US industrial R&D expenditure in the mid-1970s and late 1980s notwithstanding, reductions in the pace and output of technological change seem nearly impossible to establish,[1] let alone associate with sluggish performance.[2] The OECD has labelled this situation "paradoxical" and bemoans that "whereas technological change seems to be pervasive in everyday life ... as Professor Solow has put it, we see computers everywhere except in the economic statistics" [30 (p. 2)]. Economic crisis therefore cannot be taken as *prima facie* evidence of slackening technological innovation, insufficient R&D, or declining R&D potency. This is yet to be proven, and the situation is probably less a paradox than a reflection of the complex dynamics connecting technological change and R&D to economic welfare.

2.2 Problems in theory and measurement

The current empirical paradox is produced by the limitations of existing research methods. By and large, R&D dynamics reflect the creation of a technical advance, but the economic indicators with which they are linked capture the cumulative performance of entire innovation systems, whether national, sectoral, or corporate.

This point is made most simply by referring to the descriptive model of technical change advanced by Schumpeter and widely accepted among innovation economists [31–33]. In this model, technical change is represented as three sequential stages of invention, commercial adoption, and diffusion, with 'impacts' reflecting the ultimate economic contribution of the total innovation system (impacts on trade, employment, growth, and so forth). The most critical feature of the model is the *discontinuous* nature of the stages over time. Diffusion lags alone can last decades, and, as Stoneman notes, "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" [33 (p. 14)].

The productivity and trade performance measures used in econometric research reflect the net economic effects of all three stages of technical change. In turn, R&D as an empirical measure really only captures the invention stage, broadly defined as the production of technical advances (radical and incremental) and know-how. R&D does not meaningfully operationalize either the commercial adoption of innovations or their diffusion. Quite simply, we are trying to explain economic outcomes that result from the discontinuous (but cumulative) dynamics of invention, commercial adoption, and diffusion by essentially measuring only the first stage of the process.

As a final point, the research upon which R&D policies are based does not address competitiveness *per se*. Export structures and productivity are not, technically, competitiveness: the first may result from it and the second may be instrumental to it, but neither reflects the ability to prevail in a state of rivalry, which is the essence of competitiveness [34]. Analyzing the impact of R&D on competitiveness requires measures that capture the results of rivalry, since competitiveness is intrinsically a relative phenomenon.

There is little empirical work to suggest hypotheses about industrial R&D and national competitiveness. Limited microeconomic research confirms that the organizational determinants of adoption and diffusion act as powerful intervenors to the commerical impacts of R&D [35]. In international trade research, US export performance does seem to be closely related to R&D intensity, but international comparisons show a strong industry-specific bias in the degree to which R&D intensity acts a determinant of trade performance [36].

We are therefore left with the following question: what role *does* industrial R&D play in national competitiveness? On the basis of the above discussion, current analytical constructs and empirical research do not help. One solution is to assume that the relationship is not direct, and to develop a full-blown model of technical change and competitiveness in which each stage of innovative activity is captured separately. A straightforward functional relationship is offered here, however, for the sake of parsimony. That is, a nation's competitive performance is assumed to be a direct function of its industrial R&D efforts. The following three hypotheses logically derive. They reflect not a delicate connection between R&D and competitiveness, but the sort of preponderant influence that is presumed in policymaking.

> *H1. US comparative advantage will be in the most R&D-intensive industries.*
>
> *H2. The most R&D-intensive industries will demonstrate the strongest competitive performance.*
>
> *H3. Vis-à-vis other countries, the industry with the higher relative R&D effort will also be the more competitive.*

3. R&D and competitiveness

The above hypotheses are explored separately in this section using three types of data. Revealed comparative advantage, competitiveness (net exports and import penetration), and R&D spending are calculated for US industrial sectors at the 2- and 3-digit SIC level for the years 1970–86. These time-series data are then analyzed to construct typologies of performance using pattern-matching methodologies [37]. To assess the relationship between relative R&D efforts and competitiveness, US–Japanese bilateral competitiveness is compared for the same years, at the same levels, and with respect to their bilateral industrial R&D efforts.

The levels of industrial aggregation are admittedly problematic, since highly differentiated sectors such as electronics and instruments will reflect some degree of noise in their patterns. However, the choice is driven by available R&D data: this is the standard reporting configuration for both US and Japanese R&D statistics. The measures of comparative advantage and competitiveness analyzed here are constructed from the Compatible Trade and Production Database of the Organization for Economic Cooperation and Development. This series reports ISIC manufactures trade and production data, which were then concorded into the US SIC.

R&D data represents company-funded R&D expenditures.[3] Japanese figures are those as reported in the annual *Report on the Survey of Research and Development* [38]; US data are taken from the annual *National Patterns of Science and Technology Resources* [39]. Because some US company-funded data were occasionally not reported for the years 1975–80 for business confidential reasons, these data were imputed. 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 US data have therefore been adjusted to reflect these differences. Yen were converted using OECD purchasing power parities and all R&D data were deflated to constant 1982 dollars, using the GNP implicit price deflator.[4]

3.1 Comparative advantage and R&D intensity

Table 1 presents revealed comparative advantage indicators for the 2- and 3-digit US manufacturing

TABLE 1 Revealed comparative advantage and R&D intensity

Industry and R&D intensity	Revealed comparative advantage		
	1972	1982	1986
High technology			
Electronic equipment	104	116	111
Instruments	143	144	144
Electrical machinery	108	108	91
Office & computing machines	186	217	205
Aerospace	343	242	340
Drugs & medicines	105	109	142
Medium technology			
Motor vehicles & equipment	100	70	74
Non-ferrous metals	60	71	61
Nonelectrical machinery	133	137	106
Rubber & plastic products	67	61	69
Chemicals	112	111	107
Other manufacturing	88	69	63
Low technology			
Textiles, footwear & leather	38	48	41
Ferrous metals	32	24	16
Wood, cork & furniture	70	74	77
Other transportation equipment	NA	75	80
Stone, clay & glass products	61	61	55
Fabricated metal products	80	78	56
Food, drink & tobacco	104	95	105
Petroleum refining	59	77	88
Paper & printing	102	101	105

industries by the R&D intensity of the industry. Revealed comparative advantage is a relative concentration index commonly used to measure the comparative export strengths of different countries [40, 41]. Revealed comparative advantage reflects the share of a country's exports accounted for by a particular industry relative to that industry's share of world exports; to state it mathematically, if X_{ij} is equal to the exports of country i and industry j, X_{ima} is equal to the total manufacturing exports of country i, and n is the number of countries, then the comparative advantage index of country i and industry j is:

$$CA_{ij} = \frac{[X_{ij} \div X_{ima}]}{[\Sigma\, X_{ij}(1 \ldots n) \div \Sigma\, X_{ima}\,(1 \ldots n)]}$$

Thus an index above 100 reflects comparative advantage in trade, and below 100, disadvantage.

R&D intensity is typically measured by R&D-to-output ratios. However, industry-level, time-series, R&D-to-sales data are not consistently available for all the US industries examined here. As a consequence, R&D intensity is represented in this analysis by the categorization of industries into high, medium, and low technology groupings. The particular classification scheme employed here (see Table 1) is used pervasively by OECD, and is based upon the R&D-to-output ratios of each industry [42]. Thus high tech industries are the most R&D intensive, and low tech industries the least R&D intensive.[5]

With regard to the first hypothesis of the preceding section, that *US comparative advantage will be in the most R&D-intensive industries*, it does appear that this is substantially the case. In 1986, five of the nine US industrial sectors that demonstrate revealed comparative advantage are high tech industries. In fact, the United States has revealed comparative advantage in five of the six industrial sectors that the OECD considers to be high tech. An additional two of the nine advantaged sectors are medium technology, and two are low technology. The two low tech sectors (food, drink & tobacco, paper & printing) are considered to be Ricardo goods, whose comparative advantage derives from natural resource endowments. If we exclude comparative advantage that accrues from conventional factor endowments, it does appear that R&D acts as a significant correlate of US comparative advantage.

3.2 US competitiveness and the R&D intensity of industries

Analyzing long-term trends in US competitiveness is complicated by the existence of the macroeconomic disruptions of the mid-1980s (the budget deficit, collapsed export demand, misaligned exchange rates) which severely distorted US trade and competitiveness patterns. To be able to identify US industrial competitive strengths and weaknesses, indicators and patterns must be able to discriminate between macroeconomic effects (e.g. leading business cycle recoveries, exchange rate values) and intrinsic, market-based competiuve ability. Two measures are consequently used here: balance of trade and import penetration data rather cleanly identify competitive stature when used in conjunction with one another [43].

US net export data consistently reveal a core set of deficit-generating industries. Although the United States ran net manufacturing trade surpluses throughout most of the 1970s, the motor vehicles, steel, textile, and electronics industries have been in deficit since at least 1970 and accounted for most of the gross manufactures deficit.[6] By 1982, these industries generated two-thirds of the gross deficit, and much of the trade/competitiveness crisis can be attributed to them: the deficit created by motor vehicles, electronics, and textiles[7] accounts for almost half of the total decline in US manufactures trade in the core years of the 'competitiveness crisis', 1982–86.

Prior to the macroeconomic disruptions, the declining performance of these industries was not problematic (at least from a trade balance perspective) because the electrical and nonelectrical machinery sectors generated enough surplus to completely offset these core deficits. With the onset of economic recovery in 1982, the two machinery industries experienced dramatic reversals in their trade accounts, from large surpluses to large deficits. Until that time, electrical machinery had historically been the single largest surplus-generating industry, substantially larger even than aerospace. The vast bulk of the trade crisis in the 1980s was therefore generated by five industries. Ongoing deficits in motor vehicles, electronics, and textiles, combined with the reversals in machinery, created nearly 70% of the total decline in the US trade balance from 1982 to 1986 and about 60% of the total 1986 deficit.

A juxtaposition of import penetration ratios (the percentage of domestic markets accounted for by foreign goods) with the trade trends gives greater precision to the pattern of competitive decline. The five industries which accounted for the substantial worsening in the trade deficit from 1982 to 1986 are also among the most highly penetrated industries, with several having 20% or more of their markets accounted for by imports. If the trade developments of the early 1980s were merely a matter of strong recovery effects, then substantial rises in import penetration should not occur during the same period: domestic output would rise commensurate with demand and no major shifts in domestic market share would occur.

Yet, of the major US business cycles during 1970–1986, the 1982–86 period accounted for a very disproportionate one-half of the increase in import penetration of the durable goods industries over the 16-year period.[8] This suggests that imports were not flowing in to temporarily satisfy a recovering demand economy, but to displace domestic production. For industries characterized by both major trade declines *and* significant increases in import penetration, it seems reasonable to conclude that a competitive realignment transpired between 1982 and 1986.

A four-fold competitive typology of the US manufacturing sector emerges from the combined trade and import penetration trends for the years 1970–86 (Table 2). By 1986, manufacturing industries could be classified as either core noncompetitive (suffering from trade deficits and high import penetration since the early 1970s), newly noncompetitive (major reversals in trade and rapid rises in import penetration after 1982), at-risk competitive (showing signs of competitive disability), or competitive (consistently balanced trade[9] and low levels of import penetration). However, in 1986 misaligned exchange rates still influenced trade dynamics, and the at-risk and newly noncompetitive industries were affected by these price distortions.

After exchange rate adjustments went into effect in 1987, the competitive status of several sectors became clearer. First, all the at-risk industries once again became solidly competitive. Second, the 'newly noncompetitive' instruments and nonelectrical machinery industries returned to their pre-1982 competitive stature. Third, the trade deficits and import penetration levels of the electrical machinery and office & computing machine industries continued to worsen, indicating that these two sectors did experience a reversal in their competitiveness during the 1980s.

TABLE 2 Competitiveness typology for US manufacturing industries, 1986

Industry	Import penetration (%)	Trade balance status	Technology class
I. Core noncompetitive			
Motor vehicles & equipment	30.3	largest deficit	medium
Textiles, footwear & leather	21.7	2nd largest deficit	low
Electronic equipment & components	21.3	3rd largest deficit	high
Ferrous metals	13.2	4th largest deficit	low
Other manufacturing	31.2	6th largest deficit	medium
Other transportation	16.1	16th largest deficit	low
Non-ferrous metals	14.8	11th largest deficit	medium
Wood, cork & furniture	13.5	7th largest deficit	low
II. Newly noncompetitive			
Instruments	18.6	reversal from surplus	high
Electrical machinery	17.3	reversal from surplus	high
Nonelectrical machinery	15.2	reversal from surplus	medium
Office & computing machines	25.0	declining surplus	high
III. At-risk competitive			
Rubber & plastic products	10.0	worsening deficit	medium
Stone, clay & glass products	9.2	worsening deficit	low
Fabricated metal products	5.3	reversal from surplus	low
IV. Competitive			
Aerospace	11.0	stable surplus	high
Chemicals	8.4	declining surplus	medium
Drugs & medicines	6.6	declining surplus	high
Food, drink & tobacco	5.4	worsening deficit	low
Petroleum refining	5.0	improving deficit	low
Paper & printing	4.3	worsening deficit	low

Looking at the association between R&D intensity and industrial competitiveness, it does not appear that the second hypothesis — *the most R&D-intensive industries will demonstrate the strongest competitive performance* — is supported. As seen in Table 2, a significant number of competitive US industries are low technology: fabricated metal goods, paper & printing, and petroleum refining, to name a few. (We should remember that the at-risk industries in Table 2 were at risk because of exchange rates; by 1990, they were fully competitive once again.)

Conversely, three critical high technology industries — electronics, electrical machinery, and office & computing machines — were noncompetitive. (Like the at-risk class, instruments moved from newly noncompetitive to competitive after exchange rate adjustments.) What is especially peculiar about the noncompetitiveness of these three sectors is that all reflect revealed comparative advantage in trade. Revealed comparative advantage can therefore be misleading. Because it measures the structural composition of one country's exports relative to another — and is essentially a proportional measure — it obscures the issue of *magnitude*. For example, net exports of drugs & medicines, one of the most R&D-intensive industries in the US with both competitive status and a high revealed comparative advantage index, were $1.6 billion in 1989. This modest surplus stands in sharp contrast to the $45.5 billion deficit in motor vehicle imports — a crude comparison to illustrate the point that high tech (and even high growth) industries do not necessarily command the magnitude of global demand that would offset domestic consumption in consumer products or mature industries.

3.3 R&D and US–Japanese bilateral competitiveness

Evaluating the third hypothesis — *compared to other countries, the industry with the higher relative R&D effort will be the more competitive* — requires that US industrial competitiveness relative to other countries be established. However, import data are not available which report the country of origin for US imports at the SIC industrial levels used here, prohibiting the development of market share data (the most instructive indicator of US competitiveness vis-à-vis other countries.) As a consequence, US A/E schedule trade data for the years 1980–87 are used to establish bilateral competitiveness of the US relative to Japan [44]. A/E data are product classes that can be crudely concorded to proxy the SIC groupings. Japan was selected as the country of comparison because a substantial amount of qualitative case study analysis exists which can corroborate patterns of relative competitiveness. Second, of all other nations, Japan is closest to the US in terms of overall R&D spending and technological competence. It also has the most thoroughly reported industrial R&D data.

Some import patterns emerge from the concorded A/E trade data. Japan accounts for 25% or more of all imports in seven industries for which case study research has shown it to be a preponderant or major foreign competitor: autos, electronics, instruments, office & computing machines, electrical machinery, nonelectrical machinery, and steel. In four of the seven — autos, electronics, instruments, office & computing machines — Japan accounts for 50% of total imports. Using a '25% of imports rule' to qualify Japan as more competitive than the US, a basic typology of bilateral strength was constructed (Table 3).

Four separate indicators of R&D activity from 1970 to 1986 were used to establish the relative strength of US and Japanese R&D efforts: (1) absolute volumes of R&D expenditure; (2) rates of change in the absolute levels of spending; (3) R&D-to-sales ratios; and (4) rates of change in R&D-to-sales ratios. For each of these measures Japan's industrial R&D efforts were rated as higher, the same as, or lower than comparable US efforts. Patterns for all four Japanese R&D indicators were quite stable relative to the US by industry and over the 1970–86 period. This made it straightforward to construct a ranked typology of R&D effort. Japanese industries that had higher R&D efforts than the US on three or four of the measures were rated as superior; those that had no consistent pattern of R&D strength or weakness were rated as mixed; industries whose R&D efforts lagged those of the US on three or four of the measures were rated as inferior.

As seen in Table 4, relative R&D efforts do not discriminate competitive from noncompetitive industries in the least. Japan's competitive industries do not have any systematically superior R&D effort relative to the US, and in two sectors, electronics and instruments, Japan's industrial R&D efforts are well below those of the United States. Moreover, there are two Japanese industries which demonstrate superior R&D effort but are nonetheless noncompetitive — stone and glass products and fabricated metals. One explanation for this pattern may be that aggregating four measures of R&D effort into a single typology of performance masks patterns that any one indicator alone might predict. However, the patterns of competitiveness reflected in Table 3 cannot be explained by any one of the four R&D indicators alone or in alternative combinations.

Working on the assumption that R&D inputs may be too crude a measure of invention and technical innovation, patent indicators and R&D subsidies were also separately evaluated. While government R&D transfers to industry do not effectively differentiate competitive Japanese industries from noncompetitive, one sector does receive government assistance not fully captured by Japan's industrial R&D data. The electronics industry has been a prime recipient of government research funds through MITI's large-scale R&D projects [2, 45].

Japanese patenting activity in the United States also sheds some light on the R&D quality of

TABLE 3 Relative competitive status of US and Japanese industries[a,b]

Industry	Industries in which US is more competitive	Industries in which Japan is more competitive
High technology		
Instruments		*
Electronic equipment & components		*
Electrical machinery		*
Office & computing machines		*
Drugs & medicines	*	
Aerospace	*	
Medium technology		
Motor vehicles & equipment		*
Nonelectrical machinery		*
Rubber & plastic products	*	
Chemicals	*	
Low technology		
Ferrous metals		*
Fabricated metal products	*	
Stone, clay & glass products	*	
Food, drink & tobacco	*	
Petroleum refining	*	
Paper & printing	*	

[a] A Japanese industry is classified as more competitive than the US if it accounts for 25% or more of all imports in the equivalent US A/E trade schedule product group as of 1987.
[b] This table excludes noncompetitive US industries for which Japan is not a competitor.

TABLE 4 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 Japanese industry	
	Competitive	Noncompetitive
Type I. Superior performance (above average on three or four R&D dimensions)	Ferrous metals Electrical machinery	Fabricated metals Stone & glass
Type II. Mixed performance (combination of good, poor, and/or average on R&D)	Motor vehicles Nonelectrical machinery	Food Chemicals Rubber
Type III. Inferior performance (well below average on 3 or 4 R&D dimensions)	Electronics[a] Instruments	Paper & printing Pharmaceuticals Aerospace Petroleum refining

[a] Includes the office and computing machines industry. (It is not possible to separate Japanese electronics from office and computing machine R&D data.)

electronics, instruments, and autos. Even though these three industries reflect mixed or inferior R&D performance relative to the United States, Japanese patenting levels, both absolutely and relative to R&D dollars spent, are superior to US patenting in these industries. This suggests that the overall quality and fecundity of Japan's R&D in these sectors may indeed be superior.

All of Japan's competitive industries —except nonelectrical machinery — consequently reflect greater (or higher quality) R&D effort relative to the US. However, the same cannot be said of the noncompetitive industries. In this instance, several do have superior R&D efforts, but are still not competitive. This suggests that R&D supremacy is a necessary, but not sufficient, condition for competitiveness. We therefore must reject the third hypothesis that better R&D efforts unilaterally lead to competitive strength.

There are three additional indicators that help explain what is going on in US–Japanese bilateral competitiveness. First, recent research on total factor productivity duplicates the patterns of competitiveness and noncompetitiveness found here and presented in Table 3 [46]. In general, competitive Japanese industries have matched or exceeded US levels of total factor productivity, while noncompetitive ones have not. Second, a comparison of the Japanese industries in the competitive and noncompetitive classes reflects some significant technological differences. All of the competitive industries except steel represent product cycle goods with integrated sequential processing and assembly methods, and an emerging body of research suggests that Japan possesses unique competitive manufacturing advantages in these industries [45, 47–51]. The noncompetitive Japanese industries are predominantly continuous process and bulk materials industries which cannot readily exploit the manufacturing techniques of assembled goods (e.g. machine cells, just-in-time production systems, and so on).

Third, a comparison of total industrial *basic* research expenditures is illuminating. Basic research has been demonstrated to have higher rates of return to firms than other forms of R&D [12, 13], and basic research represents the most radically innovative portion of the R&D portfolio [31].[10] Table 5 shows that, for all but two industries in which Japan is competitive, basic research efforts in 1975 (several years prior to the trade crisis, to allow for a lagged effect) were considerably higher than in the US *on a dollar-per-dollar basis* and relative to net sales. The two exceptions to this basic research preponderance are electronics and instruments, industries for which patent data reveal greater technological potency per R&D dollar spent. Additionally, patent citation analysis [52] demonstrates that Japan's patents in these industries signal some of the most important, seminal inventions in the US patent system. Note also that US basic research spending may be quite high (relative to Japan) in these two industries because of the high degree of defense-related R&D funds that these two sectors get from the US government.

These findings suggest three points. First, all other things being equal, cost-oriented factors (e.g. total factor productivity) are the final arbiters in the marketplace. Second, the technical nature of Japan's competitive industries reinforces the theory that the organizational and technological basis of production is the primary determinant of productivity advantage [11, 53]. Finally, consistent with theory but counter-intuitive with respect to Japan, the basic research association does highlight the relationship between 'radical' innovation and competitive strength.

4. Conclusions and policy implications

The question initially posed in this research was whether US R&D-oriented competitiveness policies were likely to be effective in light of a number of concerns — both theoretical and empirical — regarding the deterministic role that R&D was presumed to play in competitiveness. Two critical assumptions of these policies were explored: that US competitive performance is greatest in R&D-intensive industries, and that levels of R&D investment have a direct influence on competitive performance.

Given limitations to the data and the analytical approach used here, it is wise not to take the research implications too far. As is usually the case, more research and refinements are required. For this particular topic, better empirical models of technical change are needed, as well as more disaggregated competitiveness indicators. There is

TABLE 5 Japanese industrial basic research efforts relative to the United States

Competitive status	Japan's basic research efforts, 1975	
	Level of expenditure	Intensity index[a]
Industries in which Japan is more competitive than the US		
Primary metals	186% of US	3.5
Electrical machinery	221% of US	5.0
Motor vehicles	267% of US	7.0
Nonelectrical machinery	130% of US	2.4
Electronic equipment[b]	18% of US	0.6
Instruments	32% of US	1.5
Industries in which Japan is less competitive than the US		
Fabricated metals	26% of US	0.5
Stone & glass	19% of US	0.3
Food & beverages	100% of US	3.0
Chemicals	28% of US	0.5
Rubber	22% of US	1.0
Paper & printing	NA	NA
Pharmaceuticals	33% of US	0.8
Aerospace	NA	NA
Petroleum refining	4% of US	0.1

[a] Intensity index = Japanese ratio of basic research to net sales relative to the US ratio.
[b] Includes the office and computing machines industry. (It is not possible to separate Japanese electronics from office and computing machine R&D data.)

still quite a bit of noise at the 2- and 3-digit level, although even more comprehensive 3-digit data would be an improvement.

In spite of the quantitative reductionism of the methodology used here, there are some signal findings. First, as was expected, US export specialization — as reflected by revealed comparative advantage indicators — is predominantly in the high and medium technology industrial sectors. Second, in spite of these export advantages, there are strong indications of noncompetitiveness in several high tech industries. Net export levels and import penetration rates are not consistent with the picture of comparative advantage that export structure alone provides. Third, R&D-intensive industries do not appear to be systematically more competitive than other industrial classes.

With regard to the relationship between R&D efforts and competitive performance, total R&D does not appear to have a transparent relationship to international competitiveness. However, industrial basic research does seem to effectively discriminate competitive and noncompetitive US and Japanese industries vis-à-vis one another. Research done by others identifies similar competitive patterns between the US and Japan, and provides additional explanatory variables: total factor productivity, and the distinctiveness of Japan's approach to manufacturing in particular kinds of industry.

What can we make of this coalignment of basic research, total factor productivity, manufacturing skill, and competitive ability? Quite possibly it reflects the fundamentally different economic payoffs of two distinct kinds of technological leadership. To put it more simply, the data reflect the unequal rewards of national innovation cultures, the US being primarily one of technology push, and Japan, demand pull. These different innovation styles have been explored and explained more thoroughly elsewhere [54–57], but the point is that they yield different competitive advantages.

Technology push creates radical product innovations for which new markets are slow to evolve; demand pull generates an emphasis on process innovation and markets with proven demand.

Consider, for example, the contradictory findings between export specialization and the more precise measures of domestic market competitiveness. This suggests that the comparative advantage which the US enjoys in key high tech sectors — reflected by its exports to the rest of the world — is not sufficiently large to offset domestic consumption in different product lines. Good examples would be US exports in supercomputers and advanced computing machinery relative to imports of personal computer peripherals, and advanced information technologies relative to consumer electronics. Few would dispute US technological leadership in the upper end of these industries and markets, yet at present they do not command sufficient global demand to compensate for the lack of US competitiveness at the 'lower ends' of the market.

Japan's heavy emphasis on basic research in competitive industries runs against received wisdom but is consistent with Japan's technological record. While the popular impression is that Japan does not 'do' basic research or create major innovations, a growing body of research suggests otherwise. The character of basic research in Japan (even in industry) is quite fundamental and its scope is extensive. The evidence ranges from detailed interviews, to the bibliometric record, to expenditure patterns, to technometric studies [58–63].

The areas of Japan's basic research strength and emphasis, together with its total factor productivity advantages, manufacturing strategies, and pronounced emphasis on process innovation [64], all point to Japan as a technological leader in manufacturing and electromechanical technologies. This creates competitive leadership in industries and product lines with *pre-existing* demand, and has potentially high spillover effects within the manufacturing sector. The demand pull nature of Japan's innovation system generates a form of technological innovation that generates substantial competitive advantage.

In sum, US R&D policies that indiscriminately stimulate R&D or neglect the market pull (diffusion) dynamics of successful innovation are likely to miss their mark. The US may continue to advance in high technology sectors for which it has structural comparative advantage, but the total economic payoff relative to other countries and industries may be limited. Relatedly, a number of other US industries enjoy competitive advantage but are not necessarily R&D intensive. Some attention should be paid to the macroeconomic and business policies that sustain a healthy environment for competition. R&D stimulus alone is unlikely to substantially alter the portrait of US competitive advantage and disadvantage developed here.

Notes

[1] This is also the case qualitatively. There is mixed evidence (largely comparisons in technological advances) regarding US 'leadership' in technology, but certainly none that is compelling regarding an overall slowdown in the pace of technological change among the advanced industrialized nations. It seems reasonable to assume, as has Allan Bromley, former Assistant to the President for Science and Technology, that in spite of the US erosion in technological leadership in a few targeted technologies, "the United States still has the strongest science and technology base the world has ever seen" (as quoted in Council on Competitiveness, *Challenges*, 4(2) 8).

[2] Note that the slowdown itself is an ongoing mystery. Not only can we not attribute it to problems in technical innovation, but other conventional causes do not seem to tie in with it. See Bailey and Chakrabarti [1] for a straightforward review of the scope of the growth and productivity 'crisis' and problems in explaining it.

[3] Total US 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 into the 'civilian' economy. US company-funded R&D is a better measure of US industry's self-initiated technical innovation activities.

[4] Note that the US trade data were not deflated because both market share and revealed comparative advantage indicators are proportional measures and do not require it. Net exports are nominal since the precise magnitude of the balance of trade is not as important here as its movement vis-à-vis market share trends.

[5] The OECD has calculated average R&D-to-output ratios for each of these three categories. The R&D intensity of the high tech sector is 11%; medium technology, 2%; low technology, 0.5%. See [42].

[6] It is often useful to distinguish between 'net' and 'gross' balances of trade (whether surplus or deficit). While a net balance refers to the sum of exports less imports, the gross balance refers to the sum of all deficit (or surplus) generating categories of trade. In this particular instance, the net balance of trade was calculated for each industry; those industries generating a net deficit were then summed to calculate a gross deficit.

[7] Quotas on steel imports went into effect in the early 1980s, and as a consequence the balance of trade did not worsen after 1982 for this industry. It did, however, remain in a deficit.

[8] US business cycles averaged about 4 years in length after 1970, with 1978–82 being characterized by a somewhat sustained recession. The cycle beginning in 1982 ran until 1990/91; for the sake of analysis with the previous cycles a four-year increment is used here.

[9] A few industries classified as competitive here run very minor deficits.

[10] Although there is some uncertainty about the relative competitive advantages of incremental versus radical innovations, radical innovation is believed to generate sustained competitiveness because it creates new markets and associated 'monopoly rents'.

References

1 M. Baily and A. Chakrabarti. *Innovation and the Productivity Crisis.* Brookings Institution, Washington, DC, 1988.
2 L. Tyson. *Who's Bashing Whom?* Institute for International Economics, Washington, DC, 1992.
3 C. Freeman. *The Economics of Industrial Innovation.* MIT Press, Cambridge, MA, 1982.
4 M.I. Kamien and N.L. Schwartz. *Market Structure and Innovation.* Cambridge University Press, Cambridge, UK, 1982.
5 S.J. Kline and N. Rosenberg. An overview of innovation. In: R. Landau and N. Rosenberg (eds), *The Positive Sum Strategy: Harnessing Technology for Economic Growth.* National Academy Press, Washington, DC, 1986.
6 D. Mowery and N. Rosenberg. The influence of market demand upon innovation: a critical review of some recent empirical studies. *Research Policy,* VIII (1979) 102–153.
7 M.L. Tushman and W.L. Moore. *Readings in the Management of Innovation.* Ballinger Publishing Co., Cambridge, MA, 1982.
8 S. Berger *et al.* Toward a new industrial America. *Scientific American,* 260(6) (1989) 39–47.
9 R.H. Hayes and S.C. Wheelwright. *Restoring our Competitive Edge: Competing Through Manufacturing.* John Wiley and Sons, New York, 1984.
10 D.A. Hicks (ed.) *Is New Technology Enough?* American Enterprise Institute, Washington, DC, 1988.
11 M.E. Porter. *The Competitive Advantage of Nations.* Free Press, New York, 1990.
12 Z. Griliches. R&D and productivity: Measurement issues and econometric results. *Science,* 237 (July 1987).
13 Z. Griliches (ed.). *R&D, Patents, and Productivity.* University of Chicago Press, Chicago, IL, 1984.
14 Z. Griliches. R&D and the productivity slowdown. *American Economic Review,* 70(2) (1980) 343–348.
15 A. Link. Basic research and productivity increase in manufacturing: Additional evidence. *American Economic Review,* 76(1) (1981) 1111–1112.
16 E. Mansfield. Basic research and productivity increase in manufacturing. *American Economic Review,* 70(5) (December 1980) 863–873.
17 W.H. Gruber, D. Mehta and R. Vernon. The R&D factor in international trade and international investment of United States industries. *Journal of Political Economy,* 75 (1967) 20–34.
18 W. Ethier. The theory of international trade. In: L. Officer (ed.), *International Economics.* Kluwer Academic Publishers, MA, 1987.
19 K.E. Maskus. Comparing international trade data and product and national characteristics data for the

analysis of trade models. In: *International Economic Transactions: Issues in Measurement and Empirical Research*. University of Chicago Press, Chicago, IL, 1991.

20 K. Maskus. *The Changing Structure of Comparative Advantage in American Manufacturing*. UMI Research Press, Ann Arbor, MI, 1985.

21 M. Noland. *Pacific Basin Developing Countries: Prospects for the Future*, Institute for International Economics, Washington, DC, 1990.

22 H. Bowen, E. Leamer and L. Sveikauskas. Multicountry, multifactor tests of the factor abundance theory. *American Economic Review*, 77 (December 1987) 791–809.

23 G. Hufbauer. The impact of national characteristics and technology on the commodity composition of trade in manufactured goods. In: R. Vernon (ed.), *The Technology Factor in International Trade*. (National Bureau for Economic Research, New York, 1970.

24 W.B. Walker. *Industrial Innovation and International Trading Performance*. JAI Press Inc.,Greenwich CT, 1979.

25 National Science Foundation. *International Science and Technology Data Update 1990*. National Science Foundation, Washington, DC, 1991.

26 E.F. Denison. *Trends in American Economic Growth, 1929–1982*. Brookings Institution, Washington DC, 1985.

27 E. Mansfield *et al. Technology Transfer, Productivity, and Economic Policy*. Norton, NY, 1982.

28 Z. Griliches and F. Lichtenberg. R&D and productivity growth at the industry level: is there still a relationship? In: Z. Griliches (ed.), *R&D, Patents, and Productivity*. University of Chicago Press, Chicago, 1984.

29 A.S. Englander, R. Evenson and M. Hanazaki. *R&D, Innovation and the Total Factor Productivity Slowdown*. Mimeo, Department of Economics, Yale University, 1989.

30 OECD. *Aims and Organization of an International Seminar on Science, Technology, and Economic Growth*. OECD, Paris, 1988.

31 E. Mansfield. How economists see R&D. *Research Management* (July 1982) 23–29.

32 N. Rosenberg. *Inside the Black Box: Technology and Economics*. Cambridge University Press, Cambridge, UK, 1982.

33 P. Stoneman. *The Economic Analysis of Technology Policy*. Clarendon Press, Oxford, UK, 1987.

34 D. Encaoua, P. Geroski and A. Jacquemin. Strategic competition and the persistence of dominant firms: a survey. In: J. Stiglitz and G.F. Methewson (eds.), *New Developments in the Analysis of Market Structure*. MIT Press, Cambridge, MA, 1986.

35 P.S. Adler. Technology strategy: A guide to the literature. In: R. Rosenbloom and R. Burgelman (eds.), *Research on Technological Innovation, Management, and Policy*. JAI Press, Greenwich, CT, 1989.

36 F. Bergsten *et al.* (eds.). *Japan's Growing Technological Capability*. National Academy Press, Washington, DC, 1992.

37 R. Yin. *Case Study Research: Design and Methods*. Sage, Newbury Park, CA, 1989.

38 Government of Japan. (Annual) *Report on the Survey of Research and Development*. Statistics Bureau, Tokyo.

39 National Science Foundation. *National Patterns of Science and Technology Resources*. National Science Foundation, Washington, DC, 1988.

40 B. Balassa. *Comparative Advantage, Trade Policy, and Economic Development*. New York University Press, NY, 1989.

41 B. Balassa and M. Noland. *Japan in the World Economy*. Institute for International Economics, Washington, DC, 1988.

42 Organization for Economic Cooperation and Development. *OECD Science and Technology Indicators No. 2: R&D, Invention, and Competitiveness*. OECD, Paris, 1986.

43 M. Papadakis. Did (or does) the United States have a competitiveness crisis? *Journal of Policy Analysis and Management*, 13(1) (1994) 1–20.

44 Department of Commerce. *United States Trade Performance in 1987*. US GPO, Washington, DC, 1988.

45 D. Okimoto. *Between MITI and the Market*. Stanford University Press, Stanford, CA, 1989.

46 D.W. Jorgenson and M. Kuroda. Productivity and international competitiveness in Japan and the United States, 1960–85. *Economics Studies Quarterly*, 43(4) (1992) 313–325.

47 J. C. Abegglen and G. Stalk. *Kaisha: The Japanese Corporation*. Basic Books, New York, 1985.

48 S. Cohen and J. Zysman. *Manufacturing Matters*. Basic Books, NY, 1987.

49 D. Friedman. *The Misunderstood Miracle*. Cornell University Press, Ithaca, NY, 1988.

50 C. Johnson, L. Tyson and J. Zysman. *Politics and Productivity*. Ballinger, New York, 1989.

51 J. Stowsky. Trapping the benefits of technological innovation: The development impacts of industrial organization in the military and the marketplace. Unpublished doctoral dissertation, Department of City and Regional Planning, University of California, Berkeley, CA, 1990.

52 F. Narin and D. Olivastro. Technology indicators based on patents and patent citations. In: A.F.J. Van Raan. *Handbook of Quantitative Studies of Science and Technology*. Elsevier, New York, 1988.

53 M. Piore and C. Sabel. *The Second Industrial Divide*. Basic Books, NY, 1984.

54 J.C. Derian. *America's Struggle for Leadership in Technology*. MIT Press, Cambridge, MA, 1990.

55 R. Florida and M. Kenney. *The Break Through Illusion*. Basic Books, NY, 1990.

56 C. Freeman. *Technology, Policy, and Economic Performance: Lessons from Japan*. Pinter Publishers, London, 1987.

57 R. Gomory and R. Schmidtt. Science and product. *Science* (27 May, 1988) 1131ff.

58 R. Barre. A strategic assessment of the scientific performance of five countries. *Science and Technology Studies*, 5 (1987) 32–38.

59 G. Gamota and W. Frieman. *Gaining Ground: Japan's Strides in Science and Technology*. Ballinger, Cambridge, MA, 1988.

60 D. Hicks and M. Hirooka. *Defining Basic Research in Japanese Companies and Science in Japanese Companies*. National Institute for Science and Technology Policy, Government of Japan, Tokyo, 1991.

61 F. Narin and J.D. Frame. The growth of Japanese science and technology. *Science* (11 August 1989) 600–605.

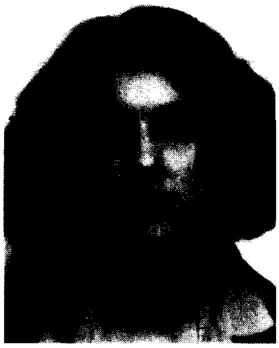
62 S. Okamura. History of engineering education in Japan. In: E. David and T. Mukaibo (eds.), *Engineering Education: United States and Japan*. National Science Foundation, Washington DC, 1988.

63 M. Papadakis and J. Jankowski. Sizing up basic research in the United States and Japan. Technology and Information Policy Program Working Paper, The Maxwell School, Syracuse University, Syracuse, NY, 1991.

64 E. Mansfield. Industrial R&D in Japan and the United States: a comparative study. *AEA Papers and Proceedings*, 78(2) (May 1988) 223–228.

65 R.R. Nelson. Institutions supporting technical change in the US. In: G. Dosi *et al. Technical Change and Economic Theory*. Frances Pinter, London, 1988.

66 OECD. *Technical Change and Economic Policy*. OECD, Paris, 1980.



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