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11 R&D and Productivity Growth: Comparing Japanese and U.S. Manufacturing Firms

Zvi Griliches and Jacques Mairesse

11.1 Introduction

In economic terms, Japan is a large country with a large internal market in addition to its export potential. In an area that is one twenty-fifth of the United States, Japan has slightly over half of the population of the United States, and more than one-third of its GNP. Japan's manufacturing sector is relatively larger, with total employment in manufacturing around 42% of that in the United States. One of the major differences between the two countries has been the much faster rate of productivity growth in Japanese manufacturing.

Although the oil crises of 1973 and 1979 affected both economies severely and output and productivity growth slowed in both of them, the productivity of labor in manufacturing continued to increase much faster in Japan than in the United States during the 1970s.[1] These events elicited many comments and studies but mostly at the aggregate macrolevel. Also, while there has been much discussion of the possible role of differential R&D policies in these events, there has been little quantitative examination of the R&D-productivity growth relationship; what there has been has focused largely on aggregate data and single-country analysis.[2] It is our intention to look at these issues using Japanese and U.S. company data in an attempt to assess the contribution of R&D to productivity in both countries.

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This paper can be viewed as a continuation of our previous work on R&D and productivity growth at the firm level in the United States and in France. In analyzing the data for French and U.S. manufacturing we found that differences in R&D effort do not account for much of the observed difference in the average rate of productivity growth or its distribution across industrial sectors or firms (see Griliches and Mairesse 1983, 1984; Cuneo and Mairesse 1984.) The availability of similar data for Japan led us to extend these comparisons to that country and the United States, between which the contrasts are even larger.

Our work differs from much of the productivity-comparisons literature by taking the individual firm data as its primary focus. Firm data have the virtue of providing us with much more variance in the relevant variables and a more appropriate level of analysis, the level at which most of our theories are specified. By working with microlevel data we escape many of the aggregation problems that plague macroeconomics. On the other hand, these benefits do not come without cost. Our data bases rarely contain enough variables relevant to the specific circumstances of a particular firm, and the available variables themselves are subject to much higher relative error rates, which are largely averaged out in aggregate data.

The basic approach we follow in this paper is to compute simple productivity-growth measures for individual manufacturing firms both in Japan and the United States for the relatively recent 1973–80 period and relate them to differences in the intensity of R&D effort. We start by describing our data sources and the overall pattern of R&D spending in manufacturing in both countries and by reviewing the major trends in productivity growth across different industrial sectors. We then turn to the discussion of regression results that attempt to account for the differences in labor productivity growth by the differences in the growth of the capital-labor ratio and in the intensity of R&D effort across different firms for total manufacturing as a whole and also separately within specific industrial sectors.

Since, as we shall point out in some detail later on, the Japanese R&D data at the firm level turn out to be especially incomplete, we cannot provide a solution to the original puzzle of differential growth rates, but we still have some interesting facts and several new puzzles to report.

11.2 Comparing R&D Expenditures

Before we look at our R&D data at the firm level, it is useful to compare the industrial distribution of R&D expenditures in both countries. Tables 11.1 and 11.2 show comparative statistics on the magnitude and industrial distribution of R&D expenditures for manufacturing in both countries, focusing on the role of "large" firms (firms with more than a 1,000 employees).[3] We look primarily at large firms because they account for most of the R&D in either country and also because these are the firms represented in our microdata sets.

Table 11.1 **R&D Firms in Manufacturing, Japan, 1976: The Relative Importance of Large Firms (1,000 or More Employees) and Their Industrial Distribution**

	No. of Employees in Millions and Percentages	Sales in Units of 100 Billion Yen and Percentages	Company R&D Expenditures in Units of 100 Billion Yen and Percentages	No. of Firms	R&D Sales Ratio[a]
All Firms	8.8	1,244	15.14	85,650	.012
R&D firms	59	69	100	11,950	.018
Large firms	41	52	78	1,120	.018
Large R&D firms	39	50	78	1,030	.019
Large R&D doing firms:					
Total	3.5	623	11.82	1,030	.019
Distribution by industry:[b]					
1. Food & kindred	5.1	9.0	2.2	60	.005
2. Chemicals & rubber	11.0	14.2	16.6	98	.022
3. Drugs	2.3	2.1	5.8	29	.051
4. Primary & fabricated metals	13.7	16.8	9.8	104	.012
5. Machinery	8.0	6.5	6.2	91	.018
6. Electrical equipment	19.1	14.0	30.4	123	.041
7. Transportation equipment	23.7	22.0	20.5	329	.018
8. Instruments	2.1	1.4	2.1	29	.028
9. Other	15.0	14.0	6.4	167	.009

Source: Report on the Survey of Research and Development (Prime Minister's Office 1976).

Note: "Manufacturing" excludes petroleum refining.

[a] Total R&D /total sales (not average of firm ratios).

[b] The numbers in the first three columns are percentages and add up to 100.

Table 11.2 R&D Firms in Manufacturing, United States 1976: The Relative Importance of Large Firms (1,000 or More Employees) and Their Industrial Distribution

	No. of Employees in Millions and Percentages	Sales in Billions of Dollars and Percentages	Company R&D Expenditures in Billions of Dollars and Percentages	No. of Firms	R/D Sales Ratio[a]	
					Total	Company Financed
1977 All Firms	21.5	1,275	18.00	295,000	.022	.014
R&D firms	62	63	100	2,835	.035	.022
Large firms	65	70	94	1,910	.030	.019
Large R&D firms	56	61	94	1,140	.035	.022
1976 Large R&D firms:						
Total	11.7	672	15.30	1,137	.036	.023
Distribution by industry[b]						
1. Food & kindred	7.6	12.7	2.0	102	.004	.004
2. Chemicals & rubber	9.7	11.4	13.2	112	.030	.026
3. Drugs	2.3	3.5	6.8	29	.063	.062
4. Primary & fabricated metals	13.1	13.0	4.8	165	.009	.008
5. Machinery	6.7	6.1	5.9	135	.023	.022
6. Electrical equipment	20.0	14.8	30.9	159	.077	.047
7. Transportation equipment	18.3	20.6	25.2	90	.065	.028
8. Instruments	3.5	2.6	6.6	55	.066	.057
9. Other	18.8	16.3	4.7	290	.008	.007

Source: Information for all firms in manufacturing from *Enterprise Statistics: General Report on Industrial Organization* (U.S. Bureau of the Census 1977). R&D related numbers from NSF, *Research and Development in Industry,* 1976 and 1977 issues.

Note: "Manufacturing" excludes petroleum refining.

[a] Total R&D/total sales (not average of firm ratios).

[b] The numbers in the first three columns are percentages and add up to 100.

Comparing the two tables we can see that large firms are more numerous in the United States, and that, on average, they are also larger (about 10,000 employees per firm versus 3,500 in Japan). Large firms account for 70% of total sales and 65% of total employment in manufacturing in the United States versus 52% and 41%, respectively, in Japan. Similarly, large firms do almost all of the R&D in the United States—94%—but only about three-quarters in Japan.[4]

Allowing for differences in the size of the countries and the size distribution of firms, there is very little difference either in the intensity or the sectoral distribution of company-financed R&D expenditures in the two countries. There is a big difference, however, in the involvement of government in the financing of R&D performed in manufacturing. In the United States, over a third of total R&D has been federally financed while in Japan the state accounts for less than 2% of the total.[5] Since our micro data reflect only company financed R&D we shall not be able to discuss the role of public R&D support in this context.[6]

While, in absolute terms, large Japanese manufacturing companies spend only about a third as much on R&D as U.S. companies do, the relation of these expenditures to sales is remarkably similar (about 2%) in both countries. The distribution of total company R&D by industry and of the intensity of R&D effort are also very similar in the two countries. Most of the R&D is done in three sectors: electrical equipment, transportation equipment, and chemical industries.[7] The highest R&D to sales ratios are to be found in the drug and electrical equipment industries, the only noticeable difference being the somewhat higher relative R&D expenditure in the U.S. instruments industry.

We turn now to the consideration of our firm-level data sources. In both countries the responses to official R&D surveys are confidential and not publicly available. However, information on individual firms' R&D expenditures is available in their public annual reports or their filings with the respective securities markets regulatory authorities (10K statements in the United States). In Japan such data are collected and organized by the Nihon Keizai Shimbun Corporation and are known as the NEEDS data base. In the United States, the equivalent is Standard and Poor's Annual Industrial Compustat.

We have worked previously with the Compustat data and have created a consistent panel data set based on it.[8] This is, however, our first experience with the NEEDS data, and we had to invest heavily in cleaning them and in trying to understand their construction and provenance. Except for the R&D numbers, as we shall see below, these data seem of comparable quality to the Compustat data for the United States.

The general characteristics of the parallel firm samples that we have constructed are depicted in table 11.3. If we insist on continuous data from 1972 through 1980 with no major mergers or major jumps in the series and require also consistent reporting of R&D expenditures throughout this period, we

Table 11.3 Japan and the United States: 1976 Characteristics of the 1972–80 Continuous Samples

Variable	Japan[a]			United States	
		R&D Reporting			
	Total	Original[b]	Corrected[c]	Total	R&D Reporting[d]
N	1,032	394	406	968	525
Average employment, in thousands	2.7	3.4	4.5	68	17
Average sales, in millions of dollars	215	242	345	655	872
Average plant, in millions of dollars	118	128	187	330	434
Average R&D, in millions of dollars	—	3.1	6.9	—	22.7
Average R&D/sales ratio[e]	—	.012	.013	—	.024

[a] From the NEEDS (Nihon Keizai Shimbun) data base. Converted to dollars at \$1 = ¥300.

[b] In addition to the 394 continuously R&D reporting firms in the Japanese sample, there are also 338 firms that reported nonzero R&D expenditures in one or more years in the 1972–80 period.

[c] The data on largest R&D-performing firms in Japan reported in OECD (1984) were used to fill in some missing values and adjust others for apparent underreporting.

[d] In addition to the 525 continuously R&D reporting firms in the U.S. sample, with no major jumps, there are also 129 firms that reported nonzero R&D expenditures in one or more years in the 1972–80 period.

[e] Average of individual firm R&D to sales ratios.

have complete data for about 400 R&D firms in Japan and slightly over 500 R&D firms in the United States.[9] The U.S. firms are significantly larger, by a factor of four on average. They also seem to be doing much more R&D, even relatively. Here we stumble on our major difficulty with the NEEDS data. The R&D data appear to be badly underreported in this source. If we compare the numbers in table 11.1 with those in table 11.2, we observe that the overall company financed R&D to sales ratio is roughly similar in both countries and only slightly lower in Japan (1.91% vs. 2.3% in the United States for large R&D performing firms), while the numbers in table 11.3 imply that the U.S. firms are twice as R&D intensive.

It does not take very long to convince oneself that indeed the NEEDS data are heavily deficient in their R&D coverage. Table 11.4 reports coverage ratios for 1981 of the NEEDS R&D numbers relative to the official Japanese R&D survey. While the large firms in the NEEDS sample account for close to 80% of the relevant employment and sales totals, the coverage of R&D expenditures is only slightly above one-third.[10] Looking at the distribution by industrial sector we see that coverage varies from good to reasonable for the chemical, drug, and instruments industries, but that it is abysmal for motor vehicles and transportation equipment and poor for the rest of manufacturing. The magnitude of the problem can be appreciated when it is realized that neither Toyota, Hitachi, Nissan, nor Honda report positive R&D expenditures in the NEEDS data base.

Using information published by the Organization for Economic Cooperation and Development (OECD 1984) on the 20 largest R&D performers in Japan in 1979, we find that of the 18 firms that should be within our definition

Table 11.4 **Comparison of NEEDS 1981 Data to the Japanese Official 1981 R&D Survey Coverage in Ratios Expressed in Percentages**

	Firms	Employees	Sales	R&D Expenditures
All	1.2	30	46	29
R&D reporting	4.2	35	38	29
Large firms (1,000 or more employees)	58	79	78	35
Large R&D-reporting firms, total	45	51	49	35
By sector:				
1. Food & kindred	27	30	45	26
2. Chemicals & rubber	65	70	80	92
3. Drugs	71	92	95	98
4. Metals	60	55	70	42
5. Machinery	46	45	54	27
6. Electrical equipment	51	60	69	26
7. Transportation equipment	38	44	38	14
8. Instruments	42	58	73	75
9. Other	42	48	53	29

of manufacturing and are indeed in the NEEDS file, 10 report no R&D whatsoever, 3 report about the same amount of R&D in both sources, and, what may be even more worrisome, 5 companies report significantly less R&D in the NEEDS data base than is reported by the OECD. For example, the reported R&D expenditures of the Sony Corporation differ by a factor of two. If the OECD information is added to the NEEDS data set, total R&D expenditures come close to doubling, and the coverage ratio rises to a respectable 73%.

Thus the problem we face is not only that R&D is missing for some firms, a problem that we could either ignore or adjust for in some way, but also that the reported figures themselves appear to be inaccurate. They reflect not only real differences in this variable but also differences in reporting practices. Since there was nothing else that we could do at this point, we complemented or adjusted the R&D figures for the 18 very large R&D firms for which we had OECD information and proceeded to analyze these data as if they actually mean what they say. The best we can hope for is that the reported R&D numbers are still acceptable proxies for the true figures.[11] We will come back, however, to this issue in interpreting the results of our analyses.

A few words should be said at this point about the U.S. R&D data. They indeed seem better. Even though they are not exactly conceptually equivalent, the 10K-based reports and the NSF-collected (National Science Foundation, various issues) numbers are not very far apart, especially as far as industry totals are concerned. A recent analysis by the NSF (1985) of data for the 200 largest R&D performers finds the totals in 1981 remarkably close (within 3%), though this covers up significant individual variability. Forty-seven percent of the firms reported totals within 10% in both sources; 22% were within 10% to 25% and only 13% were off by more than 25%. Eighteen percent were not included in the Compustat-based data base, primarily because they were either privately or foreign owned. Using 1976 totals and adjusting for differences in definition and coverage, we ourselves estimated that the Compustat-based universe contained about 85% of total R&D reported to the NSF, with the major discrepancy arising from the above mentioned absence of privately and foreign owned firms in these data.[12] At the same time, our selection of "continuous R&D" firms preserves about 80% of the total R&D reported in the 1976 large Compustat cross section. Thus, roughly speaking, the firms contained in our U.S. sample account for about 70% of the total company financed R&D as reported to the National Science Foundation.

11.3 Comparing Trends in Productivity Growth

Bearing in mind the limitations of the R&D data, we look now at the productivity record of the firms in our samples for both countries during the 1970s. Tables 11.5 and 11.6 list the sample sizes, averages, and standard deviations for some of our major variables by industrial sector and for manufac-

Table 11.5 **Continuous R&D-reporting Firms Subsample for Japan, 1973–80 Growth Rates (per Year) and 1973 Levels: Means (and Standard Deviations) for Major Variables**

				Average Growth Rates 1973–80			
Industry	*N*	Average Employed, 1976 in Thousands[a]	*R/S* 1973 (estimated)[b]	Employed	Deflated Sales per Employee	Adjusted Gross Plant per Employee	Approximate TFP[c]
Total	406	4.5	.010	−.021	.058	.085	.036
		(9.4)	(.013)	(.038)	(.046)	(.034)	(.045)
1. Food & kindred	22	2.3	.004	−.012	.029	.090	.007
		(2.3)	(.006)	(.028)	(.030)	(.032)	(.026)
2. Chemicals & rubber	82	3.0	.011	−.023	.026	.079	.006
		(3.8)	(.010)	(.035)	(.027)	(.037)	(.027)
3. Drugs	31	2.4	.037	.006	.072	.082	.051
		(2.4)	(.022)	(.030)	(.037)	(.029)	(.036)
4. Metals	41	5.5	.006	−.029	.035	.078	.016
		(12.9)	(.006)	(.031)	(.044)	(.029)	(.042)
5. Machinery	48	1.8	.008	−.030	.067	.081	.046
		(2.5)	(.008)	(.035)	(.039)	(.032)	(.037)
6. Electrical equipment	67	7.2	.011[d]	−.017	.105	.087	.084
		(14.4)	(.013)	(.035)	(.035)	(.037)	(.034)
7. Transportation equipment	33	12.3	.001[d]	−.006	.066	.084	.044
		(17.5)	(.005)	(.033)	(.034)	(.030)	(.031)
8. Instruments	17	2.3	.015	−.015	.106	.101	.081
		(2.0)	(.017)	(.055)	(.040)	(.037)	(.035)
9. Other	65	3.0	.004	−.039	.041	.094	.017
		(3.5)	(.004)	(.043)	(.042)	(.028)	(.040)

[a] Average employed, 1976 − arithmetic average.

[b] *R/S* 1973 (estimated) − 1972 through 1974 average R&D divided by average sales in 1972 and 1974.

[c] Approximate TFP (total factor productivity) = growth in deflated sales per employee − .25 (growth in plant per employee).

[d] OECD data based corrections raise this number to .016 and .009 for electrical and transportation equipment industries, respectively. For the total sample, however, this adjustment raises R/S to only .011.

Table 11.6 **Continuous R&D-reporting Firms Subsample for the United States, 1973–80 Growth Rates (per Year) and 1973 Levels: Means (and Standard Deviations) for Major Variables**

Industry	*N*	Average Employed, 1976 in Thousands[a]	*R/S* 1973 (estimated)[b]	Average Growth Rates 1973–80			
				Employed	Deflated Sales per Employee	Adjusted Gross Plant per Employee	Approximate TFP[c]
Total	525	16.9	.025	.019	.016	.044	.005
		(48.9)	(.023)	(.067)	(.038)	(.051)	(.038)
1. Food & kindred	22	17.0	.006	.012	.022	.042	.012
		(17.7)	(.005)	(.042)	(.044)	(.036)	(.041)
2. Chemicals & rubber	71	18.3	.026	.014	.007	.048	–.005
		(32.5)	(.013)	(.052)	(.034)	(.036)	(.033)
3. Drugs	44	14.6	.038	.040	.005	.044	–.006
		(15.1)	(.027)	(.066)	(.033)	(.043)	(.032)
4. Metals	50	9.5	.012	.002	.001	.045	–.010
		(18.0)	(.010)	(.053)	(.031)	(.042)	(.032)
5. Machinery	82	7.8	.024	.027	.002	.046	–.009
		(12.9)	(.021)	(.074)	(.031)	(.054)	(.030)
6. Electrical equipment	106	19.4	.035	.024	.044	.046	.032
		(51.9)	(.024)	(.080)	(.045)	(.068)	(.047)
7. Transportation equipment	34	66.0	.018	.004	.003	.040	–.007
		(147.8)	(.013)	(.065)	(.032)	(.049)	(.028)
8. Instruments	39	10.1	.050	.047	.030	.020	.024
		(23.6)	(.032)	(.072)	(.025)	(.040)	(.025)
9 Other	77	9.9	.010	.001	.012	.048	–.000
		(14.0)	(.007)	(.058)	(.027)	(.048)	(.026)

[a] Average employed, 1976 – arithmetic average.

[b] *R/S* 1973 (estimated) – 1972 through 1974 average R&D divided by average sales in 1972 and 1974.

[c] Approximate TFP (total factor productivity) = growth in deflated sales per employee – .25 (growth in plant per employee).

turing as a whole. The construction of the major variables is similar for both countries except that in the United States we were able to use 3-digit SIC-level price deflators and business segment information to construct individual firm sales deflators, while for Japan we had to use general 2-digit level deflators.[13] In both countries the gross plant figures were converted from historical to constant prices using the information contained in the net versus gross plant distinction.[14] In neither data set do we have information on hours worked, and materials purchases are available only for Japan.

There are a number of interesting observations to be made on the basis of tables 11.5 and 11.6, some less obvious than others. The major contrast between the two countries is in the employment story and the associated productivity movements. In Japan, total employment declined in eight out of the nine industrial groupings, whereas, in the United States, it rose in all sectors. In fact, real output per firm as measured by deflated sales grew at about the same rate in the United States as in Japan, 3.5% per year on average, with the big difference in the productivity numbers coming essentially from the behavior of the employment series.

The same thing is also true for the growth in the capital-labor ratio, which grew twice as fast in Japan than in the United States, while the capital stock was growing at roughly similar rates in both countries during this same period (about 6.4% per year). It is also interesting to note that in both countries the growth of the capital-labor ratio was very similar for the different industrial groupings, varying much less than the growth in the output-labor ratio. This is consistent with the hypothesis that the ratio of real wages to capital user costs moved differently between the two countries but essentially similarly for the different industries within these countries.

If one estimates total factor productivity growth by assuming that value added and sales vary proportionately and that the capital input weight in value added is constant and equal to 0.25 for all firms in both countries, one finds several commonalities and also some contrasts. In both countries the high R&D industries split in their productivity experience: electric equipment and instruments have the highest productivity growth rates while chemicals are among the lowest ones. The major contrasts occur in the machinery, transportation equipment, and drug industries, where there was significant productivity growth in Japan but not in the United States.[15] Only in the food industry did the United States do better than Japan as far as total factor productivity growth is concerned.

Our numbers are not strictly comparable to similar macroestimates, both because they are unweighted firm averages and because many of the firms in our two samples are multinationals with neither their employment nor productivity restricted entirely to the country of origin. Nevertheless, table 11.7 presents the figures on average growth rates of labor and labor productivity that we have gathered at the industry level and for manufacturing as a whole in the two countries, and the corresponding measures from our two total

Table 11.7 Average Growth Rates, 1973–80, of Labor and Labor Productivity at Company and Industry Level

	Japan					United States				
	Total Sample			National Accounts		Total Sample			National Accounts	
Industry	*N*	Employed	Deflated Sales per Employee	All Persons	Real Output per Person	*N*	Employed	Deflated Sales per Employee	All Persons	Real Output per Person
Total	1,032	-.024	.055	-.005	.038	968	.013	.012	.007	.004
		(.042)	(.047)				(.066)	(.042)		
1. Food	82	-.011	.034	-.003	.049	63	.020	.020	-.002	.023
		(.035)	(.032)				(.052)	(.042)		
2. Chemicals & Rubber	149	-.019	.026	-.009[b]	.039[b]	91	.012	.009	.007	-.002
		(.032)	(.031)				(.056)	(.034)		
3. Drugs	37	.005	.071			52	.035	.003	.010	.015
		(.030)	(.043)				(.068)	(.032)		
4. Metals	149	-.031	.036	-.007	.026	135	-.004	-.008	-.005	-.013
		(.035)	(.041)				(.053)	(.052)		
5. Machinery	154	-.028	.063	-.007	.039	113	.028	-.000	.023[a]	-.004[a]
		(.044)	(.037)				(.070)	(.030)		
6. Electrical Equipment	152	-.018	.102	.003	.083	140	.026	.043	.022	.051
		(.036)	(.039)				(.081)	(.047)		
7. Transportation Equipment	79	-.008	.063	.010	.065	63	-.004	-.001	-.005	-.009
		(.040)	(.036)				(.066)	(.043)		
8. Instruments	33	-.016	.102	.007	.062	46	.052	.026		
		(.045)	(.038)				(.073)	(.026)		
9 Other	197	-.044	.042	-.010	.013	265	-.001	.012	.006	.000
		(.049)	(.047)				(.059)	(.034)		

[a] Machinery and instruments.

[b] Chemicals & rubber, and drugs

samples.[16] There is no striking inconsistency in the two sets of micro- and macroestimates, but rather a rough agreement in terms of the pattern of differences both across industries and countries. For example, productivity growth is clearly the highest for electrical equipment in the two countries and about the lowest for metals; it is also the case that transportation equipment did quite well in Japan contrary to the United States.[17] It is interesting to note, however, that the overall growth in productivity tends to be more rapid for the firms in our samples than for manufacturing as a whole (the differential being as much as 1.7% per year in Japan and 0.8% in the United States), while the contrast in employment experience is even larger: 2.5% slower growth in our firm data in Japan versus the United States, as against only a 0.8% differential in the national-income-accounts-based industry totals.

11.4 R&D Intensity and Productivity Growth at the Firm Level

The model we consider can be thought of as a modified version of the Cobb-Douglas production function in its growth rate form, with labor productivity being a function of the physical capital-labor ratio and research capital.[18] Because we have only a very short history of research expenditures for most of these firms, it is difficult to construct a reliable research capital measure. We use, therefore, the R&D intensity version of this model instead, in which the beginning period R&D to sales ratio is substituted for the unavailable R&D capital variable.

Let the true equation be

$$(q-l) = \lambda + \alpha(c-l) + \gamma k + \mu l + u,$$

where small lettered variables stand for rates of growth (logarithmic changes): q, l, and c represent output, employment, and physical capital, respectively; k is a measure of accumulated research capital; α, β, γ are the elasticities of output with respect to physical capital, labor, and research capital; $\mu = (\alpha + \beta - 1)$ is the economies of scale coefficient; λ is a constant that reflects, among other things, disembodied technical change; and u is a random disturbance standing in for all other unspecified effects affecting measured productivity growth.

The research capital elasticity γ is equal, by definition, to $(dQ/dK)(K/Q)$. Since $k = dK/K$, we can simplify $\gamma k = (dQ/dK)(K/Q)(dK/K)$ to $\rho(R/Q)$, where $\rho = dQ/dK$ is the marginal product of research capital and R is the level of R&D expenditures. Two points need to be made about this type of simplification: it assumes that R, gross expenditures on R&D, is a good proxy for net investment (dK) in R&D capital. This can be true only if there is no or little depreciation of research capital or if we are in the beginning phases of accumulation and the initial stocks of K are small. Also, it is assumed that ρ rather than γ is constant across firms, that the rate of return ρ is the parameter that is more likely to be equalized across firms.[19]

The equations that we estimate are then of the form

$$(q-l) = \lambda + \alpha(c-l) + \mu l + \rho(R/Q) + u,$$

where the rates of growth of $(q-l)$, $(c-l)$, are generally computed over the seven-year period 1973–80.

The adoption of this specification has two important consequences: first, the estimating equation is expressed in terms of rates of growth of productivity (first differences of the logarithms of the various variables) and thus does not relate differences in productivity levels to differences in R&D capital. This has the advantage of protecting the estimates from potential biases due to (correlated) specific effects but at the cost of ignoring the large variability of the data in the cross-sectional dimension. We know from previous work that results based on this dimension (between-firms) are usually stronger than those based only on the time dimension (within-firms) (see, e.g., Griliches and Mairesse [1984] and Cuneo and Mairesse [1984]). A second consequence is that we relate differences in the rate of growth of productivity to differences in R&D to sales ratios (rather than to the differences in the rate of growth of R&D capital stock).[20]

Several alternative measures of R&D intensity, R/Q, were tried with largely similar results. The final variable chosen, AR/S, relates the average amount of deflated R&D during 1972–74 to the mean (geometric) levels of deflated sales for the period as a whole (average of 1973 and 1980 sales). The numerator of this ratio refers to the beginning of the period and allows, implicitly, for an approximate three-year lag in the effects of R&D.[21] The denominator is positioned in the middle of the period to reduce the spuriousness that may arise when a growth rate is based on a ratio whose denominator is in fact the initial level from which the growth rate is measured.[22] Instead of a unique trend term we include, usually, separate industry dummy variables, which allow for differential industrial trends of disembodied technical change, and also for deflator errors and industrywide changes in capacity utilization. Such equations were also estimated separately for each industrial grouping.

Table 11.8 summarizes our main econometric results. The estimated R&D coefficients in the productivity growth equations are of similar magnitude in both countries. They fall substantially when industry dummies (trends) are allowed for, implying, possibly, the presence of significant interfirm R&D spillovers. The major difference is that, in this case, the coefficients for Japan are not statistically significant at conventional significance levels.

Although significant, the contribution of the R&D intensity to the explanation of the variance in productivity growth across firms is rather small, the fit barely improving in the second decimal place. Nor can R&D account for the mean difference in growth rates between the two countries. Both the average R&D intensities and the estimated coefficients are quite close to each other. Nevertheless, if these coefficients are taken at face value, they imply that R&D contributed between 0.4% and 0.6% per year to productivity growth in both countries. This is not a small matter after all.

Table 11.8 **Productivity (Deflated Sales per Employee) Growth in Manufacturing at the Firm Level as a Function of Growth in the Capital-Labor Ratio and R&D Intensity: Japan–United States Comparisons, 1973–80**

	Coefficients and (Standard Errors)							
	Japan			United States			R^2 and (MSE)	
Regression	C/L[a]	L[b]	AR/S[c]	C/L	L	AR/S	Japan	United States
1	.372			.132			.072	.031
	(.067)			(.032)			(.00198)	(.00141)
2	.397		.562	.146		.410	.085	.066
	(.066)		(.229)	(.032)		(.093)	(.00196)	(.00136)
3	.298			.152			.500	.220
	(.051)			(.030)			(.00111)	(.00116)
4	.311		.302	.155		.267	.502	.251
	(.051)		(.214)	(.029)		(.096)	(.00110)	(.00112)
5	.236	−.240	.203	.107	−.080	.248	.531	.265
	(.052)	(.049)	(.209)	(.033)	(.026)	(.096)	(.00104)	(.00110)

Note: Equations 3–5 contain an additional 13 industry dummy variables. Regression 5 includes also the average 1972–74 employment level as a control variable for initial size. Its coefficient is small, positive, and significant for the United States and essentially zero for Japan. MSE is the mean square error of regression residuals.

[a] C/L = growth rate of gross-plant in constant prices per employee.

[b] L = growth rate of employment.

[c] AR/S = average R&D to sales ratio. R&D averaged for the years 1972–74, sales at mid-point of the period: geometric average of beginning (1973) and end-period (1980) sales. Both variables are deflated.

What is most striking in our results is the lower estimated contribution of physical capital to output growth in the United States. It is about half of what is estimated for Japan.[23] In fact, if we apply the coefficients in table 11.8 (regression 3) to the first row of table 11.5, we can account for about half of the Japan–United States difference in productivity growth by (1) the twice-as-fast rate of growth of the capital-labor ratio in Japan, and (2) its twice-as-large effect on productivity there. The reasons for both of these findings remain to be elucidated.

On the other hand, the Japanese data seem also to imply a much sharper rate of diminishing returns. This last estimate (the $-.24$ coefficient in regression 5) seems rather difficult to believe; it could be due to errors in the Japanese labor variable or to our inability to properly account for the problem of varying capacity utilization and hours of work. In any case, since the Japanese firms reduced their average employment during this period, such "diminishing returns" could not serve as a brake on their productivity growth.

Table 11.9 summarizes our attempts to look at the same issues at the individual industry level. Given the high error rates in the data at the firm level and the relatively small sample sizes, there is little to be seen here. Consistent with our earlier finding that the overall R&D coefficient was not statistically significant in Japan, the individual industry estimates are found to be about half positive and half negative, and only three of them have both the right sign and exceed their estimated standard error. For the United States, the results are only slightly better: seven out of the nine industries have positive R&D coefficients, and three of them are larger than their estimated standard errors. There is little relationship, moreover, in the relative size of these coefficients across the same industry groupings in the two countries (see lower panel of table 11.9).

We made several efforts to improve matters by redefining variables and changing the time periods somewhat, but this had little effect. The results are quite robust to the use of net rather than gross physical capital measures or to changes in the averaging procedures for the R&D data. Changing time periods, however, makes more of a difference. Using the slightly shorter 1974–79 period improves the estimates somewhat in Japan but deteriorates them in the United States.[24] This leads us to a disappointing finding: the instability of the productivity-R&D relationship and its sensitivity to the business cycle and macroeconomic supply shocks.

Table 11.10 presents annual estimates of the R&D coefficients using approximate total factor production (TFP) growth as the dependent variable. We use TFP here to avoid adding another source of variation, which would come from allowing also the physical capital elasticity to vary from year to year.[25] What is striking is that, though the exact timing was a bit different, the oil shock–induced sharp recession of 1974–75 hit the R&D-intensive firms disportionately hard in both countries. It is not clear, however, whether what we see in this table represents a real phenomenon or is just another reflection of

Table 11.9 **Distribution of the *R/S* Coefficients by Industry (Regression 4)**

	Coefficients			
	< 0	0–.5	>.5	Total
t-ratios for Japan:				
< 1	3	2		5
>1	1		3	4
Total	4	2	3	9
t-ratios for the United States:				
< 1	1	3	1	5
>1	1	1	2	4
Total	2	4	3	9

	Coefficients for Japan			
	<0	0–.5	>.5	Total
Coefficients for the United States:				
< 0	1		1	2
0–.5	1	1	2	4
> .5	2	1		3
Total	4	2	3	9

Table 11.10 **Coefficients of R&D Intensity in TFP Growth Regressions, by Year, Japan and the United States, 1974–80**

Year	Japan	United States
1973–74	−.73	1.50
	(.91)	(.38)
1974–75	−.73	−1.48
	(.91)	(.42)
1975–76	.51	−.58
	(.81)	(.33)
1976–77	.85	.65
	(.70)	(.34)
1977–78	1.01	.35
	(.67)	(.27)
1978–79	.60	1.28
	(.64)	(.29)
1979–80	.55	.38
	(.58)	(.32)

Note: Approximate TFP growth is calculated as: (percent growth in deflated sales per employee) − .25(percent growth in gross plant per employee). All equations contain an additional set of industry dummies and a base year (1973) size variable. The R&D intensity variable, *AR/S*, is calculated as the average of 1972–74 R&D divided by the average (geometric) 1973 and 1980 sales (both deflated). It is the same for all years.

the thinness of our data and our inability to estimate the effects of R&D precisely.[26]

11.5 Tentative Conclusions

Japanese manufacturing firms spent about as much of their own money on R&D, relative to their sales, as did similar U.S. firms; about 1.9% versus 2.3%, respectively, in 1976. On the basis of the econometric analysis of our sample of R&D firms, we cannot reject the hypothesis that the contribution of these expenditures to productivity growth was about the same in both countries. There is no strong prima facie evidence for the hypothesis that differences in either the intensity or the fecundity of R&D expenditures can account for the rather large difference in the observed rates of growth of productivity between the two countries.[27] The reasons for this difference must be looked for elsewhere.

We do find two important differences between Japan and the United States that help to account for some of this difference but require an explanation of their own:

1. In spite of their success in growing and exporting, Japanese firms reduced their employment levels significantly during this period while U.S. firms were increasing theirs. This alone is enough to account for the twice-faster growth in the capital-labor ratio in Japanese manufacturing since the capital stock itself has been growing at roughly similar rates in both countries.

2. For reasons that are not well understood, the estimated effect of growth in the capital-labor ratio on firm productivity in manufacturing appears to be twice as large in Japan than in the United States. An exploration of the reasons for this difference awaits better data, another occasion, and perhaps a different approach to the problem.

There are a number of other puzzling findings that we hope to return to in the future: Why did the chemical industry perform so badly during this period in both countries? Why did the drug industry do so badly in the United States during these same years? Is this a real fact or an artifact of poor deflators? While the oil price shocks provide some explanation for the poor performance of the chemical firms along lines outlined by Bruno and Sachs (1985), it is doubtful that they can also explain the experience of the pharmaceutical firms in the United States. Why does the effect of R&D intensity on productivity growth vary so much over the cycle? Is it because it should only be observable at or near full capacity? How can such consideration be incorporated into a more complete analysis of our data?

An improved analysis of the role of R&D expenditures in the growth of Japanese firms will require better data than are currently available to us. The Japanese Statistics Bureau has collected much more extensive and presumably more reliable data on R&D expenditures of firms for many years but as far as we know these data have not been accessible, nor have they been used in their detailed micro form. In the United States, similarly collected data by the National Science Foundation (NSF) and the Bureau of the Census have been matched for different surveys and brought together in a usable data file. The confidentiality problem was solved by performing all of the major data assembly and cleaning operations within the Census Bureau and by releasing only variance-covariance matrices for the major variables across firms and years without disclosing any individual firm information.[28] It would be certainly interesting to launch a similar effort in Japan. Another way of dealing with the confidentiality requirement is to carry out the econometric analysis within the National Statistical Offices themselves, as was the case for our studies for France.[29]

We cannot expect, however, that having better and more reliable data will solve all the problems. What we are looking for are effects that are at best variable, uncertain, and more or less long term in nature and that are also relatively small in magnitude. This does not mean, of course, that these effects are unimportant or that we should not devote more effort in trying to analyze them. But we cannot expect to account for much of the observed growth in productivity by focusing only on the firm's own R&D investments. The role of research spillovers between firms, sectors, and countries and the impact of other, less formal, ways of generating technical progress, are likely to be quite large and still remain to be measured.

Addendum

After the revision and completion of this paper for this volume, we gained access to new R&D information at the firm level for Japan. We are grateful to Fumio Hayashi for his help in getting these data.

Besides the R&D figures reported in the NEEDS data base and the official R&D survey of the Statistics Bureau of Japan, there exists in fact another R&D survey performed and published by the Nihon Keizai Shimbun Corporation in recent years. This survey is the source of the OECD numbers, which we already used to adjust the NEEDS figures for 18 of the largest R&D firms. In order to check our numbers on a larger scale, we matched these new data to our total sample of 1,032 firms for the fiscal year 1978 or 1979. We found 1,000 firms in common, among which 877 were reporting R&D expenditures. These 877 include our sample of 406 firms that reported R&D consistently from 1972 through 1980 in NEEDS and 471 firms that did not. When we compare the R&D numbers in the two sources for our 406 firms sample, the discrepancy is less than 5% for more than half of the sample; it is less than 50% for another quarter, but it is more than 400% for 48 firms. Contrary to the 18 large R&D adjusted firms, these 48 firms are smaller than average, and it is quite plausible that a major part of their R&D expenditures is external or cooperative and is not declared in NEEDS.

We have adjusted our R&D-intensity variable using the new R&D information (as we already had done with the OECD figures), and we have rerun our main regressions using these adjusted measures for various subsamples: the 406 R&D reporting firms, among which we consider the 48 R&D reporting firms with very large R&D discrepancies separately, and the remaining 358 R&D reporting firms. We have also used the new R&D data for the 471 firms that did not report, or reported intermittently, R&D expenditures in NEEDS. Pooling together this sample and the previous ones, we have two overall samples of 877 (406 + 471) and 829 (358 + 471) firms. The results for the simplest regression (with constant returns to scale and without industry dummies, comparable to regression 2 in table 11.7) are given in table 11A.1.

Using the adjusted R&D-intensity variable does not really improve our estimates. They remain about the same if the 48 firms for which the discrepancies are extreme are excluded, and they look worse if we do include them, the coefficient of R&D being smaller and not significant. Clearly one would like to know more about the 48 problematic firms. The estimates for the additional 471 firms sample and for the pooled 829 firms sample are also very similar to our previous results.

Table 11A.1 **Productivity Growth-R&D Intensity Regressions With and Without R&D Adjusted Measures for Various Samples of Japanese Firms: 1973–80 (Similar to Regression 2 in Table 11.8)**

	R&D Measures from NEEDS, Coefficients and Standard Errors			R&D Adjusted Measures, Coefficients and Standard Errors		
Various Samples	*C/L*	*AR/S*	R^2 MSE	*C/L*	*AR/S*	R^2 MSE
406 R&D reporting firms	.38	.56	.085	.37	.16	.075
	(.07)	(.23)	.0020	(.07)	(.13)	.0020
48 R&D reporting firms with very large R&D	.00	5.22	.090	−.06	.00	.002
discrepancies	(.20)	(2.53)	.0010	(.21)	(.20)	.0020
358 R&D reporting firms without very large R&D	.42	.48	.101	.42	.58	.109
discrepancies (406 − 48)	(.07)	(.24)	.0019	(.07)	(.21)	.0020
471 nonconsistently R&D				.25	.48	.060
reporting firms	. . .	. . .	. . .	(.050)	(.22)	.0019
877 R&D reporting (consistently and nonconsistently) firms	. . .	. . .	. . .	.29	.28	.063
(406 + 471)				(.04)	(.11)	.0020
829 R&D reporting (consistently and nonconsistently) firms, without firms with very large R&D discrepancies	. . .	. . .	. . .	.31	.56	.077
(358 + 471)				(.04)	(.15)	.0020

On the whole these computations confirm our earlier results. This is reassuring since R&D expenditures are poorly reported in the NEEDS data bank. But it is also unfortunate since one would have hoped for somewhat stronger and more significant estimates with better and more accurate figures. Again the quality of the data is not our only problem.

Notes

1. See, e.g., the *Economic Report of the President* (Council of Economic Advisers 1984, table 3.3).

2. One exception at the macrolevel is Mohnen, Nadiri, and Prucha (1984). After this paper was written we became aware also of the work of Odagiri (1983) and Odagiri and Iwata (1986), who use the same Japanese data base to construct value-added-based TFP growth measures and relate them to firm R&D intensities. Their results for Japan are similar to ours but they make no cross-country comparisons, however.

3. These numbers come from the national R&D surveys conducted by the Statistics Bureau in the Prime Minister's Office (various years) in Japan and the National Science Foundation (various years) in the United States.

4. Some of this contrast may be an artifact of different reporting conventions in the two countries. A perusal of the individual-firm data seems to indicate that there is less consolidation in Japan, with more units, which in the United States would be treated as subsidiaries, appearing as independent firms in the Japanese sources.

5. See Peck (1985) for more discussion of this difference.

6. See Griliches (1980, 1986) for more discussion on this topic.

7. Because we try to have reasonably sized samples in the various "industries," we have aggregated some of the more detailed statistics into nine industrial "sectors." Thus, sector 2 includes chemical and rubber firms, but not pharmaceutical firms, sector 6 includes computers, electrical machinery, and electrical and communication equipment, while sector 9 brings together the textile, paper, wood, glass, and miscellaneous manufacturing industries. Petroleum refining is excluded from our definition of "manufacturing."

8. See Bound, Cummins, Griliches, Hall, and Jaffe (1984) and Hall, Cummins, Laderman, and Mundy (1988) for a discussion of the construction and description of this data set, which includes also a match to the Patent Office data on the number of patents granted to these firms.

9. If we do not require consistent reporting of R&D expenditures we have samples of about 1,000 manufacturing firms in each country. Because of the significant and intermittent nonreporting of R&D one cannot assume that the other firms (the ones not included) are truly "zero-R&D" firms. Thus one cannot separate our samples cleanly into R&D and non-R&D firms and compare the results. This has only been possible in a study for France, because it was conducted within the National Institute of Statistics and we had access to the individual data of the French R&D survey (see Mairesse and Cuneo 1985).

10. The coverage ratios in table 11.4 are for the most recent year that we had data for in both the NEEDS and R&D surveys (1981) but they are not much different in the earlier years. There has been little improvement in R&D reporting in the NEEDS data base. The coverage ratios for the large firms were 30% and 35% in 1976 and 1981, respectively. Firms that do report their R&D in the NEEDS data base do so continuously and apparently on a consistent basis.

11. Even if the total R&D levels are about right (after correction) and comparable in the two countries, if the individual observations are subject to much error and different reporting practices (especially for the smaller R&D performers), our subsequent regression-based estimates of the "importance" of R&D may be significantly biased downward. Actually, however, adjusting the R&D data for the 18 large R&D-performing firms, using the OECD (1984) information, had very little effect on our regression estimates.

12. See Bound et al. (1984) for more detail.

13. The 2-digit deflators for Japan are taken from the Prices Indices Annual issues (Bank of Japan, various years). In previous work, we were able to verify that using 2-digit deflators, instead of more detailed ones, in the case of the United States had very little effect on the regression estimates.

14. See the appendix of Griliches and Mairesse (1984) for more detail on the adjustment of the gross plant numbers for inflation. Using alternative measures for physical capital had little effect on our results.

15. Using a more appropriate price deflator for the drug companies in Japan than one used for the chemical industry as a whole (which was done in an earlier version of the paper) results in a significant rise in their estimated productivity growth, but it has no effect on regression results that allow for separate industry constants.

16. The macroestimates for Japan are taken from the Annual Reports on National Income Statistics. Those for the United States are constructed from output series based on the Survey of Manufactures and from the price indices used in National Accounts—see Griliches and Lichtenberg (1984) for details. Note that table 11.6 is based on total samples, not just the R&D firms. A comparison of tables 11.5 and 11.6 with 11.7 shows only minor differences between our total sample and the R&D firms subsample.

17. Our numbers are also consistent with the macroevidence given in Jorgenson, Kuroda, and Nishimizu (1987).

18. A number of issues are ignored in such a framework, not because they are unimportant, but primarily because there is little that we can do about them here. For example, much of the Japanese progress may be based on imported technology, for which we have no data. However, to the extent that R&D expenditures are required to absorb borrowed or imported technology, this may still be captured, in part, by our measures. We can also do little about the role of government R&D support (there are no data on this at the firm level in either data base) or spillovers in this context (see Griliches 1979 for a discussion of these and other caveats).

19. See Griliches (1979) and Griliches and Lichtenberg (1984) for a related discussion of such models.

20. There are several difficulties in interpreting the estimated coefficient of R&D intensity, ρ, as the marginal product of or rate of return to R&D. The exact meaning of the estimated ρ depends on the measure of R&D intensity, the measure of output, and what else is included in the equation. Since we use an R&D to sales ratio, ρ should be interpreted as a gross marginal product in terms of output. But leaving material inputs out of the equation brings it closer to a value-added interpretation, which would presumably have resulted in a lower coefficient if value added were substituted for sales in the denominator. On the other hand, leaving out the "depreciation" of the existing R&D capital stock would bias the estimated coefficient downward (on the order of a half). It is also the case that the estimated ρ may be affected by the fact that R&D labor and R&D capital are counted twice, once in the available measures of labor and physical capital and again in the measure of R&D. Hence ρ might be viewed as an excess marginal product or rate of return (above the usual remuneration). Such an interpretation must be qualified however, since it does not apply easily to estimates in the time dimension (see Griliches 1979; Schankerman 1981; Griliches and Lichtenberg 1984; and Cuneo and Mairesse 1984 on these matters). Thus the estimated ρ coefficients are only very distant reflections of the relevant "rate of return" concept.

21. We also tried shorter lags, i.e., by defining the R&D measure as of 1976 (the middle of our period) but this produced significantly worse results in both Japan and the United States. We could not really try for longer lags within the framework of our data bases.

22. Using sales in 1973 or an average of 1972 and 1974 sales as a base does indeed make our results look significantly better. Using the $R/S73$ (estimated) ratio (i.e., $2R73/[S72 + S74]$) in eq. 5 of table 11.8 for example, we get for its coefficient .36 with a t-ratio of 2.6 in Japan and .42 with a t-ratio of 5.5 in the United States. These are significantly higher than the comparable numbers in table 11.8. Since the R&D numerator is the same in both measures, this does imply that our worries about potential spuriousness may not be groundless.

23. The higher capital elasticity estimate in Japan is consistent with the higher capital share in output reported by Jorgenson, Kuroda, and Nishimizu (1987).

24. About half the inflation during our seven-year study period of 1973–80 took place in the first year, 1973–74, and in the last one, 1979–80, as a consequence of the two oil shocks of 1973 and 1979. We thought that the potential errors in price deflators and hence in our productivity measures would thus be smaller for the shorter period 1974–79 and hoped for better results over this period.

25. The estimated physical capital elasticity also varies from year to year. But since the growth in the capital-labor ratio and R&D intensity are nearly uncorrelated, the R&D coefficients are almost unaffected by the constraining of the capital coefficient implicit in the TFP equations.

26. Using average rates of growth over a number of years to estimate the relation of productivity to R&D has the advantage of minimizing the possible biases due to measurement errors and to the timing problem. We expected, therefore, to find instability when looking at this relation on a single year basis, but not to such an extent.

27. Given the high standard errors associated with the Japanese estimates, it is not strong evidence against this hypothesis either.

28. See Griliches (1980, 1984) and Griliches and Hall (1982) for more detail on these data and their construction and for results of analyses using them.

29. Since this was first written we have been informed that such efforts are indeed underway by researchers associated with the Economic Planning Agency in Japan. See Goto and Suzuki (1989).

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Comment Edwin Mansfield

In this paper, which is a continuation of work they have carried out concerning the United States and France, Zvi Griliches and Jacques Mairesse compare the contribution of R&D to economic growth in Japan and the United States. They conclude that there is no strong evidence "that differences in either the intensity or the fecundity of R&D expenditures can account for the rather large difference in the observed rates of growth of productivity between the two countries."

Before commenting directly on their paper, I would like to summarize some of my own results, which supplement those of Griliches and Mairesse. First, it appears that there are advantages in disaggregating R&D into (1) applied R&D and (2) basic research. Using a model similar to that employed by Griliches and Mairesse, me, and others, there is evidence, based on industry data, that applied R&D in Japan has yielded a higher rate of return than in the United States. This seems reasonable, given Japan's greater emphasis on commercial (rather than government-financed) projects and its reliance on advanced technology from the West, which could be adapted and improved at relatively low cost. On the other hand, my econometric results provide no indication that basic research has been particularly effective in Japan.[1]

Second, it is very important to disaggregate R&D into process and product R&D. The American firms in my sample devote about two-thirds of their R&D expenditures to the improvement of product technology (new products and product changes) and about one-third to the improvement of process technology (new processes and process changes). Among the Japanese firms, on the other hand, the proportions are reversed, two-thirds going for the improvement of process technology and one-third going for the improvement of product technology. It seems likely that Japan's relatively high returns from applied R&D are due in part to its emphasis on process R&D.[2]

Third, there is considerable evidence that the Japanese develop and commercially introduce new products and processes more quickly and cheaply than do their American rivals, although the extent of this difference varies considerably from industry to industry. For innovations based on external technology (i.e., technology developed outside the innovating firm), the Japanese have a big advantage. For innovations based on internal technology (i.e., technology developed within the innovating firm), they have no advantage that I could detect.[3]

Fourth, there is a marked difference between Japan and the United States in the allocation of resources within the innovation process, this difference being undetectable if one looks at R&D alone. The percentage of total innovation cost devoted to tooling and manufacturing equipment and facilities in Japan is almost double that in the United States. This reflects Japan's emphasis on

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process engineering and efficient manufacturing facilities. Equally striking is the fact that the percentage of total innovation cost devoted to marketing start-up (i.e., preintroduction marketing activities like market research) in the United States is almost double that in Japan. If American firms could reduce this percentage to the Japanese level (while holding constant the amounts they spend on other stages of the innovation process), it appears that about 60% of the Japanese cost advantage would be eliminated.[4]

Fifth, it is instructive to look at industrial robots, an important industry where Japan is widely regarded as being ahead of the United States. In both countries, high-growth robot producers tend to devote a much higher proportion of innovation costs to tooling and manufacturing facilities than do low-growth robot producers, and the proportion devoted to marketing start-up seems to be much lower among high-growth than low-growth robot producers. Based on the available data, it appears that the more successful firms in both countries, like the Japanese, tend to emphasize manufacturing in the innovation process, not marketing.[5]

Sixth, although the industrial robot was largely an American invention, the rate of diffusion of robots has been slower in the United States than in Japan. In both the United States and Japan, the imitation process can be represented reasonably well by a simple econometric model similar to that in Mansfield (1961). According to the results, Japan's higher rate of imitation can be explained entirely by its later start, which enabled it to utilize earlier experience in the United States and elsewhere. But this does not explain the much higher intrafirm rates of diffusion of robots in Japan than in the United States, which seem to be due in considerable part to differences in the minimum rate of return required to justify investing in robots.[6]

Having provided this brief summary of some of my results in this area, I would like to stress that Japan's relatively rapid rate of technological change has been due largely to the importation of foreign technology. In 1978, the Ministry of International Trade and Industry carried out a survey of Japanese business leaders to determine the relative contributions made by domestic and foreign technologies to product quality and production processes. According to the results, purely indigenous technology accounted for only about 5% of the advances in product quality and about 17% of the advances in processes.[7] While surveys of this sort obviously must be treated with caution, a host of case studies indicate essentially the same thing. For example, in high density polyethylene, Sumitomo Chemical licensed technology from ICI, Mitsui licensed technology from du Pont, and Mitsubishi licensed technology from Gulf Oil.

To a considerable extent, Japan's success in utilizing and obtaining foreign technology has been due to its effectiveness in monitoring foreign technological developments. In 1983, I asked 100 major American firms in 13 industries to rank each major country's firms with regard to their effectiveness in this regard.[8] The consistency with which the Japanese were ranked first is an impressive tribute to the systematic programs carried out by both Japanese firms and government agencies to learn about foreign technology (see table 1).[9] Of course, the effectiveness of the intelligence-gathering activities of a nation's firms depends in part on how much they spend on such activities. As shown in table 2, less than 30% of the American firms in the above survey

Table 1 **Average Rank of Five Major Countries by the Perceived Effectiveness of Their Industry in Monitoring Technological Development outside Their Own Country, 1983**

Industry	France	Germany	Japan	United Kingdom	United States
Chemicals	3.8	3.0	1.5	4.4	2.2
Pharmaceuticals	4.2	3.1	1.4	4.2	2.0
Petroleum	3.6	2.2	1.2	4.6	3.0
Primary metals	4.2	2.7	1.0	4.6	2.5
Electrical equipment	3.8	2.9	1.0	4.0	3.3
Machinery	3.8	2.7	1.2	4.4	2.8
Transportation equipment	3.7	2.0	1.0	4.7	3.7
Instruments	4.1	2.6	1.4	3.7	3.3
Rubber	3.5	3.0	1.0	5.0	2.5
Stone, clay, and glass	4.0	3.6	1.0	3.8	2.6
Other[a]	4.0	2.8	1.5	4.2	2.4
Average	3.9	2.8	1.2	4.3	2.8

Source: See n. 8.
[a]Includes fabricated metals, food, and paper.

Table 2 **Percentage of U.S. Firms Spending at Least as Large a Percentage of Sales on Monitoring Foreign Technological Development as the Average Amount Spent by Their Foreign Rivals, 1983.**

	Percentage of U.S. Firms Compared With Firms in			
Industry	France	Germany	Japan	United Kingdom
Chemicals	58	58	42	67
Pharmaceuticals	78	89	33	89
Petroleum	60	40	22	60
Primary metals	60	50	60	80
Electrical equipment	44	33	22	56
Machinery	20	20	10	40
Transportation equipment	67	33	33	67
Instruments	56	67	33	56
Rubber	0	0	0	100
Stone, clay, and glass	60	60	0	80
Other	58	67	67	75
Average	51	47	29	70

Source: See n. 8.

reported that they spent as much (as a percent of sales) on these activities as their Japanese rivals. American firms have been criticized for their "apparent inability to adequately scan and adopt foreign R & D."[10] Perhaps they would do better if they devoted more resources to intelligence-gathering of this sort.

Given the overwhelming importance of the importation of foreign technology to Japan's success story, as well as the less publicized fact that the United States also benefits greatly from imported technology, it should be noted that the model used by Griliches and Mairesse assumes that a firm's rate of productivity increase depends only on its *own* R&D expenditures, not on the amount it spends on foreign technology or on the amount spent on R&D by foreigners. I recognize that it is not easy to include international technology transfer in models of this sort,[11] although a few limited attempts have been made (e.g., Mansfield 1984; and Mansfield and Romeo 1984), but there is the obvious possibility that the omission of technology imports may result in serious specifications errors, particularly in the case of Japan.

Moreover, leaving aside international technology transfer, their model also ignores the impact of one American (or Japanese) firm's R&D on another American (or Japanese) firm's rate of productivity growth. As many econometric analyses and case studies have indicated, these impacts frequently are very substantial. Much of the R&D carried out by the typical firm is aimed at advances in its products, not its processes, and hence may have more effect on the productivity of its customers than its own productivity. For this reason, work during the past decade (see, e.g., Mansfield 1980; Scherer 1982; and Terleckyj 1974) has tended to focus on the total amount of R&D used by a particular industry or firm, rather than the amount of R&D originating in a particular industry or firm. Again, I understand the data problems that Griliches and Mairesse encountered, but it is unfortunate that they were forced to ignore these important interfirm effects.

Also, their model assumes that a firm's government-financed R&D has no effect on its rate of productivity growth. Case studies indicate that major spillovers have occurred from military and other government-financed R&D to the civilian economy. Recent econometric studies by Mansfield and Switzer (1984), Levy and Terleckyj (1983), and others suggest that a firm's government-financed R&D tends to enhance the productivity of its company-financed R&D. While government-financed R&D ordinarily has considerably less effect on a firm's rate of productivity growth than company-financed R&D, there are problems, particularly in a comparison of the United States and Japan, in ignoring it altogether.

In addition, the regressions that Griliches and Mairesse run are subject to identification problems. There is the distinct possibility that firms with relatively high rates of productivity growth tend to have the sorts of managements and other characteristics that lead to relatively high R&D expenditures. Thus, the line of causation may run both ways, and their estimates of the effect of a firm's R&D on its productivity growth may be biased. Further, although relatively little is known about the time lags from R&D to the commercial introduction and diffusion of technical advances stemming from that R&D, the available evidence indicates that these lags frequently are long enough so that R&D in 1973 had effects on productivity that were not felt until after 1980, when the analysis ends.

In conclusion, as Griliches and Mairesse recognize, while it is true that "we cannot reject the hypothesis that the contribution of [R&D] expenditures to productivity growth was about the same in both countries," it is also true that, on the basis of their results, one cannot reject the hypothesis that there is a considerable difference in this regard between the two countries. Obviously, this is not the fault of the authors; as they point out, the data they use are imperfect in a number of ways. I agree with their statement below, that "the omissions arise largely from the state of the available data and are not something we could do very much about." Nonetheless, their study sheds light on an important topic.

Notes

1. For further discussion, see Mansfield (1988a).
2. Ibid.
3. For further discussion, see Mansfield (1988b).
4. Ibid.
5. For further discussion, see Mansfield (1987).
6. For further discussion, see Mansfield (1989).
7. See Okimoto (1986), 544.
8. Each firm included in the survey was chosen at random from a list of major firms in the 13 manufacturing industries in table 1. In general, it was the firm's vice president for research and development who responded, and there was essentially no problem of nonresponse. This survey was part of a larger study I carried out, which was supported by a grant from the National Science Foundation.
9. For an interesting case study in the steel industry, see Lynn (1982). It is important to note in this regard that new technology tends to leak out relatively quickly. See Mansfield (1985).
10. Report of the Conference on U.S. Competitiveness, Harvard University, 1980.
11. For some relevant discussion, see Mansfield et al. (1982).

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Reply

Zvi Griliches and Jacques Mairesse

In his comment, Mansfield reports on several aspects of his own work in this area which indeed make a valuable contribution to our limited knowledge of these matters; he notices a number of omissions and ambiguities in our work. The omissions arise largely from the state of the available data and are not something that we could do very much about. What we tried to do is to analyze, to the best of our abilities, the data that do exist and to which we had access. Admittedly, they are incomplete, but progress is made, we believe, by trying to comprehend an imperfect world in imperfect ways.

We have only a few comments on some of the points raised by Mansfield. While monitoring technological developments elsewhere is clearly an important activity for any technologically "active" firm, it is not entirely obvious how this should impinge on measured productivity numbers. Even though France has the second worst record in this regard in Mansfield's table 1 above, much worse than the United States, French firms nevertheless experienced a significantly higher rate of productivity growth in the 1970s than their U.S. counterparts (Griliches and Mairesse 1983).

Knowledge spillovers are indeed a major omission in our analysis. It is not a topic that can be handled easily at the individual-firm level, unless one has a much richer data base that would allow the construction of some differential measure of technological "connectedness" between firms. Otherwise, this is an effect that would be common to all firms within an industry. In the United States, where we have had access to more detailed data, it has been possible to construct a measure of technological distance between firms and make more progress on the measurement of spillover effects (see Jaffe 1986).

We did ignore governmentally financed R&D expenditures because there were no data on them in our sources. The evidence on the effect of such expenditures on the magnitude and productivity of privately financed R&D is mixed. Griliches (1986) finds only small effects, while Lichtenberg (1984) interprets the stimulating effect of governmentally financed R&D as reflecting the rent-seeking behavior of firms, stimulated by governmental defense procurement activities, rather than a direct productivity spillover.

It is obvious that lags and differences in lag structures are an important aspect of the R&D story. Our functional form, which relates differences in average growth rates to differences in R&D intensity, is, however, not well adapted to looking at this question. We have some scattered evidence showing that moving the R&D dating from 1972–74 to 1976 in analyzing 1973–80 growth rates deteriorates our results somewhat. Thus, there is an indication here that there may indeed be nonnegligable lags in this process.

The causality issue is also very important and has been discussed by us in other contexts. Here, the best we could do is to relate "subsequent" growth (1973–80) to "early" (1972–74) R&D intensity. To do more, will require a full-fledged theory of R&D investment, a topic on which some of us have been working in recent years (Mairesse and Siu 1984; Pakes 1985; Hall and Hayashi, 1989; Lach and Schankerman 1989; and Griliches, Hall and Pakes 1990).

There are also a number of difficulties not mentioned by Mansfield, especially problems associated with the measurement of total factor productivity, the measurement of output and price in technologically sophisticated and changing industries, and the associated problems of making international comparisons that may overshadow the other issues discussed by Mansfield and us. Nevertheless, something is to be learned from looking at the data as they are and then trying to improve on them. Our work is only a first step in this direction and a progress report from a continuing quest for understanding. We have, indeed, benefited from the comments of Mansfield and other participants in this discussion and we hope that this will reflect itself in our future work on this range of topics.

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