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The Impact of R & D on Productivity Increase in Japanese Manufacturing Companies

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Abstract

This paper estimates the impact of R & D expenditures (as a ratio to value added) on the rate of total factor productivity increase using the data of 135 to 168 Japanese manufacturing companies in each of two periods -- Period I (1966 - 1973) and Period II (1974 - 1982). The rate of return on R & D stock is estimated at 20 percent in Period I and 17 percent in Period II, but is found to decrease when industrial intercept dummies or the rate of deflated sales growth is added as an explanatory variable, which is interpreted as suggesting the interindustry differences in the rate of exogenous technical progress and the existence of learning effect. Interindustry differences in the rate of return on R & D are also investigated.

1. Introduction

This paper purports to investigate the contribution in Japan of R & D expenditures to the increase in total factor productivity (TFP). In addition to being a (rare) study for Japan, it has two novelties. One is the use of company data in place of more commonly used industrial data, similarly to Link (1981), Griliches and Mairesse (1984), and Cuneo and Mairesse (1984). Whereas the latter two estimated a Cobb-Douglas production function with deflated sales as the measure of output, and capital stock, employment, and R & D stock as the inputs, with the combined data of time series and interfirm cross section, our anaylsis, like Link's, regresses the rate of TFP increase on the intensity of R & D, namely R & D expenditures as a ratio to value added, by means of interfirm cross section.[1)] This approach has the advantages of allowing the production coefficients to vary across firms and avoiding the possible bias due to simultaneous output and input decisions, but also the disadvantage of presuming competitive factor markets, cost minimization, and constant returns to scale.

The other novelty is our examining the impact of output growth on TFP increase, to show that the marginal productivity of R & D tends to decrease when output growth is taken into account. Elsewhere one of the authors (Odagiri, 1985) observed the same tendency with the Japanese industrial data of 1960-1977 and argued that this owes to the learning effect which can be properly reckoned only with a simultaneous equations system. Though the present analysis is confined to a single equation model, one may think of it as complementary to that previous analysis.[2)]

Before proceeding to the discussion in Section 2 of the data, variables and models, the results in Sections 3 and 4, and the summary and conclusion in Section 5, let us briefly mention the advantages and disadvantages in the use of company data as compared to the use of industrial data. An obvious advantage is an increase in the number of observations. Thus we had only 15 observations in Odagiri (1985) whereas here we have 135 to 168 observations. The second advantage is that we can now inquire into the differences across firms within an industry which may be assumed to possess more or less equal technological opportunities. Thus the variances in TFP increase across firms may be now separated between those resulting from different R & D intensity and those resulting from the different speed of change in basic technology which tends to be common knowledge to all the firms in the industry.

The disadvantage, on the other hand, is the weaker confidence in the accuracy of the data, which stems from two sources — deflators and R & D expenditures. In calculating the rate of change in TFP, value added and capital assets have to be deflated. The choice of the deflator is particularly difficult with the company data because deflators are only available at the industry level whereas the firms often operate in multiple industries and change the composition of their products over time.

R & D expenditures are reported by many, thought not all, of the Japanese firms in their financial statements. However, there is no regulation as to which expenses to be included under the heading of R & D expenditures; consequently, the coverage may differ from firm to firm. Thus the company R & D data is likely less accurate than the industrial R & D data, which is compiled by the government who sends the questionnaires with a detailed definition of the items concerned. For these reasons, the company data may be less reliable than the industry data and this disadvantage has to be weighed against the above advantages, particularly the advantage of a big sample.

2. Data and Variables

Our basic sample consists of 311 Japanese manufucturing firms that satisfy three conditions: i) listed on the Tokyo Stock Exchange (Market 1) through

1966 to 1983, ii) without any merger that substantially changed the size of the firm (e.g., by more than a quarter), and iii) all the data needed to compute for TFP are available in the NEEDS financial data tape.[3)] Because among these firms were many who did not report the R & D expenditures, it was necessary either to assume that these firms did not expend any for R & D or to drop these firms out of our sample. The first alternative is hardly appealing when, as we found, such supposedly research intensive firms as Hitachi, Matsushita and Honda did not report the figures. Hence we decided to confine our analysis to those firms reporting the R & D expenditure.[4)]

The period of study, 1966-1982, is divided into two periods, Period I (1966-1973) and Period II (1974-1982). Since the oil embargo and the sharp rise in the price of crude oil in 1973-1974 is believed to have had tremendous effects on the industrial structure of Japan as witnessed by its being called the 'oil shock' there, it is appropriate to allow for a structural change between before and after the shock by dividing the entire period into two. This leaves each period with eight or nine years which is perhaps long enough to capture the lagged effect of R & D. The number of sample firms is 135 in Period I and 168 in Period II.

We have computed the rate of change in total factor productivity, V, with the following formula (t refers to the fiscal year that starts in April and ends in March of the following calender year):

$$V = \sum_{t=t_1}^{t_2} \left[\frac{Y_t - Y_{t-1}}{Y_{t-1}} - \frac{S_{t-1}+S_t}{2} \frac{L_t - L_{t-1}}{L_{t-1}} - \left(1 - \frac{S_{t-1}+S_t}{2}\right) \frac{K_t - K_{t-1}}{K_{t-1}}\right] / (t_2 - t_1 + 1)$$

where Y_t is the real value added, L_t is the number of employees, K_t is the real capital assets, S_t is the labor share, namely, total employee compensations devided by value added, t_1 is 1966 in Period I and 1974 in Period II, and t_2 is 1973 in Period I and 1982 in Period II. Y_t and K_t have been obtained with the following deflation procedures. To get Y_t, we divided the sum of employee compensations, depreciation allowances, and operating profits by the wholesale price index for the industry the firm is supposed to belong.[5)] To get K_t, we first obtained the real capital stock as of 1966 by multiplying the reported figures of the non-land tangible fixed assets and land by the respective current-value-to-book-value ratios of the same year estimated by Konya and Wakasugi (1981) of the industry the firm is supposed to belong, and then for each year added the increments of buildings, land, and other tangible fixed assets deflated with, respectively, the deflator for non-dwelling construction, the price index for the land in industrial use, and the price index for capital goods.[6)]

When the assumptions of constant returns to scale, price-taking behavior in factor markets, and cost minimization are satisfied, V is a proper measure of the rate of increase in total factor productivity.[7)] In addition, if R & D stock can be assumed to increase by the amount of current R & D expenditures, the slope coefficient in the regression of V on the ratio of R & D expenditures to value added, SRD, is the measure of the rate of return on R & D stock, whereas the intercept is the measure of the rate of exogenous disembodied technical progress (see Link (1980)). In our analysis SRD is measured by the average of the ratios of R & D expenditures to value added in the first two years of each period; hence, from the time of expending on R & D to the time of resultant productivity increase, the maximum lag of seven to eight years is allowed.

Other variables used in this analysis are as follows:

SIZE: sales (deflated to the 1966 price) in common logarithms

SAT: advertising expenditures as a ratio to sales

GSK: the annual rate of increase in the ratio of net worth to total assets

GSL: the annual rate of increase in deflated sales.

All these variables were obtained as the average of eight (in Period I) or nine (in Period II) yearly figures. These are included in the linear regressions as the independent variables implying that the rate of non-R & D-dependent disembodied technical progress is supposed to be affected by these factors. That SIZE is used to examine the different speed of technical progress between big firms and smaller firms and SAT is used to examine the influences of advertising intensity should be rather obvious. GSK is used as a proxy for managerial ability. It has been long argued among Japanese businessmen that the Japanese firms are too much levered, that is, their net-worth-to-total-assets ratios are too low. Their desire to increase the ratios, however, was perhaps not only difficult to fulfill but also suboptimal in the fast-growing Period I when investment opportunities were abundant. This changed after the oil shock because investment opportunities became scarcer and the financial markets liberalized so that chronic excess demand for funds observed before the oil shock has in effect disappeared, with the consequence that many excellent firms decreased their debts. According to this popularly held notion, therefore, the excellently managed firm should have a larger GSK in Period II and it should be reasonable to assume that such a firm has been also keen in raising the productivity.

To test the nonlinear effect of size and growth, we also tried the SIZE squared, SIZESQ, and the GSL squared, GSLSQ. The coefficient(s) of one or two of these are reported only when they are significant (which turned out to be rather rare). Otherwise we report the estimated regression without the squared terms.

3. Results

The basic results are presented in Table 1. Equation (1) does not include the growth rate variable GSL or industry dummies and is closest to the equational form usually used to estimate the rate of return on R & D stock. The results show that this rate was 20 percent in Period I and 17 percent in Period II. While these figures appear intuitively reasonable, we note that the rates may be underestimated due to the double counting of research capital equipments in both K and SRD and of scientists in both L and SRD. In fact, as Schankerman (1981) has shown, the coefficient on SRD when R & D is double-counted may approximate the return on R & D as an excess to the return on non-R & D inputs. Hence it seems appropriate to assume that the true rate is somewhat larger than the estimated rate (20 or 17 percent) but does not exceed the sum of the estimated rate and the rate of return on conventional inputs.

In estimating equation (2), we added 14 (in Period I) or 15 (in Period II) industry dummies as explanatory variables,[8)] to allow for the different rates of exogenous technical progress across industries. Not surprisingly the fit improved significantly. More interestingly, the estimated rates of return have decreased to 17 percent in Period I and 11 percent in Period II with the t-values having also decreased. This suggests that in an industry with rapid progress in basic technology V is increased by both exogenous technological forces and the stimulated R & D activity in the industry, resulting in a larger slope coefficient when the intercept is fixed as common to all the industries. Thus the rates in equation (1) may better be considered overvalued.

The estimated coefficients of industry dummies tended to be larger for such high technology industries as the electric equipments and precision instruments industries, and smaller for the foods and petroleum refinery industries in Period I and the petroleum refinery, chemical, glass and cement industries in Period II. These industries (particularly in Period II) are known as energy-consuming and are usually said to have seriously suffered from the oil shock. The results seem to support this argument.

In equations (3) (without industry dummies) and (4) (with dummies), we added the real sales growth rate GSL as an explanatory variable. This variable turned out to be highly significant. More impressively all the coefficients of SRD now have smaller estimates as well as smaller t-values (except for the slightly larger t-value with Period I, equation (3)) to the extent that three out of the four estimates are now insignificant at the 10 percent (two-tailed) level. Thus with the dummies the rate of return is now estimated to be 16 percent in Period I and 7 percent in Period II, though these are significant only at the 22 to 20 percent level.

This tendency, the highly significant effect of output growth and the reduced coefficient of the R & D variable, agrees to what Odagiri (1985) observed with the industrial data. Because the definitions of TFP and R & D intensity are different between the previous analysis and the present one as well as the observation units, a direct comparison of the estimated rates of return (which are much larger in Odagiri (1985)) is perhaps misleading; however, the comparison across models within each analysis is meaningful and that this comparison yielded the same result between the two studies is encouraging. As discussed in the previous analysis, we consider this finding to be the evidence of a strong learning effect. That is, when R & D activity is made, this will first increase the productivity, which will then enhance output growth through a lowered price or improved quality. This output growth will in turn further increase the rate of productivity increase when the learning effect is present, which takes place as a result of the accumulation of skills, knowhows and experience in the human and physical resources of the firm. With this interaction of the learning effect and research activity, the contribution of R & D on productivity increase tends to be overestimated if the output growth variable is excluded, because the estimated coefficient captures the learning effect as well.

Although the investigation of this interaction between the learning and research effects can be precise only with a simultaneous equations system as in the previous study, we confined our analysis here to the OLS estimation of a single equation model because the feedback of productivity increase to output increase through lowered prices is difficult to formulate and the price data is not available at the firm level. Notwithstanding this limitation in the present study, the estimated result strongly indicates the presence and importance of the learning effect.[9)]

Another observation that agrees with the previous study is the consistently lower estimate of the rate of return in Period II than in Period I. Thus suggested is a decline in the productivity of R & D expenditures after the oil shock.[10)]

Finally, not many significant results were obtained as for the variables other than SRD and GSL. GSK always have positive coefficients as expected but the coefficient is significant at the 5 percent level only in the model with GSL and dummies for Period II. Thus the hypothesis of GSK measuring the managerial ability is only partly supported. The effect of advertising intensity is negligible. The effect of size tends to be negative, implying that small firms are *ceteris paribus* more successful in raising TFP, but not significant. In Period II, when industry dummies are not used, we found a significant quadratic effect. From the estimated coefficients, we found that *ceteris paribus* V hits the bottom at the size slightly larger than the sample mean.

4. Industrial Differences

The analyses in the last section allowed the constant term to vary across industries but not the coefficient of SRD. That is, we presumed that the marginal contribution of R & D on productivity increase does not vary across industries. Since there may be arguments against this presumption, it is desired to inquire into the industrial differences in this respect.

A most straightforward such inquiry can be made by employing a slope dummy on SRD for each industry in addition to the intercept dummy. This regression, however, proved that none of the slope dummy is statistically significant in either period. Moreover, some of the estimated combinations of slope and intercept dummies did not make much sense, perhaps because the number of observations is limited in some of the industries and hence the presence of one or two extraordinary sample exerted a strong bias.[11)] The result is not reported therefore. Nevertheless it gives two important implications. First, the presumption of constant coefficient of SRD across industries in the previous section may not be farfetched. Second, if the industrial differences should be nonetheless investigated, the industrial classification may better be broad so as to give large degrees of freedom for each category.

Two such attemps are reported in Table 2. The first takes note of the exceptionally high research intensity of the pharmaceutical industry and divide the whole sample into pharmaceuticals and others. The second separates four research intensive industries; the chemical, pharmaceutical, electric equipment, and presicion instrument industries. Odagiri (1983) called the firms in these industries <u>innovators</u> and others, <u>noninnovators</u>. Griliches and Mairesse (1984) made a similar distinction, calling the firms in the chemical, pharmaceutical, computer, electronics, and instrument industries <u>scientific firms</u> as opposed to <u>other firms</u>.

When the pharmaceutical firms are excluded, the estimated coefficient of SRD increases in Period I if the industry intercept dummies are not used, but decreases if they are used. In Period II all the coefficients decrease and are not significant. In the pharmaceutical industry, the coefficients increase in Period I (with or without GSL) and in Period II (with GSL). The degrees of freedom here are only seven, however, and the reliability of the estimates should not be emphasized.

Odagiri (1983) showed that research intensity (R & D expenditures divided by sales) affects the rate of sales growth in 1969-81 only for the innovators, and Griliches and Mairesse (1984) showed that the marginal productivity of R & D stock is positive and significant for the scientific firms but negative and insignificant for the other firms. Looking at Table 2 we found the same tendency in Period I (though the estimates are not significant) but a reverse tendency in Period II. One of the major causes for these tendencies may be the performance of the chemical and petroleum refinery industries. As discussed previously, these are the typical energy-consuming industries and recorded the lowest V in Period II. However, the research intensity is quite different between the two industries. The chemical industry, on the one hand, is research intensive and the firms there recorded large SRD. It is therefore conjectured that the combination in these firms of large SRD and relatively high V in Period I and very low V in Period II has resulted in the observed tendency for the innovators. The petroleum refinery industry, on the other hand, has small SRD. Thus the combination of small SRD and low V in this industry in Period II may account for the positive and significant coefficient of SRD for noninnovators in this period.

Another possible cause is the incompleteness of the data. As discussed in Section 2, some of the highly research intensive firms with a large TFP increase in the innovating industries are excluded from our sample due to their not reporting the R & D expenditures. It appears not difficult to suppose that a positive impact of SRD on V would have been more strongly observed were it not for this incomplete sample.[12)]

5. Summary and Conclusion

We have estimated the impact of R & D intensity on the rate of total factor productivity increase using the data of 135 to 168 Japanese manufacturing companies in each of two periods — Period I (1966-1973) and Period II (1974-1982). Without industrial dummies and the growth rate variable, the rate of return on R & D stock was estimated at 20 percent in Period I and 17 percent in Period II. When industrial (intercept) dummies are introduced to allow for the interindustry differences in the rate of exogenous technical progress, the estimated rate decreased. Also when the rate of deflated sales growth is added as an explanatory variable, the rate decreased. The latter fact is interpreted as an evidence of the learning effect, following Odagiri (1985). The attempts to discover the interindustry differences in the contribution of R & D yielded only a few clear or expected results. Attempts were made to explain this result.

In general, the results obtained here are complementary to those in Odagiri's previous analysis based on the industrial data and indicate an important contribution of R & D activity in Japan as well as the presence of the learning effect.

Notes

1. This methodology has been used by many in the analyses with industrial data: see, e.g., Terleckyj (1980), Mansfield (1980), and Griliches and Lichtenberg (1984).

2. Another study of the R & D-productivity relation in Japanese manufacturing industries was given by Caves and Uekusa (1976).

3. Published by Nihon Keizai Shimbunsha, Tokyo.

4. In some of the preliminary studies we also made estimations with the first assumption. The general tendency seemed unaffected and $\bar{R}^2$ usually increased by dropping the non-R & D-reporting firms.

5. The industrial classification of the firms followed that used in the Tokyo Stock Exchange.

6. In adding the deflated net increase of capital stock rather than adding the deflated gross investment and deducting the retired capital stock (of which the data is unavailable), our measure of K_t may be overestimated by the extent that the new capital to replace the retired one is not deflated.

7. However, the use of value added as a measure of output rather than output itself (treating materials as one of the inputs) maybe the source of some bias. See Bruno (1978).

8. The number of dummies is smaller in Period I because the number of sample firms in the metal products industry was zero in Period I but positive in Period II.

9. Another cause of the strong effect of GSL can be a vintage effect. A larger GSL implies a larger proportion of newer capital. If the newer capital is more productive than older capital of the same (deflated) cost, our measure of capital increase will underestimate the increase in productive capacity and V will overestimate the TFP increase for a firm with large GSL.

10. Odagiri (1985), however, shows that though the rate is lower in 1973-77 than in 1966-73, there is no evidence that the 1973-77 rate is lower than the rate in 1960-66 with some evidences suggesting otherwise.

11. The firms in five industries were excluded from the sample in this regression because the number of the firms in each of these industries was too small (e.g., less than three).

12. Because in Odagiri (1983) non-R & D-reporting firms were assumed to have expended zero for R & D, for comparability we repeated the above regressions under the same assumption. The comparison between innovators and noninnovators discussed above was found unaffected in any essential manner by this alternative assumption.

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Table 1. Estimation Results

Period	Equation No.	Constant	Variables						$\bar{R}^2$
			SIZE	SIZESQ	GSL	SAT	SRD	GSK	(adjusted)
I	(1)	13.598* (3.303)	- 0.509 (- 0.572)			-0.201 (-1.358)	0.201*** (1.842)	0.0669 (1.113)	0.01252
	(2)	6.401 (1.459)	- 0.248 (- 0.276)			0.0449 (0.292)	0.170 (1.263)	0.102*** (1.781)	0.2164
	(3)	10.086* (2.681)	- 0.956 (- 1.186)		0.372* (5.577)	-0.138 (-1.025)	0.187*** (1.902)	0.00253 (0.0456)	0.1982
	(4)	3.572 (0.876)	- 0.533 (- 0.644)		0.412* (4.723)	0.0895 (0.632)	0.156 (1.260)	0.0450 (0.834)	0.3380
II	(1)	64.048** (2.220)	-26.595** (- 2.201)	2.817** (2.240)		0.0638 (0.445)	0.169* (2.878)	0.00376 (0.226)	0.05480
	(2)	3.723 (1.322)	- 0.542 (- 0.934)			-0.0526 (-0.489)	0.113*** (1.906)	0.0180 (1.610)	0.5806
	(3)	47.852** (2.087)	-18.649 (- 1.941)	1.810*** (1.806)	0.570* (9.842)	-0.0537 (-0.469)	0.00138 (0.0279)	0.0164 (1.240)	0.4063
	(4)	6.237** (2.308)	- 1.081*** (1.939)		0.289* (4.555)	-0.0662 (-0.656)	0.0737 (1.303)	0.0237** (2.248)	0.6299

Notes:
(a) In parentheses are t-values. *, ** and ***, respectively, indicate statistical significance at the 1, 5 and 10 percent two-tailed tests.
(b) Period I is 1966-1973 and has 135 observations. Period II is 1974-1982 and has 168 observations.
(c) Industry dummies are used in equations (2) and (4).
(d) When the coefficient of SIZESQ is not reported, it is not significant at the 10 percent level and the reported results are those of equations without SIZESQ.
(e) The data for all the variables except SIZE and SIZESQ are in percentages.

Table 2. Estimated Coefficients of SRD

Period	Sample	Without dummies Without GSL	With dummies Without GSL	Without dummies With GSL	With dummies With GSL	Number of observations
I	all manufacturing	0.201*** (1.842)	0.170 (1.263)	0.187*** (1.902)	0.156 (1.260)	135
	excl. pharmaceuticals	0.407** (2.388)	0.125 (0.747)	0.281*** (1.821)	0.0821 (0.580)	121
	pharmaceuticals	0.232 (0.832)		0.306 (1.085)		14
	innovators	0.0285 (0.234)		0.0776 (0.689)		63
	noninnovators	-0.266 (-0.933)		-0.146 (-0.525)		72
II	all manufacturing	0.169* (2.878)	0.113*** (1.906)	0.00138 (0.0279)	0.0737 (1.303)	168
	excl. pharmaceuticals	0.00919 (0.106)	0.0902 (1.394)	-0.101 (-1.480)	0.0303 (0.492)	154
	pharmaceuticals	0.167 (1.261)		0.256*** (1.997)		14
	innovators	0.118 (1.438)		-0.0456 (-0.849)		77
	noninnovators	0.341* (3.022)		0.231** (2.305)		91

See the notes to Table 1.