Productivity Growth and R&D Expenditure in Taiwan's Manufacturing Firms

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ABSTRACT

This study sets out to estimate the impact of R&D on productivity within the private sector, with further analysis of the different impacts of R&D within high-tech and conventional firms. The study also aims to estimate total factor productivity (TFP) at firm level, whilst testing the Schumpeterian hypothesis, that the impact of R&D is an increasing function of firm size.

Based on a sample of 136 large manufacturing firms listed in the Taiwan Stock Exchange (TSE) during the period 1994-2000, our findings suggest that Taiwan's R&D investment had a significant impact on firm productivity growth in the second half of the 1990s, with output elasticity standing at around 0.18. When the sample is divided into high-tech and conventional firms, we observe statistically significant differences in R&D elasticity between these two categories, with the R&D output elasticity for high-tech firms (0.30) being significantly greater than that of conventional firms (0.07).

Our empirical results also show that there was a dramatic decline in TFP in 1998 for all selected industries, but that this started to climb again in 1999. The most likely explanation is that Taiwan's economy had been seriously damaged by the Asian financial crisis during that particular period. Finally, our results do not support the Schumpeterian hypothesis.

Keywords: R&D, R&D output elasticity, total factor productivity.

INTRODUCTION

Research and development (R&D) investment has been regarded as an important factor in the improvement of productivity levels since the 1960s. The rationale is that knowledge, which can be created and accumulated through the R&D efforts of a firm or industry, will subsequently be available to the production process or product innovation (Mansfield, 1965; 1969), and as a result, nationwide economic development is promoted. Indeed, the advanced countries have invested significant expenditure on R&D activities based upon this rationale.[1]

Two notable issues have been explored, the first of which is the extent to which R&D influences productivity, whilst the second is concerned with the rate of return provided by R&D. Numerous studies have attempted to estimate the marginal product of R&D capital, or the rate of return on R&D investment (see for example Griliches, 1980; 1994; Scherer, 1983; 1993; Griliches and Lichtenberg, 1984; Goto and Suzuki, 1989). Based upon several different levels of data aggregation or different types of estimation model, these studies show that the output elasticity of R&D lies between 0.06 and 0.14, whilst the rate of return on R&D investment is around 2 per cent to 50 per cent. However, these studies have continually failed to produce consistent results, with some findings not confirming the contribution of R&D to productivity growth (Link, 1983; Griliches and Lichtenberg, 1984).

Substantial amounts of expenditure on R&D are invested annually within Taiwan's manufacturing sector. According to data reported by the National Science Council (2001), the average share of R&D expenditure within the manufacturing sector accounts for over 95 per cent of domestic R&D expenditure. However, the resultant growth in TFP, the impact of R&D on productivity growth, and the rate of return on R&D expenditure have seldom been seriously examined.

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[1] For example, the average annual rates of R&D expenditure relative to gross domestic product in the US and Japan are around 2.64 per cent and 3.04 per cent, respectively (National Science Council, 2001: 195).

This study therefore sets out to estimate firm productivity growth based upon panel data for a sample of 500 firms for the period 1994-2000. The aims of the study are to determine to what degree R&D influences productivity, to further estimate the rate of return on R&D investment within manufacturing firms, and to analyze the differences in productivity growth and the rate of return on R&D investment between industries. Finally, we will test the famous Schumpeter hypothesis, that the returns on R&D are an increasing function of firm size.

Following on from this introduction, the remainder of this paper is organized as follows. In the next section we undertake a review of previous studies in this area, followed by an introduction to the methodology adopted in this study, including both the model and the data resources employed in the estimations. Some basic statistics and the results of our estimations and tests are presented and interpreted in the penultimate section. We conclude with some remarks on our findings in the final section, and offer some suggestions for further research.

LITERATURE REVIEW

There are two main considerations in any general examination of previous studies; the first is the level of data aggregation, and the second is the type of estimation model used. At firm level, Griliches and Mairesse (1984; 1990) and Cuneo and Mairesse (1984) used time series data to estimate the contribution of R&D based on the production function model. They found that the estimated output elasticity of R&D capital lies approximately between 0.06 and 0.10. In a cross-sectional study, Griliches (1995) further demonstrated that the output elasticity of R&D stock was around 0.09-0.14. Adopting the model of R&D intensity, Clark and Griliches (1984), Griliches (1986) and Lichtenberg and Siegel (1989) showed that in US manufacturing firms, the rate of return on R&D lies between 10 per cent and 39 per cent. Goto & Suzuki (1989) further concluded that the rate of return on R&D

investment in Japanese manufacturing industries tends to be around 40 per cent. However, in an earlier study, Link (1983) found that in the 1970s, the R&D coefficient in US manufacturing industries failed to achieve statistical significance.

At industry level, most researchers adopt an R&D intensity model. Terleckyj (1974), Griliches and Litchenberg (1984), Scherer (1993) and Griliches (1994) each found that the rate of return on R&D lies between 20 per cent and 50 per cent in US manufacturing industries, whilst Goto & Suzuki (1989) showed that the estimated R&D rate of return in Japanese manufacturing industries was around 26 per cent. Furthermore, van Meijl (1997), and Vuori (1997) found that the rates of return on R&D investment within manufacturing industries in France and Finland were around 19 per cent and 14 per cent, respectively.

It should be noted, however, that the estimations of the Griliches and Lichtenberg (1984) study showed a rate of return on R&D investment in value added of only 2 per cent to 5 per cent, or so. Utilizing the same data, and based on the production function model, they demonstrated that the estimates of R&D capital were not significant. Scherer (1983) also concluded that the impact of R&D on productivity was insignificant.

METHODOLOGY

The Model

In common with most analyses of the contribution of R&D to productivity growth (see for example, Griliches, 1986; Lichtenberg and Siegel, 1989; Goto and Suzuki, 1989; Wakelin, 2001), the model adopted for this study is the extended Cobb-Douglas production function model:[2]

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[2] One could of course consider more complicated functional forms, such as the Trans-log or CES functions, but based on most empirical studies and on some exploratory computations, we use the C-D function.

$$Q_{it} = \mathrm{A} e^{\lambda t} L_{it}^{\alpha} K_{it}^{1-\alpha} R_{it}^{\gamma} e^{\varepsilon_{it}} \quad (1)$$

where Q, L, K and R represent value added (or sales), labor, physical capital and R&D capital, respectively. R&D capital is a measurement of the stock of knowledge possessed by a firm at a given point in time. In addition, ë is the rate of disembodied technical change, A is a constant, and constant returns to scale have been assumed with respect to the conventional factors (L and K). The parameters, á and ã, are the output elasticity of labor and R&D capital.

By taking logarithms of the variables, Equation (1) can be expressed in log form:[3]

$$(q-k)_{it} = a + \lambda t + \alpha(\ell - k)_{it} + \gamma r_{it} + \nu_{it} \quad (2)$$

where the variables in lower case (*q*, *l*, *k*, and *r*) are the logarithms of value added, labor, physical and R&D capital, respectively, and ν_{it} is the error term in the equation.

Equation (2) is the model employed to estimate the effects of R&D on productivity growth; however, two points relating to ν_{it} are worth noting. Firstly, in addition to the inputs listed in the model, some unobservable factors, such as managerial capabilities, also have considerable impacts on the creation of a firm's value added (Wernerfelt, 1984; Barney, 1991; Deteraf, 1993). These factors will vary across firms, thus, the variance of ν_{it} is heteroskedastic. In other words, the variance derived from some unobservable factors is viewed as an error component of ν_{it}.

Secondly, within our data set, each firm is observed at several points during each year, and some factors omitted from Equation (2) may be correlated across periods.

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[3] An alternative model would allow γ to vary across firms and to assume the equality of rates of return on R&D across firms. We do not adopt such an alternative model here since this model presupposes that the rate of obsolescence of R&D capital is zero.

After accounting for this possibility, it is reasonable to model the data as having serial correlation. Since the empirical literature is overwhelmingly dominated by the AR (1) model (Greene, 1993: 417), the disturbance process of v_{it} with an AR (1) form is assumed in our model. To summarize, these two problems will be considered in the estimations since they could result in biased or inefficient estimates.

The Data and Variables

The examination of related issues is based on a longitudinal data set. The data set includes a sample of 156 large firms stratified from the TSE. As a result of a number of missing observations on R&D expenditure, and questionable data on other variables, we have had to limit the sample to 136 firms. These samples are fully balanced over the seven-year period, 1994-2000.

The sample covers most R&D performing manufacturing industries, including food (11 firms), textiles (31 firms), chemicals (30 firms), metals (9 firms), machinery (12 firms) and electronic equipment (43 firms).[4] Since the number of firms within each of these industries is too small to work with separately, we classify the sample into two groups, high-tech firms within the electronic equipment industry (32 per cent), and other industrial firms (68 per cent).[5] Through this method of classification, in addition to alleviating the problem of heterogeneity, the difference in R&D effect on productivity growth between the high-tech sector and other manufacturing firms can also be explored.

Table 1 provides general information (some descriptive statistics) on the samples and variables, with columns three to six respectively representing labor growth rates,

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[4] Electronic equipment includes computers and peripherals, integrated circuits (IC), telecommunications and other electronics.

[5] Here we divide the sample into two because R&D expenditure is the indicator most widely used in identifying high-tech organizations or industries (Baruch, 1997).

physical capital, value added and R&D to sales ratio (R&D intensity) across each sector for the period 1994-2000. The figures in the last column of Table 1 represent the R&D intensity for each industry in 2000.

Table 1 Growth rate of major variables and R&D to sales ratio

Industry	N [a]	Labor	Capital	Value Added	GRS [b]	RS [c]
Food	11	0.03	6.31	5.35	-0.007	0.85(0.29)
Chemicals	30	0.19	7.68	2.73	0.035	1.61(2.00)
Textiles	31	-0.52	8.06	5.20	-0.004	0.49(0.51)
Machinery	12	-1.25	6.58	9.70	0.003	1.59(0.98)
Metals	9	0.41	1.93	1.02	-0.027	0.66(0.29)
Electronic equipment	43	5.72	18.85	22.53	0.052	3.79(2.35)
Total	136	1.65	10.71	10.67	0.021	1.68(2.44)

Notes:
[a] N is the number of firms;
[b] GRS is the growth rates of R&D to sales ratio;
[c] RS is the R&D to sales ratio in year 2000, (figures in parentheses are standard deviations).

Based on the figures provided in Table 1, there are a number of interesting observations to be made. First of all, the average growth rate of R&D to sales ratio is much more rapid in 'high-tech' firms than in other firms. Moreover, the R&D intensity in high-tech firms is much higher than in other firms. For example, in 2000, the average ratio of R&D to sales in electronic equipment was around two to five times as much as in other firms. Secondly, there is much more rapid growth in both R&D intensity and value added in high-tech firms.

R&D capital has been viewed as a measurement of the current state of technical knowledge, determined, in part, by current and past R&D expenditure (Griliches, 1979). In other words, an increase in R&D capital in period *t* reflects not only the R&D expenditure of period *t* but also previous R&D expenditure that bears fruit during the period. There is some sort of distributed lag structure that connects past R&D expenditure to a current increase in technical knowledge and ideally, one would like to estimate the lag structure from the data. Unfortunately, it is difficult to obtain the information required to determine the lag structure, thus, we simply use the average lag.

The measurement of R&D capital is expressed as: $R_{it} = \mathrm{E}_{t-0} + (1-d)R_{t-1}$ (following Griliches, 1980; and Goto and Suzuki, 1989), where E is a deflated measure of R&D, θ is the average lag and ä is the rate of obsolescence of R&D capital.[6] The depreciation rate reflects the replacement of old knowledge by new knowledge, or the reduction in the effective appropriation of knowledge. The equation leads to R&D expenditure in period *t*- θ becoming R&D capital in period *t*.

We use the average lag θ, based on simplifying evidence, in a follow on to the approach of Goto and Suzuki (1989). Patents are a good indicator of benefit creation (Bound, *et. al*., 1984; Pakes and Griliches, 1984; Griliches, 1998), and according to Lin and Lee (1996) and Tsai (1997), R&D investment has a significant impact on patents two years later. Moreover, a simulation study indicated that the lag length of the effect of R&D expenditure on productivity growth lies between one to three years (Xu, *et. al.*, 1998). These findings suggest that the average lag in Taiwan is around 2. Pakes and Schankerman (1984) also demonstrated that the R&D lag for the chemicals, machinery and electronics industries is around two years; therefore, we set the average lag length as 2 (θ = 2) to measure R&D capital.[7]

As suggested by Goto and Suzuki (1989), we examine the length of time taken by firms' patents to generate revenue in order to estimate the rate of obsolescence of R&D capital (ä). We use the inverse of the length of time to measure the rate of obsolescence of R&D capital with the firms investigated being the sample used in our analysis. Amongst these firms, the average rates of obsolescence were around 14.5 per cent in

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[6] Other forms of lag structure, such as geometrically declining weights, could be assumed; however, various constructed lag measures and different initial conditions make little difference to the results (Griliches and Mairesse, 1984).

[7] Lagged R&D expenditure is used in many studies but there is no general agreement on the correct lag length. Hall and Jacques (1995) pointed to the stability of firm R&D expenditure in the US and Germany, and the insensitivity of the results to the choice of lag.

general machinery, 6.2 per cent in food, 12.4 per cent in chemicals, 7.2 per cent in textiles, 6.5 per cent in metals and 20.4 per cent in electronic equipment.

We measure output by value added (Q), deflated by the wholesale price index, rather than by sales. Labor (L) is measured simply by the total number of employees since there is no available information on labor working hours. Our measure of physical capital (K) is total fixed gross assets, deflated by the gross fixed capital index. Not only is the composition of R&D expenditure little known, but the available data concerning real R&D expenditure is also bedeviled by the lack of a suitable price index for R&D inputs. In view of the inherent difficulties, most of the previous studies have adopted the same means used by US government officials, i.e., the use of the gr oss domestic product index to deflate R&D index expenditure. However, since the majority of R&D expenditure in Taiwan goes into R&D equipment, here we use the price of physical capital to deflate R&D expenditure.

THE RESULTS

A number of different equations are estimated using feasible GLS. The estimates of the production function with and without Gear dummy variables (with year dummies as opposed to a time trend) are listed separately in Tables 2 and 3, which also provide the model estimates, including the product term of R&D capital by assets for all firms, as well as separately for high-tech and other firms.

It is clear that using year dummy variables instead of a linear trend makes little difference to the estimates for the whole sample. The estimate of R&D capital elasticity (ã), lying between 0.18 and 0.20, is significant at the 1 per cent level, with the results showing that R&D has a significant impact on value added growth.

Table 2   Production function estimates, excluding year dummies

Regressions	á	ã	ë	$ã_s$ [a]	R^2	MSE
All firms (N=136)						
(1)	0.485[b] (0.071)	0.187[b] (0.031)	0.037[c] (0.015)		0.352	0.167
(2)	0.467[b] (0.079)	0.184[b] (0.032)	0.037[c] (0.015)	0.004 (0.007)	0.354	0.168
High-tech firms (N=43)						
(3)	0.305[b] (0.115)	0.297[b] (0.073)	0.125[b] (0.032)		0.468	0.190
(4)	0.325[c] (0.130)	0.299[b] (0.074)	0.125[b] (0.033)	-0.003 (0.017)	0.468	0.191
Other firms (N=93)						
(5)	0.674[b] (0.087)	0.055 (0.037)	0.021 (0.016)		0.326	0.133
(6)	0.613[b] (0.094)	0.049 (0.037)	0.021 (0.016)	0.017[d] (0.010)	0.333	0.133

Notes:

[a] $ã_s$ is the parameter of the product term of R&D capital by assets; (figures in parentheses are estimated standard errors).

[b] Significant at the 1 per cent level.

[c] Significant at the 5 per cent level.

[d] Significant at the 10 per cent level.

Table 3   Production function estimates, including year dummies

Regressions	á	ã	$ã_s$ [a]	R^2	MSE
All firms (N=136)					
(1')	0.472[b] (0.071)	0.199[b] (0.031)		0.360	0.165
(2')	0.459[b] (0.079)	0.197[b] (0.032)	0.003 (0.007)	0.362	0.160
High-tech firms (N=43)					
(3')	0.292[b] (0.117)	0.308[b] (0.074)		0.473	0.191
(4')	0.308[c] (0.132)	0.309[b] (0.075)	-0.003 (0.011)	0.473	0.192
Other firms (N=93)					
(5')	0.668[b] (0.087)	0.070[d] (0.037)		0.346	0.129
(6')	0.613[b] (0.093)	0.064[d] (0.037)	0.016 (0.010)	0.351	0.129

Notes:

[a] $ã_s$ is the parameter of the product term of R&D capital by assets; (figures in parentheses are estimated standard errors).

[b] Significant at the 1 per cent level.

[c] Significant at the 5 per cent level.

[d] Significant at the 10 per cent level.

Since the sample comprised of firms engaging in R&D in rather diverse industries, it was also of interest to investigate the differences between sectors. When the sample is split into two categories, the estimates for the two groups are indeed rather distinct.[8] The estimate of R&D capital elasticity, at around 0.30 for high-tech firms, is much larger than for other firms. Note that the estimate of R&D output elasticity for other firms is around just 0.06, which is even insignificant in the model without year dummies. In addition, although the difference in the estimated time-trend coefficients (the rate of technical progress ë) between high-tech firms and other firms is rather significant, the estimates of ë are significant in the high-tech firms (ë=0.125, $p<0.01$) but insignificant for other firms.

The ideas of Schumpeter (1950) supported the belief of a greater likelihood for large firms both to undertake research activities, and to achieve a measure of success. However, although Link (1981) found evidence of a systematic relationship between firm size and the impact of R&D on productivity, the empirical results of Lichtenberg and Siegel (1991) did not provide support for the Schumpeterian hypothesis.

In our investigation, using total assets or sales as a proxy for firm size, the estimates are positive for all firms, irrespective of whether or not the model contains year dummy variables, but insignificant at the 5 per cent level. When the sample is divided into two categories (high-tech firms and other firms), the estimates of ãs are still insignificant. Obviously, we are unable to determine from these findings whether different size 'regimes' exist from the data, with respect to R&D impact on productivity.

Furthermore, based on the estimates of á, and the conventional definition of TFP ($T=Q/L^{á}K^{1-á}$), we can calculate the annual TFP growth rates for each industry. The results are listed in Table 4 which shows that for all selected industries, there was a dramatic decline in TFP growth rates in 1998. The obvious explanation for this is the

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[8] Dividing the sample into two allows for much of the heterogeneity, bringing down the sum of the square of errors (SSE) by around 12 percent (corresponding to a high F ratio of 16.05, $p<0.01$).

severe impact on the Taiwanese economy from the Asian financial crises between the fourth quarter of 1997 and the first quarter of 1999.

*Table 4 Average annual rates of TFP growth**

Unit: %

Industry	1997	1998	1999	2000
Food	0.54	-16.01	7.67	5.73
	(2.83)	(5.82)	(2.35)	(2.78)
Chemicals	-0.15	-19.63	12.50	5.46
	(2.39)	(3.76)	(2.80)	(1.72)
Textiles	0.04	-15.28	-6.30	7.39
	(2.41)	(2.71)	(2.88)	(2.39)
Machinery	0.95	-15.82	5.40	8.33
	(3.18)	(5.92)	(2.25)	(2.97)
Metals	0.59	-1.19	-0.60	-1.49
	(1.74)	(1.45)	(1.52)	(1.72)
Electronic equipment	9.08	-7.26	4.41	18.21
	(2.58)	(2.85)	(2.72)	(1.99)

Note: * Figures in parentheses are standard deviations.

CONCLUDING REMARKS

In this study, we have analyzed the relationship existing between output (value added), employment, and physical and R&D capital, based upon a complete sample of 136 large firms listed in the TSE for the period 1994-2000. Our findings suggest that R&D investment was a significant determinant of firm productivity growth during the second half of the 1990s, as documented in many earlier studies.

For the whole sample, R&D output elasticity was around 0.18; however, when the whole sample is classified into two categories, high-tech and other firms, we observe a statistically significant difference in R&D elasticity between the two samples. The R&D elasticity for high-tech firms is around 0.3, but only 0.07 for other firms. We also calculate the annual average TFP growth rates using the estimates and the conventional definition of TFP. The figures provided in Table 4 demonstrate that TFP growth declined across all the selected industries in 1998, but started to pick up again after 1999. In 2000, only the metals industry was still posting a negative growth rate. The slump in TFP growth rates in 1998 can be attributed, to a large extent, to the Asian financial crisis.

The Schumpterian hypothesis, that the impact of R&D on productivity is an increasing function of firm size, is also tested within this study; however, our empirical results do not support the proposition at the 5 per cent significance level.

In general terms, R&D work can clearly be classified into three types, basic research, applied research and experimental development, with the possibility of the impact on productivity from these different types of R&D differing markedly. A number of studies have found that the contribution from basic research is greater than that of either applied research or experimental development (see for example, Griliches and Siegel, 1991; Martin, 1998; Salter and Martin, 2001). Since the proportion of R&D expenditure spent on basic research in Taiwanese manufacturing firms has been rather small, our estimations should still be valid, even though we do not take into consideration here the distinction between basic research, applied research and experimental development.

Our study does of course have its limitations. First of all, as in the standard approach, we aggregate R&D expenditure linearly into R&D stock, ignoring the possibility that knowledge production depends non-linearly, not only on current efforts, but also on previously accumulated outcomes. Secondly, the results cannot explain the time-dimensional differences of R&D performance across firms, since the time period is not yet long enough. Thirdly, our estimation also fails to reveal how the impacts of R&D on productivity growth are actually realized. Finally, if R&D is chosen on the basis of economic incentives, it is unlikely to be completely independent of the error which affect the production relations. Here we do not discuss the simultaneity problem of R&D decision.

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