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An Empirical Study of R&D Investment Patterns, Effects, and Critical Factors in High-Tech Industries in Taiwan : The Case of the Hsinchu Science-Based Industrial Park

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ABSTRACT

This research is an empirical analysis of high-tech firms at the Hsinchu Science-based Industrial Park (HSIP) in Taiwan. In this study, three main areas were systematically evaluated: the patterns of R&D intensity along the company's attributes of capital source, industrial category, and age; the relationships between firms' R&D investment and performance; and the critical factors of successful R&D management.

Key Words : High-tech firms, Hsinchu Science-based Industrial Park (HSIP), patterns of R&D intensity, company attributes, company performance, critical factors of successful R&D management.

INTRODUCTION

In the current era of global competition, as potential sources of new technology continue to proliferate, there is general agreement that maintaining technological competitiveness is vital to the future economic well-being of businesses and nations (Porter, 1990). Under these circumstances, high technology industries have become more important for developed and developing countries. R&D investment and the performance of companies are becoming important issues for countries that want to sustain economic growth.

Since the early 1980s, in response to increasing costs of land, labour, and raw materials, and the challenge from other developing countries (e.g., Korea), Taiwan's government and businesses have made strenuous efforts to promote high technology-based industries. Electronics, information, communications, and consumer electronics industries, played a pivotal role in upgrading Taiwan's industrial manufacturing base, and special efforts were made to promote these sectors through national research projects (Chiang, 1990). One such effort was the establishment of the Hsinchu Science-Based Industrial Park (HSIP).

In 1980, the Taiwan government established the HSIP, entirely devoted to high technology industries. With its close proximity to two well-known technology-oriented universities (National Chiao Tung University and National Ching Hwa University) and a major research institute (The Industrial Technology Research Institute, ITRI), the HSIP has created a conducive intellectual climate for R&D, and has fostered cooperative research with its steady source of researchers at hand (Gwynne, 1992). The HSIP's administration not only stipulates that companies within the HSIP spend a minimum proportion of their revenues on R&D, but also requires a minimum percentage of each firm's employees be scientists and engineers. The average R&D intensity of firms in the HSIP is over 5% and employees with PhDs and Masters degrees amount to about 10%. Workers with either Bachelors degrees or post secondary technical education both make up over 20% of the work force.

In order to encourage the flow of capital into high technology industries, the government has established a wide range of economic incentives which are offered to HSIP-based companies. These incentives include low-interest loans, the right to retain earnings of up to 200% of paid-in capital, and a five-year income tax holiday within the first nine years of operation.

If the success of the HSIP were to be evaluated in terms of the cumulative sales of its firms, then the HSIP project can be regarded as highly successful. The average annual productivity of each employee in the HSIP is over US $170,000. Total sales of the HSIP soared from US$75 million in 1983 to over US$3 billion in 1991, and over US$6 billion in 1993. The list of companies in the HSIP reads like a Who's Who of high-technology corporations in Taiwan, with Acer, Mitac, United Microelectronics Corp. (UMC), and Taiwan Semiconductor Manufacture Corporation (TSMC), heading the pack. So far, the HSIP has become the centre of Taiwan's high-tech industry.

This research focuses on R&D management of high-tech firms at the Hsinchu Science-Based Industrial Park. In order to critically evaluate the justifications of R&D investment decisions and the key to improving R&D management of companies in high-tech industries, we needed to gain a deeper understanding of its effectiveness. We began the study by analysing differences of R&D investment patterns along a firm's three attributes: capital sources, industry category, and age. Then, we examined the influence of R&D on the company's performance, measured by both objective and subjective performance indices. Finally, we identified the critical success factors (CSF) in managing high-tech firms in Taiwan.

RESEARCH FRAMEWORK AND METHODOLOGY

Sample and Data

This research attempts to provide evidence for improving the establishment and operation of R&D management in high-tech industries in developing countries. Our focus was on the high technology firms located within the Hsinchu Science-based Industrial Park (HSIP) in Taiwan. There were 86 firms in the sample population providing completed data over the period 1986-1991. After initial contact with individual firms, we successfully invited 31 high-tech firms to form the sample of this study, which can be classified into six industries: semiconductor (10 firms), computer and peripherals (9 firms), telecommunications (6 firms), automation (2 firms), biotechnology (2 firms), and electro-optical (2 firms). The sample firms were chosen because of their geographical concentration and common investment incentives provided by the HSIP. By electing only the firms within the HSIP as our sample, the homogeneity of environmental factors, which can strongly affect the firms' operational as well as strategical activities, can be assured.

The data was collected in two ways. The objective data was provided by the HSIP administration, which began investigating R&D related activities (R&D expenditures, R&D employees), total employees, and sales revenue of companies within the HSIP since 1986. The subjective data that relate to the performance measures and R&D management factors were collected by interviewing HSIP firms. Three types of questionnaires were designed, based on different positions in the firm, which included the R&D manager, the project leader, and the engineer. We interviewed 80 subjects associated with 31 firms. The subjects included 31 R&D managers, 23 project leaders, and 26 R&D engineers. Subjective evaluations and competitors' evaluations for R&D activities and innovative capabilities were accessed from different perspectives so as to avoid potential bias from managerial/technical positions.

Variables and Methods of Analysis

For the purpose of improving understanding in the field of R&D, we applied systematic concepts and systematic research methods in this study.

We began by analysing the input side of R&D management and focused on exploring the pattern of R&D investment. The research analyzed patterns of R&D intensity differences along three attributes of the firms: (1) capital source, (2) industrial category, and (3) age. Capital sources differentiate firms into domestically-owned and foreign-owned categories. Due to the non-normality of the data, non-parametric methods were utilized. The Wilcoxon rank sum was used to test the difference in R&D intensity between these two capital sources. The Kruskal-Wallis test method was employed to examine the difference in R&D intensity among various industries as well as various ages of the firms. Following that, we used the Wilcoxon rank sum to test the difference in R&D intensity between new (under 2 years of age) and aged (over 2 years) firms. We also used the Spline regression method to build R&D intensity models along the various firms' age in the semiconductor and computer industries.

Then we examined the effectiveness of R&D investment and the relationship between R&D input and its outcome. The Spearman and Pearson correlation coefficients of R&D investments and company performance indices were calculated to measure the impacts of R&D on firms. The R&D investments were measured by (1) R&D intensity (R&D/sales), the traditional measure of R&D input, and (2) R&D spending per employee. Two types of performance measures were considered as the dependent variables in this study. One type was the objective indices, which were used in many other similar studies (Morbey, 1988; Brenner & Rushton 1989; Morbey & Reithner, 1990). These indices are: (1) sales growth and (2) productivity (i.e., sales/total employees). Another type of performance measure evaluated by field managers and engineers is the subjective performance indices. For these, we obtained the managers' as well as competitors' rankings of the firm's market reputation, technology innovation, technical improvement, budget and schedule control, and launch time control.

Finally, we investigated critical successful factors (CSF) in the process of R&D management. The cluster analysis method was employed to group the sample firms into three performance groups according to the performance indices. We contrasted the R&D decision processes and R&D implementation processes for the three performance groups in order to identify the CSF of R&D management. The factors of R&D management were classified into four categories: (1) decision process, (2) leadership, (3) implementation environment, and (4) department interfaces.

THE PATTERN OF R&D INVESTMENT

There are many factors that contribute to the future prospects of a company. R&D is one of the most vital factors, especially for high technology industries. The major task of a high-tech firm is to invest in R&D in order to ensure that it will continue to have competitive products on the market. But R&D expenditures directly reduce current year profits (Gilman, 1978; Rosenau, 1980). Prudence requires top management to refrain from spending too much on R&D. Thus we need to answer the question: How much should we spend on R&D? Although many studies have attempted to determine the optimum level for R&D spending based on the performance indices (Gilman, 1978; Reynard, 1979; Ellis, 1980), no previous study considered a firm's age and capital sources. Our research attempts to study evidence based on the firm's attributes in order to assist management in answering the question posed above.

In examining the influence of capital source on R&D investment decisions, we employed the Wilcoxon rank sum to test the difference between domestically-owned and foreign-owned firms at HSIP. The results showed (at a significance level of $\alpha = 0.05$) that there were significant differences in R&D intensity between these two types of firms. The R&D intensity of ROC firms is significantly higher than their foreign counterparts. Next we examined the difference in R&D intensity among the six industries using the Kruskal-Wallis test. At a significance level of $\alpha = 0.10$, we could not conclude that firms from these six industries differ from one another in terms of the patterns in R&D intensities.

Do firms of various ages have different R&D intensities? To answer this question we examined the patterns of R&D intensity among firms of various ages using the Kruskal-Wallis test. At a significance level of $\alpha = 0.05$, there was no R&D intensity difference among firms, except for new firms in existence for less than two years. We further separated the firms into two groups. One group consisted of firms of less than 2 years and the other group consisted of older firms. The Wilcoxon rank sum was used to test the difference in R&D intensity between these two groups. The results showed, at a significance level of $\alpha = 0.10$, that these two groups have different R&D intensity levels. Blocked by different capital sources, newly-founded ROC firms (aged less than two years) have significantly ($\alpha = 0.01$) higher R&D intensity than that of aged ROC firms. However such differences are not significant (P-value=0.8272) between new and aged foreign-owned firms. Finally, we tried to use a segmented model, as in Figure 1, to build an R&D investment model for ROC firms in different high technology industries. We have successfully built segmented models for ROC semiconductor and computer firms. However, no feasible model could be concluded for firms in the other four industries.

THE EFFECTIVENESS OF R&D INVESTMENT

It is a widely held belief that R&D investments are essential to the long-term health of a company, and empirical studies support this belief. Many studies have shown that higher growth companies invest in R&D much more consistently than companies with low growth rates, and also tend to have higher R&D intensities (Hambrick, MacMillan & Barbosa, 1983; Guerard, Bean & Andrews, 1987; Brenner & Rushton, 1989). Companies that spent more on R&D during a recession performed better than those that held back (Morbey & Dugal, 1992).

We know that R&D spending can lead to higher rates of new product introductions, higher quality products and gains in market share, leading to improvements in gross margin, and higher returns on investment (Collier, Monz, & Conlin, 1984).

Probably due to the high impact of R&D on new product sales, R&D intensity is more often correlated with sales growth (Schoeffler, Buzzell & Heany, 1984; Hambrick & MacMillan, 1985; Morbey, 1988; Brenner & Rushton, 1989). Some studies have also found a strong relationship between R&D and the company's subsequent productivity (Griliches, 1987; Morbey & Reithner, 1990).

Although many studies have shown the impact of R&D on a company's performance, we seldom obtain evidence from developing countries. We continue to seek such empirical evidence based on the data from high-tech firms in Taiwan.

The Pearson correlation analysis was performed to examine the relationship between R&D investment and a firm's performance, measured in terms of the objective data, and the Spearman rank correlation coefficients were calculated to test the subjective evaluation performance. The results are shown in Tables 1 and 2 respectively.

This research has reconfirmed results from Morbey and Reithner (1990) that a firm's R&D intensity is positively correlated with its sales growth. However one of our results shows that R&D spending per employee is negatively correlated with current-year's firm productivity. This conclusion is in sharp contrast to one of Morbey and Reithner's results which concludes a strong positive correlation between R&D spending per employee and subsequent company productivity. The contrast should be interpreted as follows: a company investing in R&D could improve future sales growth or productivity with new products or

FIGURE 1. A Segmented Model of R&D Investment Pattern

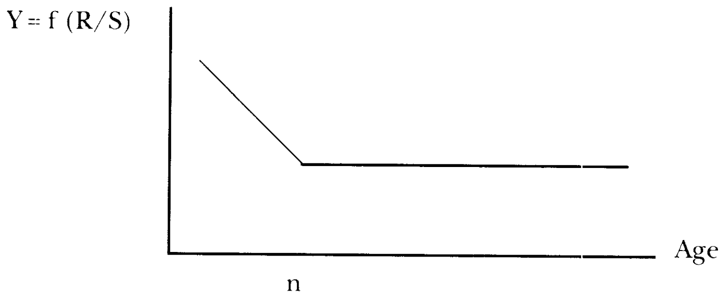

TABLE 1. Correlation between R&D and Objective Performance Measures

	Pearson Correlation Coefficient For	
	Sales Growth	Productivity
R&D Intensity	0.6167*** (0.0017)	- 0.3880* (0.0501)
R&D Spending Per Employee	0.1645 (0.4533)	- 0.5974*** (0.0013)

P — Values in parenthesis
* Indicates significance at 0.1
*** Indicates significance at 0.001

TABLE 2. Correlation between R&D and Subjective Performance Measures

Spearman Rank Correlation Coefficient for	R&D Intensity	R&D Spending Per Employee
Market Reputation (SA)	0.4200**	0.2859
Market Reputation (CA)	0.1213	0.0882
Technology Innovation (SA)	0.2859	0.3842**
Technology Innovation (CA)	- 0.1876	0.0588
Technical Improvement (SA)	- 0.2771	- 0.0632
Technical Improvement (CA)	0.0683	0.1614
Budget/Schedule Control	- 0.4368**	- 0.2164
Launch Time Control	0.0981	0.0699

SA : Self Appraisal
** Indicates significance at 0.05
CA : Competitor Appraisal

technology innovation and technical improvement. As Rosenau (1980) pointed out, companies that increased R&D spending could reduce its current year profits. When R&D spending per employee increases, employees devoted to current operations and tasks decrease because the firm is not able to recruit additional productive staff so rapidly. Therefore the current productivity of the firm will fall.

We found no substantial relationships between a firm's R&D investment and subjective performance in this study. Some exceptions did suggest that R&D intensity be positively correlated to a firm's self-appraisal on market reputation and negatively correlated to a firm's controlling of R&D project budgets and schedules. Results also indicated that a firm's R&D spending per employee was positively related to its self-appraisal of its technology innovation ability.

THE CRITICAL SUCCESS FACTORS OF R&D MANAGEMENT

If one wants to improve the success rate of R&D projects in a company, one first needs to evaluate its principal sources of uncertainty: relevance of the business objective, the fit between the technical and business objectives, transfer of project results to an internal user, and how well that user can produce, market, distribute, and sell the resulting product (Baker, Green, and Bean, 1986). Many factors critical to the successful implementation of R&D projects have been identified (Cooper, 1983 and 1986; Backer, Green and Bean, 1986; Pinto and Slevin, 1989; Millett, 1990; Sakakura, 1991; Rothwell, 1992). The most important success factors include:

* market needs recognition and satisfaction
* effective internal and external communication
* top management support
* project planning and controlling procedures
* skilled and responsible management
* the role of key individuals

Some other additional success factors, which have less attached importance to R&D management than those cited above, have been proposed by researchers (Cooper, 1983; Ranftl, 1986; Pinto & Slevin, 1989; Millett, 1990; Rothwell, 1992; Miller and Blais, 1993).

These factors are:

* the product itself (a unique and superior product)
* a well-conceived, properly executed launch
* good technical service to customers
* efficiency in R&D work, resulting in high quality production
* an awareness that technology alone is not the product
* recognition of the impacts of non-technological factors
* initial clarity of goals and direction
* trouble-shooting abilities
* organizational and operational simplicity
* effective staffing with challenging assignments
* specialized managerial training.

Studies have revealed the basic factors common to the success of R&D management. However, more empirical studies considering various contingent situations will be helpful in gaining deeper insights into R&D management theories. As a result, one of this study's objectives was to discover the critical factors of R&D management in Taiwan's high-tech firms.

We employed the cluster analysis method according to the ten performance indices to group the 31 sample firms. Then we compared the R&D management of each group with one another. The characteristics of the three performance groups resulting from the cluster analysis are shown in Table 3.

By contrasting the practices of R&D management in these three groups, we found several critical success factors. The factors are summarized as follows:

1. R&D managers dominated R&D strategies.
2. The R&D strategy planning horizon was longer than 3 years.
3. Top management strongly supported R&D projects.

TABLE 3. Characteristics of the Three Performance Groups

Clustered Group	No. of Firms	Characteristics
Group 1	8	* Sales growing stably * Authentic market reputation * Great confidence in technological ability and so regarded by competitors * Superior R&D project controlling skills
Group 2	19	* The highest average productivity * Lacking in market confidence and reputation * High confidence in technical improvement but lacking in both technology innovation and reputation
Group 3	4	* The highest sales growth * High confidence in marketing, and so regarded by competitors * Confidence in technology ability but lacking in technology innovation reputation * Superior launch time control

4. R&D project leaders possessed management skills.
5. The turnover rate of R&D employees was lower than the competitors'.
6. R&D equipment was more sophisticated than the average level in the industry.
7. Training programmes for R&D engineers included management skills.
8. R&D department kept lower frequencies of project changes.

Some of the findings support the views of many researchers. R&D managers dominating R&D with top management support have reconfirmed the viewpoints of Pinto and Slevin (1989), Millet (1990), Sakakura (1991), and Rothwell (1992). Rothwell (1992) argued the importance of having a long-term corporate strategy to facilitate a firm's innovation. The longer R&D strategy planning horizons support Rothwell's point of view. We also found that skilled and responsible R&D management is a major success factor (Cooper, 1983; Ranftl, 1986; Rothwell, 1992). Like Ranftl (1986), the research pointed out the importance of management training programmes for R&D engineers. The stability of R&D employees, the level of R&D facilities and the project change rate are other specific CSFs in Taiwanese firms.

CONCLUSIONS

R&D investment decisions have been and will always be a high risk undertaking. But much can be learned about effective R&D management decisions from a review of the experiences, in the past and in other firms. This study provided some insights regarding R&D investment decisions and R&D management, based on the experiences of high-tech firms at the HSIP in Taiwan.

A firm's attributes do affect its R&D investment decisions as shown in this study which differentiated firms according to their capital sources and R&D intensity patterns during various stages. There was also evidence that R&D investments could improve the future performance of a firm, but it might also influence its current productivity. Morbey and Reithner (1990) indicated that a company with high productivity should show significant gains in its future profit margin with increased R&D intensity. So, if long-term growth and profitability are goals of management, we suggest that a firm must be prepared to invest consistently and heavily in R&D. However, it should first pay more attention to improving current productivity.

Management can influence the future of a firm by its R&D investment decisions. We found that improving R&D management skills and providing management training programmes to R&D engineers should be considered top priorities.

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