

An Examination of Taiwan's Innovation
Policies and R&D Performance

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ABSTRACT

Much greater emphasis is now being placed upon innovation in recognition that it plays an increasingly important role in enhancing industrial technology, thus the governments of many countries are currently adopting specific strategies aimed at stimulating innovation within firms. Taiwan is no exception; however, since the industrial structure of Taiwan comprises predominantly of small and medium enterprises (SMEs), their willingness to engage in innovative activities is rather low. Furthermore, smaller firms are usually deterred from innovating because of scale barriers in some industries, particularly in the high-tech industries.

The government in Taiwan has implemented a number of policy measures in recent decades aimed at enhancing firms' innovative investment, with notable policy measures focusing on speeding up the development of the high-tech sector including: (i) establishing the Hsin-chu Science-based Industrial Park to provide an environment conducive to the high-tech industry; (ii) organizing innovation alliances to spread out firms' R&D risks and to secure first mover advantages; (iii) expanding the government-sponsored research institutes to serve as a technology transfer channel for the private sector; (iv) providing tax incentives to absorb some of the costs of firms' R&D activities; and (v) providing access to sources of venture capital.

Since these policy measures on innovation are closely tied to the development of Taiwan's high-tech industry, the purpose of this paper is therefore to discuss these measures and to examine R&D performance, since innovative capacity is invariably measured by R&D expenditure. Based upon a random effects model derived from the Cobb-Douglas production function, and a sample of 136 high-tech firms listed in the Taiwan Stock Exchange (TSE) during the period 1994-2000, our empirical results demonstrate that the output elasticity of R&D is about 0.19. This finding shows that R&D performance in Taiwan's high-tech industry is indeed noteworthy.

Keywords: Innovation, Innovation policy, R&D Performance

INTRODUCTION

Innovation has increasingly played an important role in enhancing industrial technology levels and has also emerged as the key to national competitiveness in the knowledge economy.¹ Numerous studies have demonstrated that innovative activities have a significant contribution to make to technological progress or output performance (e.g. Wakelin, 2001; Stock, et. al., 2001; Gopalakrishnan, 2000; Hannel, 2000), hence, the governments of many countries are now adopting specific strategies aimed at stimulating innovation within firms and within industry as a whole.

Taiwan is no exception; over the past ten years, the island has managed to maintain an impressive economic growth rate in excess of 6 per cent, to become the fourth largest producer of personal computers (PC) in the world. However, because of its original equipment manufacturing (OEM) production structure, there has been little attention paid to Taiwan's innovative capacity. In terms of R&D investment or product innovation, Taiwan may not be at the same level as most of the advanced industrialized countries; however, with an abundance of experienced engineers, Taiwan has made great strides in technological process innovation. As a result, Taiwanese firms have become very competitive, particularly in the information technology (IT) industry.

Taking Taiwan Semiconductor Manufacturing Corporation (TSMC) as an example, this company has used its superior manufacturing capabilities and production process technologies to establish the IC foundry model, breaking away from the traditional vertically-integrated modes of production in the semiconductor industry. The division of labor between IC design companies and foundry companies has not only created a whole new operational mode – producing IC design companies without their own production facilities – it has also enabled Taiwan's

¹ In this paper, we follow the definition of Nelson (1993) and interpret the term more broadly, innovation is considered as 'encompassing the processes by which firms master, and get into practice, product designs and manufacturing processes that are new to them, if not to the nation or even to the universe'.

semiconductor industry to break the monopoly that had been held for so many years by the US, Japan and South Korea, and to establish Taiwan as one of the world's leading semiconductor producers.

As for improvements in product quality, Taiwan's leading motherboard manufacturer, Asustek Computer Corporation, is another notable example of successful innovation. When Asustek was established in 1990, the company had capitalization of just NT\$30 million. With their superior technology and constant improvements in motherboard quality, they were soon able to win the trust of the US company, Intel, with whom they established a close partnership. As a result, Asustek was able to secure the specifications for new Intel microprocessors much earlier than other companies, which enabled the company to launch new generation motherboards earlier than their competitors, providing them with valuable first mover advantages.

However, the Taiwanese economy is comprised predominantly of small and medium enterprises (SMEs), and as such, due to their limited resources and R&D capabilities, the willingness of these firms to invest in innovation has been low. Furthermore, the barriers associated with minimum scale and the uncertainty of R&D within the high-tech industries usually deter firms from engaging in investment in innovation. Given these inherent limitations, the creation of an environment for innovation, and the implementation of a set of policy measures to facilitate firms' investment in innovation, are therefore being seen as major priorities for government policy on innovation.

The remainder of this paper is set out as follows. The next section addresses the major innovation-related policy measures in Taiwan and their effects. R&D performance is then analyzed in the penultimate section, including a description of the model used in this study and the results of our firm level empirical examination. Finally, some concluding remarks and suggestions are provided in the closing section.

INNOVATION POLICIES IN TAIWAN AND THEIR EFFECTS

Various innovation policies² have already been designed to enhance firms' innovative activities and to seek to reduce the likelihood of market failure. First of all, the Hsin-chu Science-based Industrial Park (HSIP) was established to provide an environment conducive to the development of the island's high-tech industry. Secondly, innovation alliances have been organized as a means of spreading R&D risks between firms and securing first mover advantages. Thirdly, the scope of the government-sponsored Industrial Technology Research Institute (ITRI) has been expanded to serve as a channel for technology transfer within the private sector; the majority of the budget for the National Science and Technology Projects (NSTPs) has also been allocated to ITRI in an effort to boost the Institute's innovative capacity. Fourthly, tax incentives have been made available to absorb some of the R&D costs of firms and to encourage them to engage in R&D activities. Finally, a venture capital industry has been established, with the growth of this sector having already helped to speed up the overall development of the high-tech sector. These policy measures are addressed in the following sub-sections.

The Establishment of the Hsin-chu Science-based Industrial Park

The Hsin-chu Science-based Industrial Park (HSIP) was established in 1980, with the motivation being the creation of a base for the establishment and nurturing of hi-tech industries, and the creation of a high-quality, humanized environment for R&D, production, work, life and leisure. Modeled on Silicon Valley in the US, the land for the establishment of the HSIP was provided by the government. With the National Tsing-Hua and National Chiao-Tung Universities, two of Taiwan's oldest universities, being located nearby, due to economies of scale, not only does this effectively reduce employee training costs, and land, plant construction and other infrastructure costs, but clustering benefits can also be obtained in terms of technology diffusion (Mai, 1996;

² Referring to the definition of innovation by Schumpeter (1962) and the OECD (1997), innovation policies can be seen as a framework to encourage firms to innovate, either through industrial

Mai and Peng, 1999; Mai, Chang and Hsu, 1999).

In the twenty years since the HSIP was established, the government has invested NT\$18 billion in ‘software’ and ‘hardware’ construction at the Park, turning it into the main center of Taiwan’s industrial development. In 2000, companies located within the HSIP spent, on average, 5.94 per cent of their sales revenue on R&D, whilst the number of people employed at the Park increased from 8,275 in 1986 to 102,775 in 2000. The total sales of companies located within the Park increased from US\$450 million in 1986, to US\$29.80 billion in 2000 (see Table 1).

Table 1 The development of the Hsinchu Science-based Industrial Park

Indicators	1986	2000
No. of companies established within the Park	59	289
No. of persons employed within the Park	8,275	102,775
Total paid-in capital of all companies located within the Park	US\$151 million	US\$226 billion
Expenditure on R&D as percentage of business volume	5.4 per cent ¹	5.94 per cent ²
Total business volume of all companies located within the Park	US\$450 million	US\$29.80 billion
Total export value of all companies located within the Park	US\$4.51 billion ³	US\$15.98 billion ⁴

Notes:

¹ The data provided here are from 1990, when the Park began reporting this data.

² The data provided here are 1999 data.

³ The data provided here are from 1993; when the Park began reporting this data.

⁴ Accounting for approximately 9.14 per cent of Taiwan’s total export value.

Source: Science-based Industrial Park Quarterly Statistical Report (consecutive issues)

Large numbers of technical experts of Chinese ancestry have returned to Taiwan to work within the HSIP. Whether investing in plant construction themselves or engaging in production or R&D work, these people have made a significant contribution towards raising the level of technology in related industries in Taiwan. One of the major contributions that the HSIP has made to Taiwan’s industrial development is, therefore, the role it has played in introducing overseas technology and encouraging technical specialists living overseas to return home (San and Wang, 1996). According to estimates by Sun (1999), over the period 1980–1989, a total of 14,880 people who had been studying overseas subsequently returned home to work in Taiwan;

technology/product facilitation or an approach based on the construction of a favorable environment.

however, over the period 1990–1995 the figure had more than doubled to around 30,238. These figures were equivalent to 44.4 per cent and 56.5 per cent of the respective number of people obtaining Masters or Ph.D. degrees in Taiwan during the same periods.

In a questionnaire survey of companies located within the HSIP, San (1999) discovered that amongst the main sources of technology for companies in the Park, ‘technology brought back by people who had studied abroad’ was second in importance only to ‘own research and development work.’ Clearly, the HSIP has indeed been effective in encouraging technical specialists working overseas to return home, and a considerable amount of technology has been acquired as a result. So important has the Park been to the development of Taiwan’s hi-tech industries, it has become known as ‘Taiwan’s Silicon Valley’.

Policy Tools for Reducing the Risks of Innovation and Market Failure

Since Taiwan’s SMEs lack the capital and human resource talent needed to establish marketing channels and undertake more advanced technological development, the government has adopted a number of policy tools to reduce the disparity between social and personal compensation. The main policy tools used are described below:

Innovation alliances

In order to promote industrial upgrading, from the late 1980s through to the early 1990s, the government directed a considerable number of innovation alliances in the areas of notebook computers, high-definition televisions, fax and communications equipment, and so on, working through research institutions such as the Industrial Technology Research Institute (ITRI). The most successful of these was the Notebook PC Joint Development Alliance. The Computer and Communications Laboratories of ITRI and the Taiwan Area Electrical Equipment Manufacturers Association invited forty-six companies to form this alliance in the early 1990s. The main achievement of the alliance was in terms of the efficient use of time and group resources.

Motherboard development was completed within just three months; technology standards and specifications were developed, and a prototype produced. The collective strengths of the alliance were used to create a promotional effect, announcing to the world that Taiwanese companies now had the capability to produce notebook computers. This allowed Taiwanese firms to secure first mover advantages and obtain overseas orders, and by 1998, Taiwan had overtaken Japan to become the world's largest producer of notebook computers. Indeed, by 2000, Taiwan was accounting for almost 50 per cent of the total global notebook computer output.

Technical support - ITRI and the NSTPs

In order to solve the problem of the lack of necessary scale of operations by domestic manufacturers that prevented them from undertaking R&D activities, the Ministry of Economic Affairs (MOEA) established several research institutes to provide support for private sector technology upgrading. ITRI is the largest of these, as well as being the one with the greatest number of staff and the highest level of funding. ITRI currently comprises of seven Laboratories and three Research Centers, with over 6,000 research and administrative staff. Its main task is to undertake technology and product development related to industrial development, as well as diffusing the results of this research to the private sector. The National Science and Technology Projects (NSTPs) provides financial support in order to ensure that ITRI has a stable budget to undertake long-term R&D work. Beginning in 1979, a high proportion of the NSTP budget (over 60 per cent), representing annual funding of over NT\$10 billion, was entrusted to ITRI for use in applied and technological development research, as a means of assisting the government's stated aim of promoting technological development.

Since its inception, this combination of ITRI and the NSTPs has been widely praised, mainly because the two elements function as a channel for the transmission of technology. Certain categories of generic technology with external benefits have been developed by research institutions and then transferred to the private sector, thus increasing the comparative advantage

in terms of the technology of firms, industries, and even the nation as a whole.

Secondly, the movement of personnel from ITRI into the private sector has helped to boost the R&D capabilities of the private sector and has speeded up the process of technology diffusion. Those personnel who leave ITRI generally move into industry, indirectly creating and cultivating the private sector's R&D capability. Taking the semiconductor industry as an example, a very high proportion of the staff of UMC and TSMC, from researchers up to the company chairman, had previously been employed at ITRI.

Thirdly, ITRI collaborates with the private sector to build up industrial competitiveness. Particularly successful examples include the Notebook PC Joint Development Alliance and the Semicon Process Technology Development Plan. The joint alliance was successful in strengthening Taiwan's notebook computer development capability, whilst the Technology Development Plan succeeded in bringing about a technical breakthrough in semiconductor process technology in Taiwan, allowing Taiwan to push ahead of its competitors in the semiconductor industry.

Tax incentives - The Statute for Industrial Upgrading and Promotion

In order to reduce the level of risk that manufacturers were required to absorb when undertaking R&D and personnel cultivation, the Statute for Industrial Upgrading and Promotion was promulgated on 1 January 1991, with the aim of using tax incentives to encourage companies to undertake R&D, automation, personnel training and other functional activities. At the same time, investment tax credits were offered to investors holding shares in companies in the hi-tech and other important industries, whilst a five-year tax exemption was also made available to companies within these industries, as well as venture capital companies. As Sun, et al. (1997) and Wang and Tsai (1998) noted, whether in terms of stimulating expenditure, the impact on the economy as a whole, or the contribution made to industrial upgrading, the Statute for Industrial Upgrading and Promotion has achieved impressive results.

Taking the investment tax credit for R&D as an example, the provision of an additional NT\$1 tax credit for R&D by the government led to manufacturers increasing expenditure on R&D by 16.6 per cent. Furthermore, R&D had a significant positive effect on the economy as a whole. For every NT\$1 invested in R&D in 1993 and 1994, the respective increase in real GDP was NT\$1.14 and NT\$1.08. As regards the impact of R&D investment tax credits on indicators of industrial upgrading, such as average labor output in the manufacturing industry, and the export value of technologically-intensive products, the respective increase for these two indicators was NT\$25,800 and NT\$2.574 billion. Clearly, therefore, the tax credit incentive has made a significant contribution to industrial upgrading.

Financial support - venture capital

Generally speaking, venture capitalists invest in emerging industries with strong development potential, on the basis of the expert knowledge available. Venture capital funds provide not only capital but also management assistance; once the enterprise has become a success, they sell off their holding in the company to make a profit. The US experience has shown how the marriage of venture capitalists with inventors can stimulate the development of the hi-tech sector. In terms of the inventors, unless they have been working in the R&D department of a large company, they will invariably be individuals, small groups of people, or small companies. This means that the object of venture capital investment will usually be either an individual or an SME. As a result, venture capital has made a considerable contribution to the growth of SMEs, particularly those in the emerging industries.

Taiwan's first venture capital company was established in 1984, with an initial growth rate which was relatively slow; however, some 15 years later, venture capital has now entered a growth period, constituting the main motive power behind the promotion of the hi-tech industries. By the end of 2001, there had been 199 venture capital companies set up, and 6,957 cases of venture capital investment in Taiwan, with total investment amounting to NT\$133.65 billion. In

the last few years in particular, the impressive performance of hi-tech and electronics stocks in the stock market has also effectively encouraged the establishment of new venture capital companies. As Table 2 shows, over the period 1995–2001, a total of 199 venture capital companies were established (at the end of 1994, there had been only 28).

Table 2 Venture capital companies in Taiwan, 1995-2001

Year	1995	1996	1997	1998	1999	2000	2001
Total venture capital companies	34	47	72	117	160	192	199
Growth rate (per cent)	21.43	38.24	53.19	62.50	36.75	20.26	4.12
Paid-in capital (NT\$ billion)	18.70	25.46	42.63	72.93	103.42	128.07	134.10
Growth rate (per cent)	27.25	36.15	67.44	71.08	33.33	23.84	4.71
Total no. of companies invested in (cumulative)	868	1158	1839	2994	4493	6343	6957
Total investment (cumulative)	12.35	28.63	43.52	65.11	94.70	125.51	133.65
Total no. of companies invested in (current year)	364	471	951	1155	1499	1850	614
Total investment (NT\$ billion) (current year)	5.89	8.81	17.6	21.59	29.59	30.80	8.14

Source: Taiwan Venture Capital Association (2002).

The annual growth rate in the number of venture capital companies and the amount of venture capital investment exceeded 50 per cent in 1997 and 1998, a clear indication of the rapid development of Taiwan’s venture capital sector over the last few years. Such growth has also speeded up the development of the hi-tech sector, and in addition to traditional policy measures, the government has now also adopted new tools in the knowledge era, such as policies to promote innovation incubators and automation.

Innovation incubators

The aims of innovation incubators for SMEs in Taiwan are threefold. First of all, they promote the innovative ability of SMEs. Secondly, they serve as a channel between the industrial sector and academic institutions, helping to transfer academic research results into industry. Thirdly, they play the role of regional innovation centers and promote the competitiveness of local industry.

Since 1996, the Small and Medium Enterprise Administration (SMEA) at the MOEA has continued to promote the establishment of incubators through the use of the financial support available from the Small and Medium Enterprise Development Fund for office equipment, personnel and related costs. After five years of continuous effort, the SMEA has promoted 63 incubators and attracted around 900 firms to move into these incubators.

There are, however, a number of weaknesses which still need to be overcome. First of all, the incubators have attracted mainly firms from the high-tech industry, whilst firms in the more traditional industries, which badly need to upgrade their technology, have shown only mild interest. Secondly, as a direct result of financial incentives, universities have rushed to set up their own incubators (around 90 per cent of all incubators have been set up in universities); however, although the amount of incubators has increased significantly, there is a need to improve the quality of the member firms residing in them. Thirdly, both the products and technology are very similar in all incubators, therefore, this lack of special features results in the chances of firms flourishing being rather slim.

Industrial automation

In order to achieve the overall aim of industrial automation, the National Information and Communication Initiative (NICI) set up a number of goals to be achieved between 1999 and 2004:

(i) the promotion of 200 industrial automation systems for the application of 'business-to-business' (B2B) e-commerce in five million firms, so as to upgrade their industrial competitiveness; (ii) the prioritization of the information industry as a model industry for B2B application; and (iii) the provision of assistance to 2,000 firms in order to establish automation capabilities in various industries within five years. The Taiwanese government has so far promoted 18 systems and assisted around 3,000 firms to establish such industrial automation capabilities. The MOEA has also organized an industrial automation service team and it is expected that around 300 firms will be provided with support from this service team in the

application of e-commerce.

In terms of its overall performance in e-commerce, Taiwan is taking the lead in the developing countries, and has even made strides towards performance at levels similar to some of the developed countries. Taiwan has made significant progress in the EIU/Pyramid Research worldwide rankings, from 27th in 2000, to 16th in 2001 (see Table 3). Furthermore, Taiwan has also been evaluated by the IDC/World Time ratings as being in the leading group in information society, demonstrating that the government's efforts in Taiwan have equipped it with significant development potential in industrial automation.

Table 3 E-readiness ranking of Taiwan and neighbouring Asian countries

Ranking	E-Readiness Measures		
	McConnell International	IDC/World Times	EIU/Pyramid Research
1	South Korea	Singapore	Singapore
2	Taiwan	Japan	Hong Kong
3	India	Hong Kong	Taiwan
4	Malaysia	Taiwan	Japan
5	China	South Korea	South Korea
6	Philippines	Malaysia	Malaysia
7	Thailand	Thailand	Philippines
8	Indonesia	Philippines	India
9		China	Thailand
10		Indonesia	China
11		India	Indonesia

Source: Electronic Business White Paper, NICI (2001).

R&D IMPACT ON PRODUCTIVITY

Since these policy measures on innovation are closely tied to the development of Taiwan's high-tech industries and innovative efforts are invariably measured by R&D expenditure, the purpose of this section is therefore to examine the R&D performance of high-tech industries. Specifically, we attempt to determine whether R&D input can be transformed into physical output, industrial productivity and the subsequent promotion of national economic development. We therefore aim to estimate the impact of R&D on productivity.

Methodology

The model

The model which is common to most analyses of R&D impacts on productivity growth (e.g. Griliches, 1986; Goto and Suzuk, 1989; Lichtenberg and Siegel, 1991; Sakurai, et. al., 1997; Hanel, 2000; Los and Verpagen, 2000; Wakelin, 2001) is the log form of the simple extended Cobb-Douglas production function:

$$q_{it} = a + \lambda t + \alpha k_{it} + \beta l_{it} + \gamma r_{it} + e_{it} \quad (1)$$

where the variables in lower case Q, L, K, and R are the logarithms of output (Q, sales, or value-added), labor (L), physical (K) and R&D capital (R), respectively; λ is the rate of disembodied technical progress; β , α , and γ represent the output elasticities with respect to labor, physical and R&D capital; a is a constant; e_{it} is the error term in the equation. Assuming that the output elasticity of conventional inputs (labor and physical capital) equal their shares in total costs, Equation (1) can be expressed as a linear term of labor productivity:

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

where $(q - l)$ and $(k - l)$ reflect labor productivity and the physical capital-labor intensity; v_{it} is the error term. Equation (2) is the model employed to estimate the effects of R&D investment on productivity growth. Furthermore, based on the estimates and the definition of elasticity (γ), we can compute the rates of return on R&D investment.

There is, however, one issue relating to v_{it} which is worth noting. In addition to the inputs listed in the model, some unobservable factors, such as managerial capability and marketing know-how, also have impacts on the creation of a firm's value added (Barney, 1991; Peteraf, 1993). Some of the omitted factors reflect individual differences that tend to affect the observations for a given individual in more or less the same fashion over time. Still other factors may reflect variables peculiar to specific time periods, but affecting individuals more or less

equally. Thus, here the variance of v_{it} is heteroskedastic and assumed to consist of three error components (across firms, across time periods and with random disturbance).

The data and major variables

The estimation of R&D performance in high-tech firms is based here on a panel dataset. The dataset includes 150 large firms quoted in the Taiwan Stock Exchange (TSE). As a result of missing observations on R&D expenditure, and questionable data on other variables, the sample was reduced to 136 firms. These samples are completely balanced over the seven-year period from 1994 to 2000.

The sample covers R&D-intensive manufacturing industries, including computers and peripherals, integrated circuits, telecommunications, optoelectronics and other electronics. Since the number of firms within each of these industries is too small to work with separately, the sample is not further divided into subgroups for our subsequent analysis.

In order to obviate the possible omission of materials, the output (dependent variable) is measured by value-added rather than by sales. Value-added is deflated by the weighted output price index and labor is measured simply by the total number of employees since there is no available information on labor working hours. The measure of physical capital is total fixed gross assets, deflated by the gross fixed capital index.

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 that period. There is some sort of distributed lag structure that connects past R&D expenditures to a current increase in technical knowledge; here, as in other studies, this is assumed to be a decreasing geometric form (e.g. Griliches, 1984; Griliches and Mairesse, 1984; Griliches and Regev, 1995). The measurement of R&D capital is expressed as:

$$R_{it} = \sum_j (1-\delta_i)^j E_{i(t-1-j)}, \quad (3)$$

where E is a deflated measure of R&D expenditure,³ δ is the rate of obsolescence of R&D capital, and (t-1-j) stand for lagged year, with j going from zero to infinity. The rate of obsolescence (δ) reflects replacement in the effective appropriation of knowledge. As suggested by Goto and Suzuki (1989), the length of time taken by firms' patents to generate revenue was estimated as δ . The inverse of the length of time was used to measure the rate of obsolescence of R&D capital. Amongst all of the firms analyzed in the model, the average rate of obsolescence was around 20 per cent.

Analysis

Description

For the whole of the sample, during the period 1994-2000, the respective growth rates in labor, real physical capital, value added and R&D to sales ratio were: 5.72 per cent, 15.85 per cent, 22.53 per cent and 0.052 per cent. In 2000, the average number of employees was 2,815 (SD = 3,846), the mean of real physical capital was around NT\$15,187,200 thousands (SD = 8,760,197), and the average ratio of R&D to sales was around 3.79 per cent (SD = 1.35), at least five times as much as in other industries. The figures show that the samples analyzed in the following are large firms, with greater R&D intensity by year.

Results

The model is estimated using generalized least squares (GLS), with the results being listed in Table 1. The Hausman test for the model shows that the explanatory variables are most likely uncorrelated with the individual effects ($\chi^2 = 3.83$, df = 4, P > 0.05). In contrast to the variance

³ Not only is the composition of R&D expenditure little known, but also the available data concerning real R&D expenditure is also bedeviled by the lack of a good price index for R&D inputs. Due to the inherent difficulties, the GNP deflator is usually adopted. However, based on the GNP deflator, the rate of increase in R&D expenditure is usually overestimated (Mansfield, *et. al.*, 1983). Thus, the price index for R&D expenditure here was constructed as in Mansfield, *et. al.*, (1983). Indeed, we tried to use a GDP deflator to deflate R&D expenditure, but this adjustment did not significantly change the estimation of R&D output elasticity.

component for the time series ($V_{ts} = 0.03$), the variance component for the cross sections ($V_{cs} = 0.67$) highlights the differences existing between firms in the high-tech sector.

Table 4 shows that the estimates of R&D capital elasticity (γ) were around 0.18, with significance at the 1 per cent level. The results reveal that R&D investment, during the period 1994-2000, was a significant determinant of productivity growth within Taiwan's high-tech firms. Although the estimates of γ may be difficult to compare due to the use of different data, and the different estimation method, this result is much lower than the estimates of 0.25 for US 'scientific firms' obtained by Griliches and Mairesse (1984).

Table 4 Production function estimates, 1994-2000

Parameters	α	γ	λ	γ_s
Estimates ^a	0.231 (0.088) ^b	0.187 (0.075) ^b	0.139 (0.035) ^c	-0.045(0.012) ^c

Notes:

^a MSE = 0.224; $R^2 = 0.316$; $V_{cs} = 0.67$, $V_{ts} = 0.03$; estimated standard errors are in parentheses.

^b Significant at the 1 per cent level

^c Significant at the 5 per cent level

The Schumpeter (1950) hypothesis supported the idea that R&D performance is an increasing function of firm size. In this study, using total fixed assets as a proxy for firm size, the estimate of γ_s , the parameter of the product term of R&D capital by total fixed assets, is negatively significant at the 5 per cent level ($\gamma_s = -0.045$, $P < 0.05$), which clearly does not imply that large size 'regimes' exist with regard to R&D impact on productivity. This finding is inconsistent with the empirical results of Lichtenberg and Siegel (1991).

According to the findings of Keller (1986), Ancona and Caldwell (1992) and Dougherty (1992), internal group cohesion is supportive of performance. Greater cohesion in an organization expands the capacity for coordination, and thus leads to better R&D productivity (Reagans and Zuckerman, 2001). Yu (2002) also showed that diversity impedes performance because diverse teams are less cohesive. For a large organization, the demographic distribution of organizational members is more diverse, thus thorough and totally effective internal

communication is more difficult (Dougherty, 1992; Reagans and Zuckerman, 2001). Therefore, the belief that R&D performance is linearly and positively related to firm size is not supported.

CONCLUSIONS

Innovation and the application of technology have become the growth engines for industrial productivity and national competitiveness; however, because of SME-dominated industrial structure in Taiwan, and the existing market failure phenomenon which constrains firms' innovative ability, the Taiwanese government has therefore adopted several policy measures as a means of correcting market failure and encouraging innovation behavior amongst firms. In this paper, we have attempted to illustrate the innovation policies adopted by the Taiwanese government in its efforts to promote firms' innovative ability, and to examine their overall effectiveness. Generally speaking, these market-friendly public policies have had significant impacts on Taiwan's technological development over the past thirty years. This empirical study also confirms the pay-off from Taiwan's innovation efforts.

Government assistance may, nevertheless, cause market failure; therefore, as time goes by, the government must attempt to adjust its innovation policies, switching from an aggressive involvement approach to a principle of more market-oriented and technological infrastructure provision. In the knowledge-based economy, the government should ensure that its innovation-related policies are designed to complement firms' innovation efforts, rather than to substitute for them. In this regard, information and telecommunications related infrastructure, intellectual property protection, the appraisal, exchange and sharing of knowledge, venture capital, industry and university cooperation (e.g., incubators), industry and research institute cooperation (e.g., the open laboratory), and so on, should be given a higher priority. Conventional industrial policies (e.g., strategic industry promotion, government procurement and tax incentives), should be gradually phased out.

Not only will these market-oriented policy tools encourage firms to innovate, but they will

also cause less market distortion. As already noted, it is clear that some policy measures in Taiwan, such as the provision of venture capital, incubators and industrial automation, have already moved in that direction. Although some of this effort may still be at a very early stage, it is hoped that as a result of these efforts, Taiwan is now effectively preparing itself for the era of the Knowledge Economy.

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