The Innovation Policy and Performance of Innovation in Taiwan's Technology- Intensive Industries

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Abstract: Much greater emphasis is now being placed upon innovation following 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 small and medium-sized 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.

In recent decades the government in Taiwan has implemented a number of policy measures 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 on time series data (1983-2000) and a random coefficient model derived from Cobb-Douglas production function, several results have been obtained. (1) The impacts of R&D on productivity (R&D output elasticity) in chemicals, general machinery, electrical machinery, and transportation equipment are 0.039, 0.049, 0.046, and 0.012, respectively. (2) The rates of return to R&D in chemicals, general machinery, electrical machinery, and transportation equipment are around 7%, 43%, 26%, and 12%, respectively.

Keywords: Innovation, Innovation policy, R&D Performance

Introduction

Innovation has been increasingly playing an important role in enhancing industrial technology levels and has also emerged as the key to national competitiveness in the knowledge economy.[3] Numerous studies have demonstrated that innovative activities have a significant contribution to make into the 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

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[3] 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'.

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.

Take 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, but it has also enabled Taiwan's 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, did providing them with valuable first mover advantages.

However, the Taiwanese economy is comprised predominantly of small and medium-sized enterprises (SMEs), and as such, because of 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 currently considered to be 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 are provided in the closing section.

Innovation Policies in Taiwan and their Effects

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 technology/product facilitation or an approach based on the construction of a favorable environment. However, Taiwan's SME-dominated industrial structure and a capital market which is still at the very early stage of its development leads to insufficient R&D and innovation. Therefore, by making use of various policy tools to reduce the risks associated with innovation, the government can seek to encourage innovative activities and assist in the creating an environment conducive to R&D investment, thereby reducing the likelihood of market failure.

Various policy measures 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 viewed 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. Following the model of Silicon Valley in the US, the land for the HSIP establishment was provided by the government. With the National Tsing-Hua and National Chiao-Tung Universities, two of Taiwan's oldest universities, being located nearby, not only does this effectively reduce employee training costs, land, plant construction and other infrastructure costs, but clustering benefits can also be obtained in terms of technology diffusion (Mai, 1996; Mai and Peng, 1999; Mai, Chang and Hsu, 1999).

During 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 into raising the level of technology in related industries in Taiwan. One of the major contributions that the HSIP has made into 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 of 1980–1989, a total of 14,880 people who had been studying overseas subsequently returned home to work in Taiwan; however, over the period of 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, that 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 etc., and 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 accounted 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 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 diffuses the results of this research to the private sector. The National Science and Technology Projects (NTSTPs) provide financial support in order to ensure that ITRI has a stable budget to undertake long-term R&D work. Beginning with 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.

Research grant- Small Business Innovation Research (SBIR)

In an effort to encourage small and medium sized enterprises (SMEs) to engage in innovation research on industrial technology and products, the Bureau of Industrial Technology duplicated the spirit of USA's SBIR project. SBIR has been enacted since 1998, its main purpose being to apply innovation to new products R&D, upgrade existing products or develope new technological process, inserting new application and develop new operation model so as to enhance the competitiveness of Taiwan's SMEs.

SBIR grants include two phases:

1. Preliminary research (Phase I)

Firm's creative idea with potential economic benefit can apply for Phase I's grants. The project implementation in Phase I is six months. Government subsidizes up to 50% of project budget and the ceiling for the grant is New Taiwan Dollar 1 million (about 30 thousand US dollars).

2. R&D (Phase II)

Projects aiming to develop concrete technology or products, or evaluated by preliminary research as such that can be directly developed into technology or products; can apply for Phase II grants.

The project execution period is limits to two years. Government provide up to 50% project budget and limited to 10 million research grants for each application.

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 January 1. 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, the Statute for Industrial Upgrading and Promotion has achieved impressive results in terms of stimulating expenditure, the impact on the economy as a whole, or the contribution made to industrial upgrading.

Take 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 enabled manufacturers to increase 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. Regarding 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 of 1995-2001, a total of 199 venture capital companies were established (at the end of 1994, there were 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.

The Promotion of e-Commerce

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).

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).

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.

The development of the open laboratory system: a new model for interaction between industrial and academic research

As it was pointed out earlier, there is not much interaction between academic and private industrial research institutes. This lack of interaction not only causes duplication in some of the research projects but also delays the speed of innovation. The old model of cooperation between industrial and academic research institutions is no longer capable of meeting the need for rapid developments in new products and technologies. Thus, a new model has been developed by ITRI in the form of an "open laboratory' system, which provides individual firms not only with new technologies, but with other important services as well, e.g., marketing, strategy planning, managerial consulting on organizational structure, venture capital services, legal consultation, information, communications and other knowledge-intensive services. According to ITRI, the open laboratory system is a "total resource service" for innovation. The overall concept of ITRI's open laboratory is shown in Figure 1.

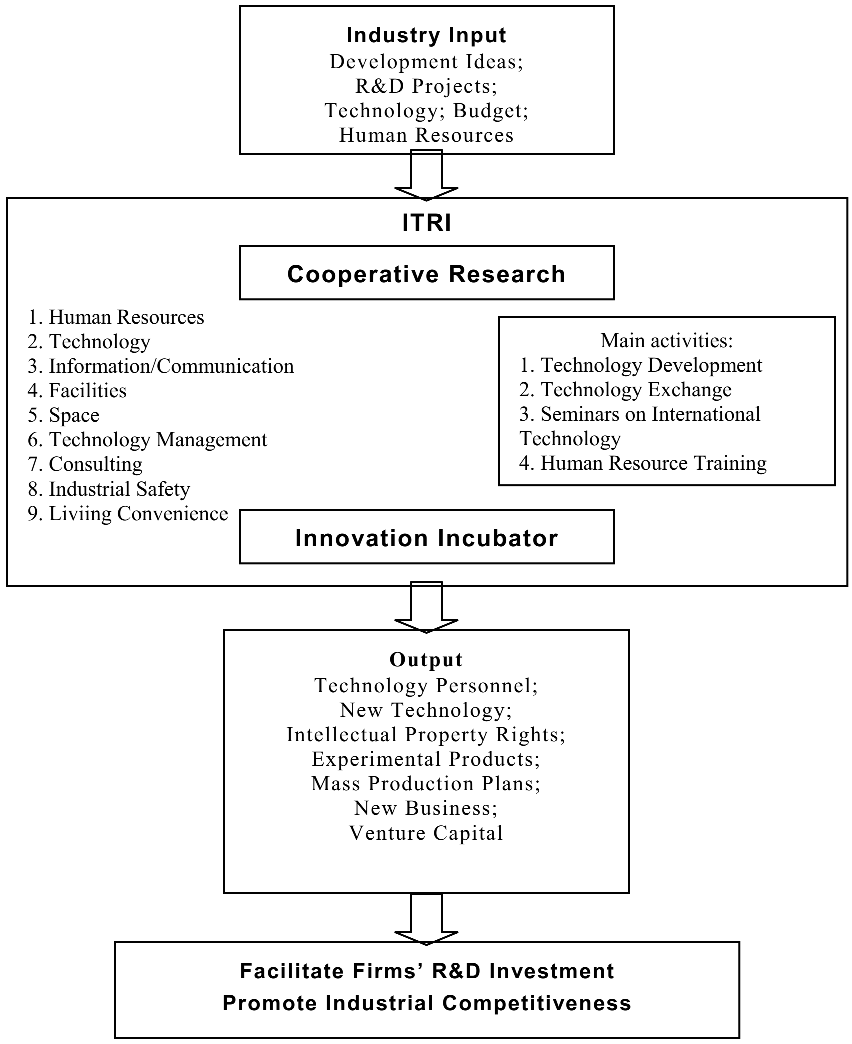

Fig. 1. The Concept of ITRI's "Cpen laboratory System" *Source:* Shih (1999).

R&D and its effects on Productivity Growth

Following our examination of firms' innovative capabilities, we use R&D input and output indicators to illustrate Taiwan's innovative efforts. In terms of R&D inputs, Taiwan's R&D intensity (R&D expenditure over GDP) was 2.05 per cent in 1999. Although this was lower than the 2.84 per cent of the US, the ratio was nevertheless quite close to that of Germany (2.29 per cent) and France (2.18 per cent), and indeed, ahead of that in the UK (1.83 per cent). Within the total population of Taiwan, the ratio of researchers per 10,000 people was also comparable to those of the advanced countries, with the exception of the US. In terms of R&D-output patents granted in the US, Taiwan ranks fourth, after the US, Japan and Germany.

In addition to these R&D indicators, 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 both the impact of R&D on productivity growth and the resultant rates of return.

Methodology

The Model

Like most previous empirical studies, here the model is based on a Cobb-Douglas production function which includes the stock of R&D as a factor of production:

$$Q(t) = Ae\lambda tL(t)\alpha K(t)\beta M(t)\nu R(t)\gamma \ , \tag{1}$$

where *Q(t)*= total output; *A*= a constant; *L(t)*=labor input; *K(t)*=stock of physical capital; M(t)=materials (including energy); *R(t)*=stock of R&D capital; α, β, ν, and γ represent the output elasticity with respect to labor, physical capital, materials, and R&D capital, respectively; λ denotes the rate of external technological change. Note that R&D capital represents the stock of knowledge an industry possesses at a certain point in time. Assuming constant returns to scale, taking logs, (1) can be written as :[1]

$$\ln T(t) = \mu + \gamma \ln R(t) + \lambda t \ , \tag{2}$$

where *T(t)=Q(t)/L(t)αK(t)βM(t)v*, normalized to 1 in 1996, is the total factor productivity (TFP); μ=lnA. The model in most previous studies using industry-level productivity growth as an indicator of the social rates of return to R&D is equation (2). However, their estimations have been at a high degree of aggregation, rarely accounting for inter-industry differences.

A variant of equation (2) is estimated on pooled time-series data (1983-2000) for all industries. Two modifications are made. First, each industry is specified to have its own intercept term, μ. Rather than including all industry dummies in the estimating equation, lnT(t) and lnR(t) are measured as deviations from the respective means.[2] Second, the time trend is generalized to a set of time dummies. These time dummies account for all "year effects" common to the included industries. Thus, the specification of the estimating equation is

$$\ln \breve{T}(t) = \gamma \ln \breve{R}(t) + \sum \tau t D t \, , \tag{3}$$

where ln*Ť(t)* and ln*Ř(t)* denote the deviations of ln*T(t)* and ln*R(t)* from the industry means, and τt is a set of parameters reflecting the "year effects" of time dummies (*Dt*). This is the basic form used to estimate the productivity of R&D for all industries. Note that since there is no reason to expect the contribution of R&D investment to be equalized across industries, a random coefficient model based on equation (3) is employed on the pooled data.[3] Furthermore, by the estimate of γ, we could estimate the rate of return of R&D ($\rho = \gamma Q/R$) for the five industries.[4]

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[1] Differentiating with respect to time, equation (2) can be further written as the intensity version of R&D capital stock model. It is the re-parameterized form frequently found in the empirical studies. Under the model, we can directly estimate the rate of return of R&D ($\partial Q/\partial R$). However, the model implies that the proportion of R&D capital relative to value added (R/Q) is a constant. Since the assumption is not convincing, here it will not be adopted in this study.

[2] Since we do not observe the μ-term for each industry and want to reduce the estimation parameters, we thus use deviations from the respective means instead of the full values.

[3] The form of the random coefficient model is: lnŤi(t) = γi lnŘi(t) + Στt Dt . Obviously, in the model estimation, we do not assume that the elasticity of R&D is common across industries.

[4] Because the data used in the estimation are at the industry level, the estimate of the rate should be called the "social" rate of return to R&D investment.

The Data

Obviously, in order to estimate the elasticity of R&D (γ), both TFP and R&D capital data are needed. The TFP data can be easily obtained from The Trends in Multi-factor Productivity reported by the Directorate-General of Budget, Accounting and Statistics. However, R&D stock has never been reported on in any publications. Thus, we have to construct the data of R&D capital.[1]

Following Griliches (1980), Nadiri (1980), and Goto & Suzuki (1989), we present R&D capital as follows:

$$R(t) = (1-\delta)R(t-1) + \sum \phi i E(t-i) \ , \tag{4}$$

where $E(t)$ = R&D expenditure; δ= the average rate of obsolescence of R&D capital; ϕ= the lag operator that connects past R&D expenditure to the current increase in $R(t)$. However, the lag information required is difficult to obtain (Griliches, 1979). Therefore, as Goto & Suzuki (1989) did, we use the average lag based on several evidences to simplify it.

According to Lin & Lee (1996) and Tsai (1997), R&D investment has a significant impact on patents two years later. And patent is a good indicator of benefit (value added) creation (Bound et al., 1984; Pakes & Griliches, 1984). Moreover, a simulation study shows that the lag length of effect on productivity growth from R&D expenditure is around two years (Xu et al., 1998). These findings suggest that the value of average lag be 2.[2] Thus, equation (4) is simplified as:

$$R(t) = (1-\delta)R(t-1) + E(t-2). \tag{5}$$

Equation (5) means that R&D expenditures in period t-2 transform into R&D capital in period t. Equation (5) is employed to calculate the R&D stock.

The depreciation of R&D capital represents that the R&D efforts of an industry become obsolete due to the development of superior techniques or products. In order to estimate δ, we survey the average length of time that firms' patents took to generate revenues. The survey is based on an investigation. The firms we investigated belonged to the five industries and were ranked 1000 top in Taiwanese manufacturing industry. The informants were the managers of R&D or engineering departments. We use the inverse of the estimate from the survey to measure the rate of obsolescence of R&D capital. Among these industries, the rates of obsolescence were 6% (chemicals), 7% (general machinery), 20% (electrical machinery), 14% (transportation equipment), and 10% (precision instrument), respectively.

Of course, besides the industries owned R&D investment the productivity growth of the industry is affected by various factors. One of the most important of them is the purchase of intermediate and capital goods. When the quality measures of a machine are increased through product development, the industry that uses the machine is to increase productivity too. In other words, the effect of R&D spillovers will take place through purchased input. Following the approach suggested by Terleckyj (1974), we employ the input-output (IO) table of transaction to calculate the R&D flow from industry i (the source industry) to industry j (the receiving industry). The form is defined as:

$$SE(t)ij = aijE(t)i \ , \tag{6}$$

where aij is the proportion of sales to j relative to the total sales of i, E(t)i is the R&D expenditure of industry i, and SE(t)ij represents the R&D flow from industry i to industry j. Utilizing equation (6), we calculate the R&D flow to these industries, i.e. chemicals, general machinery, electrical machinery, transportation equipment and precision instrument.

However, note that only seven input-output tables (1984, 1986, 1989, 1991, 1994, 1996, 2000) reported by the Directorate-General of Budget, Accounting and Statistics are available in

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[1] The R&D raw data is obtained from The Indicators of Science and Technology published by National Science Council.

[2] Pakes & Schankerman (1984) show that the R&D lag from chemicals, machinery, and electronics is about 2 years.

this study. In other words, in addition to the six input-output tables, we have to construct the I-O tables of the other years. Here biporportional adjustment (RAS) method (Miller & Blair, 1985) is used to estimate I-O coefficients (*aij*).[1]

Finally, under the assumption that the growth rate of R&D expenditures (industry owned R&D expenditures and other industries spillovers) is the same as the growth rate of R, we can roughly estimate the R&D capital through equation (5) for each industry.[2]

Analysis

Basic Description

Before turning to the results of estimation, in Table 1 we present some basic statistics on total factor productivity and R&D intensity of expenditure for the five industries. In the first column of Table 1 we show the average annual growth rate of TFP. Note that the level of TFP increases by year for the industries except for precision instrument. Among these five industries, electrical machinery has the highest increase rate.

The second column of Table 1 lists the average annual growth rate of R&D expenditure relative to value added (*E/Q*). The result shows that R&D intensity is increasing by year for all industries. Among these industries, electrical machinery has the greatest increase rate (0.53%). The third column of Table 1 indicates that the proportion of R&D expenditure in electrical machinery relative total R&D investment in manufacturing industries is increasing by year (2.03%, $p<0.01$), but those of other industries either increase non-significantly or even decline significantly. But we should keep in mind that R&D expenditures for the five industries have been significantly increasing (13%-22%, $p<0.01$, see the last column of Table 4). These findings suggest that a great amount of R&D expenditures have been spent on electrical machinery. And the result seems to significantly enhance the productivity growth in electrical machinery. However, the TFP growth is negative in precision instrument. Due to the fact that the real gross domestic product (value added) in precision instrument does not significantly increase ($p>0.05$), the negative productivity growth would be expected.

Table 4

Average Annual Growth Rates of TFP and R&D Intensity

Indicator / Industry	T	E/Q	E/ΣE	ΔE/E
Chemicals	0.89***	0.14**	-0.76 ***	13.33 ***
General machinery	1.14***	0.12**	-0.11	16.59 ***
Electrical machinery	1.43***	0.53 ***	2.03 ***	22.44 ***
Transportation equipment	0.39 *	0.30 ***	-0.04	18.30 ***
Precision instrument	- 0.44 ***	0.49 ***	0.03	21.35 ***

Notes: ΣE = the total R&D expenditures in manufacturing industries; ***, $p<0.01$; **, $p<0.05$; *, $p<0.10$.

The Results

The joint test based on model (3) illustrates the assumption that a common slope will be rejected ($F_{4, 52} = 55.47$, $p<0.01$). This means that the elasticity of R&D investment is not equal

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[1] In general, the RAS method includes three steps: (1) specifying the period t in which we want to estimate aij; (2) using the given I-O coefficients (aij*) of time period closest to t and the total intermediate demand and supply in period t for individual sector to calculate aij; (3) minimizing the objective function : ΣiΣjaij ln(aij/aij*) and estimating of aij by iterative method. The iterative process of calculating aij and the proof are too complicated to illustrate here. Please see chapter 8 of Miller & Blair (1985) for details.

[2] Not only is the composition of R&D expenditures little known, but the available data concerning real R&D expenditures are also bedeviled by the lack of a suitable price index for R&D inputs. In view of the inherent difficulties, as U.S. official government does, most previous studies use the GNP deflator to deflate R&D expenditures. However, since most of R&D expenditures are spent on R&D equipment, here we use the price of physical capital (at 1996 constant price) to deflate R&D expenditures and then construct R&D capital through equation (5).

across industries. The estimation results based on a random coefficient model are summarized in Table 5. Inspection of Table 5 shows that except for precision instrument, the estimates of γ in other industries are significant at the 1 or 5 percent level (one-tailed test).

The results reveal that R&D investment in chemicals, general machinery, electrical machinery, and transportation equipment has significant impact on productivity growth. The output elasticity of R&D in these four industries is 0.039, 0.049, 0.046, and 0.012, respectively. These estimates demonstrate the impact of R&D on productivity for each industry. Take 0.039 as an illustration; it indicates that when R&D capital increases by 1% in chemicals, the total factor productivity in chemicals will increase by 0.039%.

Table 5

R&D Elasticity and Rates of Return

Parameter / Industry	γ	ρ(%)
Chemicals	0.039 (0.011) ***	7.49 (0.18)
General machinery	0.049 (0.007) ***	42.88 (2.98)
Electrical machinery	0.046 (0.005) ***	26.34 (3.55)
Transportation equipment	0.012 (0.007) **	11.86 (1.51)
Precision instrument	NS	—

Notes: Adj-R2=0.88 ; ρ=the average rates of return to R&D investment; standard errors in parentheses; ***, $p<0.01$; **, $p<0.05$ (one-tailed test); NS = not significant.

Compared to the findings of previous studies, these results show that the impact of R&D on productivity in Taiwan seems to be smaller. Also, due to the fact that the real gross domestic product (value added) in precision instrument does not significantly increase, the estimation does not confirm the R&D contribution to precision instrument.

Furthermore, the equality of the impact (γ) among the four industries is examined. The overall test shows that the hypothesis of equality will be rejected ($F_{3,52}=12.11$, $p<0.05$). The individual tests reveal that the effect of R&D on productivity growth in chemicals, general machinery, and electrical machinery is greater than that of transportation equipment ($F_{1,52} = 6.81$, $p<0.05$; $F_{1,52} = 25.83$, $p<0.01$; $F_{1,52} = 28.73$, $p<0.01$), but the difference between chemicals, general machinery, and electrical machinery is not significant ($F_{2, 52} = 0.62$, $p>0.05$). With respect to the elasticity of each industry, the average rate of return on R&D investment (ρ) is listed in the last column of Table 2. The average rates in chemicals, general machinery, electrical machinery, and transportation equipment are around 7%, 43%, 26%, and 12%, respectively. Notice that the R&D elasticity of chemicals, general machinery, and electrical machinery seems to be equal ($F_{2, 52} = 0.62$, $p>0.05$), but the greatest rate of return comes from general machinery. Since the ratio of gross domestic product relative to R&D capital (Q/R) in general machinery is larger than that of the other two industries, this result is not surprising.

To sum it up, the present study suggests that R&D investment have significant effect on productivity growth in chemicals, general machinery, electrical machinery, and transportation equipment. Among the four industries, the R&D impact on productivity of chemicals, general machinery, and electrical machinery is greater than that of transportation equipment. Meanwhile, the paper reveals that general machinery has the greatest R&D rate of return, than electrical machinery comes the second, and that chemical comes last. But the impact of R&D on productivity fails to achieve statistical significance in precision instrument. Obviously, as the results of previous studies, here the examination shows somewhat inconsistent results in these "R&D-intensive industries".

Concluding remarks

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.

Based on the TFP series and the measurement of R&D capital, the estimation reveals that the estimated output elasticity of R&D stock lies somewhere between 0.01 and 0.05 and that the rate of return to investment in R&D tends to be about 7%-43%. But the estimation does not confirm the R&D contribution to precision equipment. To sum up, these findings imply that R&D efforts have been helpful to the economic development in Taiwan. In addition, since R&D expenditure is the indicator that is most widely used in identifying high-tech organizations or industries (Baruch, 1997), the results concretely suggest that the R&D investment in the Taiwanese high-tech industries has significant impact on productivity growth.

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 these efforts may still be at a very early stage, hopefully, the result of these efforts is that Taiwan is now effectively preparing itself for the era of the Knowledge Economy.

References

1. Bound, J., C. Cunnins, Z. Griliches, B.H. Hall and A. Jaffe (1984), "Who Does R&D and Who Patents?" In Z. Griliches (ed.) R&D, Patents, and Productivity, Chicago, University of Chicago Press, pp.21-54.
2. Gopalakrishnan, S. (2000), 'Unraveling the links between dimensions of innovation and organizational performance', Journal of High Technology Management Research, 11(1): 137-53.
3. Goto, A. and K. Suzuki (1989), "R&D Capital Rate of Return on R&D Investment and Spillover of R&D in Japanese Manufacturing Industries," Review of Economic and Statistics, 56(4), pp.555-564.
4. Griliches, Z. (1979), "Issues in Assessing the Contribution of Research and Development to Productivity Growth," Bell Journal of Economics, 10, pp.92-116.
5. Griliches, Z. (1980), "R&D and Productivity Slowdown," American Economic Review, 70(1), pp.343-348.

6. Griliches, Z. and F. Lichtenberg (1984), "R&D and Productivity Growth at the Industry Level: Is There Still a Relationship?" In Z. Griliches (ed.). R&D, Patents, and Productivity, Chicago, University of Chicago Press, pp.465-501.
7. Hanel, P. (2000), 'R&D, inter-industry and international technology spillovers and total factor productivity growth of manufacturing industries in Canada, 1974-1989', Economic Systems Research, 12(3): 345-61.
8. Lin, H.L. and X.F. Lee (1996), "The Study of the Relationship between Patents and R&D Expenditure in Taiwan: An Application of Nonnegative Integer Model," Economic Article, 24(2), pp.273-302.
9. Mai C.C. and S.K. Peng (1999), 'Cooperation vs. competition in a spatial Model', Regional Science and Urban Economics, 29: 463-72.
10. Mai C.C., P.C. Chang and C.Y. Hsu (1999), The relationship between the labor market and the diffusion of technology in the Hsinchu science-based industrial park – A case study of the semiconductor industry (project commissioned by the Science-based Industrial Park Administration), Taipei: Chung-Hua Institution for Economic Research, (in Chinese).
11. Mai, C. C. (1996), 'Clustering and Spatial Competition, with Reference to the Establishment of the Hsinchu Science-based Industrial Park', Symposium in Memory of Liu Ta-Chung, Taipei: Liu Ta-Chung Educational and Cultural Foundation, (in Chinese).
12. Miller, R.E. and P.D. Blair (1985), Input-output Analysis: Foundations and Extensions, Englewood Cliffs, NJ: Prentice Hall.
13. Nadiri, M. I. (1980), "Contributions and Developments of Research and Development Expenditures in the U.S. Manufacturing Industries," In G. M. Furstenberg (ed.), Capital, Efficiency and Growth, Cambridge, MA: Ballinger.
14. Nelson, R. (1993), National innovation system, London: Oxford University Press.
15. Pakes A. and M. Schankerman (1984), "The Rate of Obsolescence of Patents, Research Gestation Lags, and the Private Rate of Return to Research and Resources," In Z. Griliches (ed.) R&D, Patents, and Productivity, Chicago, University of Chicago Press, pp.73-88.
16. Pakes A. and Z. Griliches (1984), "Patents and R&D at the Firm Level: A First Look," In Z. Griliches (ed.) R&D, Patents, and Productivity, Chicago, University of Chicago Press, pp.55-72.
17. San G. (1999), 'Science and technology, manpower and technological progress', in Taiwan's Economic Development Since the 1980s, Taipei: Chung-Hua Institution for Economic Research, (in Chinese), 347-88.
18. Shih, C.S (1999), Taiwan's economic development since the 1980s, Taipei: Chung-Hua Institution for Economic Research, (in Chinese).
19. Stock, G. N., N.P. Greis and W.A. Fischer (2001), 'Absorptive capacity and new product development', Journal of High Technology Management Research, 12: 77-91.
20. Sun, K.N., et al., (1998), An overall evaluation of the tax incentive measures provided for by the statute for industrial upgrading and promotion (project commissioned by the Industrial Development Bureau of the Ministry of Economic Affairs), Taipei: Chung-Hua Institution for Economic Research, (in Chinese).
21. Terleckyj, N.E. (1974), Effects of R&D on the Productivity Growth of Industries: An Exploratory Study, Washington, D. C: National Planning Association.
22. Tsai, K.H. (1997), "The Impact of R&D on Patents in Taiwan," Sun Yat-Sen Management Review, 5(2), pp.371-382 (in Chinese).
23. Wakelin, K. (2001), 'Productivity growth and R&D expenditure in UK manufacturing firms', Research Policy, 30: 1079-1090.
24. Xu, J.D., J.C. Wang, K.Z. Liu and K.H. Tsai (1998), The Impact of Technology Expenditures on Economic Development. The Report of National Science Council (in Chinese).