PUBLIC R&D AND INDUSTRIAL INNOVATIONS AT THE PROJECT LEVELS: AN EXPLORATION OF TAIWAN'S PUBLIC RESEARCH PROJECTS

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This study investigates the role of the ITRI in Taiwan's technological catch-up. The authors examine the relationship between public R&D and industrial innovations in Taiwan using data encompassing 252 ITRI annual research projects and the survey on the characteristics of 5902 cases of transferred technologies within these projects. The authors develop a new index of innovative output to measure the monetary value of patents for research projects. They find that the influences of accumulated R&D stock, high-level R&D personnel, and the intensity of process innovations on project-level R&D productivity to be more pronounced when the monetary value of patents, instead of simple patent counts, is used as the proxy for innovation outputs. (*JEL* O12, L63)

I. INTRODUCTION

Economic development policies in Taiwan in the late 1950s and 1960s favored the export-oriented manufacturing sector that mostly produced labor-intensive products such as garments, toys, and furniture. Though the value of export to the United States contributed roughly 40% of Taiwan's total exports in the 1970s, no patents in the high-technology area had been granted to Taiwanese companies by the U.S. Patents and Trademarks Office until the mid-1980s. Taiwanese government's effort to enhance her manufacturing capability included a series of government-subsidized research and development (R&D) projects that began in the early 1970s. Government support for the island's attempt to emulate California's Silicon Valley in Hsinchu, Taiwan, took the form of three institutions established for the purpose of technology diffusion: (1) the Industrial Technology Research Institute (ITRI), (2) the Hsinchu Science-based Industrial Park, and (3) two neighboring universities with a heavy emphasis on science and engineering study. The resultant high-technology clustering led to a succession of collaborative R&D ventures between public institutions and private firms.

Research studying the public R&D and private sector linkage has devoted considerable effort in the past to measuring the effectiveness of industrial policy in developed economies using firm-level or country-level data. Such literature includes Irwin and Klenow (1996), who evaluated the U.S. Sematech program; Wallsten (2000), who analyzed the U.S. Small Business Innovation Research program; Branstetter and Sakakibara (1998, 2002), who examined the performance of Japanese research consortia in high-tech industries; and Stern et al. (2000), who explored the determinants of country-level innovative capacity in Organisation for Economic Co-operation and Development countries.

Literature focusing on Taiwanese government's effort toward developing the island into a science and technology (S&T) center includes Mathews's case studies (1997, 2002), in which he examined the evolution of the organizational architecture from the viewpoint of

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ABBREVIATIONS

ITRI: Industrial Technology Research Institute
MOEA: Ministry of Economic Affairs
R&D: Research and Development
S&T: Science and Technology

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management where he attributed Taiwan's success in the high-tech industry to its capacity to leverage resources and to pursue a strategy of rapid catch-up, much to the credit of its government. To the authors' knowledge, none of the previous studies has quantitatively analyzed the R&D production behaviors of public industrial R&D in Taiwan. This article targets this issue using a set of newly accessible project-level data. Rather than following the conventional approach using firm-level or country-level studies, the present sample contains data on 252 public-funded annual research projects conducted by the ITRI in Taiwan during the period 1991–99. The data are compiled from the online database of the Ministry of Economic Affairs (MOEA), final reports on ITRI S&T research projects, and the authors' surveys of the characteristics of the 5902 cases of locally transferred technologies involved within these S&T projects.

In terms of data construction in the empirical analysis, the authors adopt two new approaches. The conventional wisdom for measuring innovation output uses the number of patents achieved by an entity. Instead of this standard index, the authors measured innovation output by the monetary value of patents, applying the concepts of willingness to pay and propensity for patenting. The authors also upgrade the measurement of labor input by incorporating a quality-adjusted indicator in the R&D production function.

The empirical study includes testing the impacts of project characteristics on project-level productivity. These characteristics involve projects with an orientation toward process or product innovation that clearly had a technological focus. Effects of demographic characteristics of the participating firms, such as geographic proximity and firm size, are also tested.

The organization of this article is as follows: The next section provides description of the ITRI's activity in supervising the operations of S&T projects, presents the models for empirical measurement, and discusses the data sources. Section III analyzes the regression findings. Conclusions are in section IV.

II. EMPIRICAL MODELS AND DATA

A. *S&T Project Operations by ITRI*

The ITRI was established under the auspices of the MOEA in 1973 with a mandate to undertake industrial research and foster the technological catch-up and learning of private enterprises. The ITRI is to carry out the S&T research projects on behalf of the MOEA. Its focus is on the development of both precompetitive technologies and infratechnologies. Twenty percent of all government-funded industrial R&D in Taiwan goes to support MOEA programs, and more than half of this is appropriated for the ITRI's research activity. The scope of the ITRI's S&T projects includes the following four fields: electronics and information technology (*ELEC*); machinery and automation (*MACH*); chemicals and materials (*CHEM*); and energy, sustainable development, and biomedical (*BIO*). Table 1 shows that ITRI's S&T projects are unevenly distributed across sectors, with the electronics and information sector dominating all others in terms of both funding and labor force. The average R&D spending per project in the electronics and information sector was about US$9.8 million—much higher than in the other three sectors. In addition, more than 56% of the total staff worked in the electronics and information sector. The total amount of pubic industrial R&D funding within this sector came to approximately US$1.06 billion during the period 1991–99, an amount equivalent to the sum of government subsidies of the 10-year Sematech program in the United States.[1] Throughout this period, the ITRI has acted as the primary vehicle for the leveraging of advanced technologies from abroad and for their rapid dissemination of the newly acquired technology to local firms. As shown in Table 2, ITRI was involved in approximately 165 cases of international technology transfer during the sample period, with 114 of these cases involving transfers from the United States.[2] Based on technology attained during the early stages and its own efforts in subsequently improving both the absorptive capacity and ability to generate new

1. Sematech (Semiconductor Manufacturing Technology) was a consortium made up of the U.S. Department of Defense and private semiconductor manufacturing companies in 1991. It was dedicated to change in manufacturing technology and the domestic infrastructure to provide American semiconductor companies the capability to be world-class suppliers.

2. Due to data shortage, the authors could not analyze the entire process describing how technology transfer from overseas to ITRI and from ITRI to local companies actually occurred. This study focuses on technology transfer from ITRI to local firms only.

TABLE 1
R&D Inputs and Outputs of the ITRI's Science & Technology Projects during 1991–99

Industry	No. of Projects	R&D Spending[a]	Collaboration Fee[a]	No. of Employees[b]	No. of Foreign Patent Grants	Monetary Value of Foreign Patent Grants[a]	Licensing Fee and Royalties[a]
Electronic & information	108	1061178.08	41120.33	10944.28	664	952.01	35559.58
Machinery	65	377354.95	19848.46	4538.93	219	311.16	11828.49
Chemicals & materials	36	155151.02	5357.96	1763.98	85	131.75	6947.03
Biomedical	43	177786.1	3238.4	2372.65	50	70.88	3468.19
Total	252	1771470.12	69565.15	19619.84	1018	1465.78	57803.29

Industry	Average R&D Spending per Project[d]	Average Collaboration Fee per Project	Average Employment per Project	Average Foreign Patent Grants per Project	Average Monetary Value of Foreign Patent Grants per Project	Average Licensing Fee and Royalty per Project
Electronic & information	9825.72	380.74	101.34	6.15	8.82	329.26
Machinery	5805.46	305.36	69.83	3.37	4.79	181.98
Chemicals & materials	4309.75	148.83	49.00	2.36	3.66	192.97
Biomedical	4208.25	76.80	55.97	1.34	1.94	84.52
Total	7029.64	276.05	77.86	4.04	5.82	229.38

[a]In thousand of U.S. dollars.
[b]In person.
[c]Denotes the sum of domestic and foreign patents.
[d]Denotes average R&D per project. This definition is similarly applied to the other columns in the lower part of the table.
Source: Online data available at http://doit.moea.gov.tw.

innovations, the ITRI has been successful in gaining more than 1000 patents issued by international entities for its S&T projects across the board during the period 1991–99. A whopping 65% of the total patents were concentrated in the electronics and information sector.

There are three forms of local technology transfer, each of which is designed to promote the interests of local firms through the transfer and sharing of ITRI resources. These are (1i) collaborative research, (2) participation in technology transfer during the early stages, and (3) participation in technology transfer subsequent to completion of the project.[3] All of the patents directly emerged from the research undertaken within the S&T projects were assigned not to the participating firms but to the ITRI. All firms participating in one of these three types of collaborative efforts are required to pay either technology licensing fees, patent licensing fees, or royalties for technology transfer. Of all the S&T projects undertaken between 1991 and 1999, there were a total of 5902 cases of local technology transfer, which includes 1483 cases of type 1 technology transfer, called collaborative research, and 4,419 cases of type 2 and 3 technology transfer. In those cases that involved transferred technologies, an average of about 35% of the locally transferred technologies oriented toward process innovation per S&T project.

The ITRI has only received US$69.6 million in collaboration fees and $57.8 million in licensing fees and royalties from participating firms within all the sectors over the whole of the sample period, with approximately 60% of these fees/royalties coming from the electronics and information sector. Due to the public subsidy, the share of the licensing fees and royalties received from private firms in the total amount of the R&D expenditures in the ITRI's S&T projects is relatively low in comparison to the private R&D of U.S. companies. In 1999, it is about 2% for ITRI and roughly 27% for IBM. It is clear that the

3. The major difference among these three types of technology transfer is the timing of participation. Also private firms involved in the first type of technology transfer, known as collaborative research, pay an additional collaboration fee to ITRI before joining the project besides the payment of licensing fees or royalties in the end of project. For this reason, collaboration fee is treated as part of R&D inputs, whereas licensing fees and royalties are treated as innovative outputs in this study.

TABLE 2
Number of Cases of International Technology Transfer by Industry and by Country during 1991–99

	Electronics & Information	Machinery	Chemicals & Materials	Biomedical	Total
Country					
United States	82	17	3	12	114
Japan	1	13	1	0	15
Germany	0	5	2	0	7
England	0	11	0	0	11
Others	0	16	1	1	18
Total	83	62	7	13	165
Scale (in thousands of US$)					
Under 100	45	27	4	2	78
100–500	31	28	3	7	69
Above 500	7	7	0	4	18
Total	83	62	7	13	165
Channels					
Collaborative research	9	49	4	7	69
Technology licensing	32	12	2	2	48
Patent licensing	0	0	1	1	2
Others	42	1	0	3	46
Total	83	62	7	13	165

Source: Online data available at http://doit.moea.gov.tw.

Taiwanese government's interest lies in attaining the goals of rapid adoption of new technologies and quick diffusion to as many as firms as possible much more than the goal of maximizing the revenue of licensing fees and royalties.

B. *R&D Production Function*

The authors relate the innovative outputs received by a specific S&T project in a given year to R&D expenditure in the previous year, R&D stock, and R&D personnel, along with other control variables, according to the logarithmic relationship of the following two functions (which are estimated separately in the empirical analysis) as models (1) and (2), respectively:

$$(1)\quad LNP_t = f(LNR_{t-1},\ LNK_t,\ LNL'_t,\ Z_t) + e_t$$

and

$$(2)\quad LNM_t = f(LNR_{t-1},\ LNK_t,\ LNL'_t,\ Z_t) + e_t,$$

where P_t is a measure of the number of patents successfully achieved by a project in year t; M_t is a measure of total monetary value of the patents generated by the project; R_{t-1} is the R&D expenditure on the project in year $t-1$; K_t is the R&D stock of the project in year t; L'_t is a measure of the quantity of quality-adjusted labor employed by a project in year t; Z_t is a set of control variables common to both equations; and e_t is an error variable.[4]

Patents provide a direct and easily measured index of innovative output and have frequently been used in the literature such as Hall et al. (1986), Griliches (1990), and Stern et al. (2000). The authors use the number of foreign patent grants (mainly U.S.) obtained by an S&T project in a given year as the innovative output in equation (1). Domestic patent grants are not measured here because enterprises (including the ITRI) in Taiwan tend to be more motivated to seek protection in foreign markets than protection in the local market given

4. Patents grants and patent applications are used separately as innovation outputs in the estimation of equation (1). The authors find in the regression that the model using the number of patents granted as the dependent variable performed better than the number of patent applications.

Taiwan's export-oriented economic structure (Jung and Imm, 2002).[5]

Using patent counts as the indicator of innovative output cannot fully reflect the economic importance of innovations because patents vary in economic value. In fact, only a very small proportion of patents may have a major economic potential. Therefore it is critical to accurately measure a patent's economic value though that is not an easy task. Lieberman (1987) and Trajtenberg (1990) used renewal rates or citation counts to classify patents in terms of their economic importance. For the present sample, data on both citation counts and renewal rates for the patents generated in each S&T project are unavailable. The present approach to unearth a measure for the economic value of patent starts at the assumption that generally speaking, the monetary value of patents may be positively correlated to the amount of licensing fees and royalties. However, clearly the economic value of patents for each S&T projects cannot be properly measured by ITRI's appropriation of innovative benefits from licensing fees and royalties because they were not charged at the market values. Therefore, the authors develop an index of a patent's economic value based on the concepts of willing to pay and propensity for patenting.

The authors assume that the maximum value a private firm is willing to pay to the ITRI for a patent is not greater than the costs of a promising project that could be undertaken by the firm itself to obtain a patent, given the assumption that there is no difference between the patent value from self-performed R&D and such acquisition from the ITRI. This can be represented as:

$$(3) \qquad (\text{Max } W) \leqq C_p,$$

where W is the willingness to pay for a patent by a private firm and C_p is the cost of self-performed R&D preceding to a patent award. Once C_p is measured, the total maximum economic value of the patents generated by a given S&T project can be calculated approximately as

$$(4) \qquad M = C_p * P,$$

5. One innovation may be patented in multiple countries. The number of foreign patent grants used in this study has been justified for the double counting issue. The number of U.S. patent grants account for more than 80% of the ITRI's total foreign patent grants in 1991–99.

TABLE 3
The Estimated Average Propensity to Patent of Total Firms in the Science-Based Park in Hsinchu

Year	R&D Expenditures[a]	No. of Patents[b]	Propensity to Patent[c]
1991	153.99	35	0.227
1992	164.5	33	0.201
1993	255.29	138	0.541
1994	316.5	202	0.638
1995	474.46	467	0.984
1996	694.08	376	0.542
1997	877.47	566	0.638
1998	1143.87	788	0.689
1999	1121.34	1276	1.138

[a]In millions of U.S. dollars.
[b]Number of patents granted by foreign countries.
[c]In number of patents per million U.S. dollars.
Source: Online data available at www.sipa.gov.tw.

where P is the number of patent grants. Unfortunately, data on private R&D expenditures (C_p) is difficult to obtain because of commercial secrecy. The inverse of the firm's propensity for patenting is then used as the proxy for the cost of the firm's in-house R&D in obtaining a patent. This can be written as

$$(5) \qquad C_p = 1/r,$$

where r is a firm's propensity for patenting. Patent propensity, first introduced by Scherer (1983), is defined as the number of patents per unit of expenditure on R&D. Ideally, the authors should identify the real rate of propensity for patenting for each private firm. However, due to the lack of data, the authors use the average annual value of the propensity for patenting of all firms located in the Hsinchu Science-based Industrial Park as a proxy as shown in Table 3. The authors believe that this is an acceptable proxy because (1) more than 98% of the sales of the private firms in the Industrial Park are in the sector of electronics and information during 1995–99, which is consistent to the dominance of electronics and information S&T projects in the sample of this study; (2) their sales had accounted for around 20%–30% of the sales of the electronics and information sector in Taiwan during the period of 1995–99. Finally, from equations (3) to (5), the authors have

(6) $$M = (1/r) * P.$$

This demonstrates that if one knows the number of patents obtained by a specific S&T project, and a participating firm's propensity for patenting, the maximum monetary value of patents (M) can be directly calculated subsequently. The variable M is the dependent variable of equation (2).

One of the primary influences of the ITRI's research performance is the level of its R&D expenditure. To avoid confounding the R&D effect with the employment size effect, the authors measure the variable R_{t-1} in equations (1) and (2) by normalizing R&D expenditure by the number of research staff for each annual S&T project, as in Hall and Ziedonis (2001). Moreover, as noted in the studies of Hausman et al. (1984) and Hall et al. (1986), because technology flow often involves a time lag after R&D is undertaken, for each annual project, the log of R&D expenditure per employee for the previous year is incorporated into the regression models as $LNR(-1)$.[6]

Besides having a direct influence on innovative output, R&D expenditure may have a lasting effect on building R&D capabilities. Indeed, Kondo (1999) found a strong positive correlation between accumulated technology stock and patent applications in the Japanese industry during the 1970s and 1980s. The authors therefore also introduce R&D stock, K, into the regression model in equations (1) and (2), respectively. In accordance with the perpetual inventory model, the R&D stock of a research project in year t, K_t, is constructed as:

(7) $$K_t = R_t + (1 - \delta)K_{t-1}$$

and

(8) $$K_t = R_1/(g + \delta),$$

where δ is a constant depreciation rate of 20% per annum;[7] and g is the average growth rate of R&D expenditure from 1991 to 1999.

With reference to the treatment of embodied technical change by Denny et al. (1981), the authors incorporate a quality-adjusted indicator into the labor input of the R&D production function to describe the properties of better labor inputs. The general belief is that a major influence on the quality of R&D personnel is the ratio of the total number of research fellows and research associates to total employment, q. The labor input can be written in the augmented form as

(9) $$L' = L * h(q) = L * e^q$$

or

$$LN(L') = LN(L) + q,$$

where q is the quality-adjusted indicator and L is the total employment per annual project. The h function is an augmentation function such that for any given L, an increase in q will lead to an increase in outputs.

The authors include two time-period dummies, T_1 and T_2, to control for differences in the overall research environment for the periods 1994–96 and 1997–99, respectively, while treating the period 1991–93 as the base period. To control for sector-specific effects, the authors include in the model three sector dummies (*DELEC*, *DMACH*, and *DBIO*), with the chemicals and materials sector (*DCHEM*) being the base sector.[8]

Brouwer and Kleinknecht (1999) found that the appreciation of patents as a protection for process innovation is a less effective means to prevent imitation than for product innovation. They also found that the propensity to patent is lower in process innovation than in product innovation. Therefore, intensity of

6. Because many of the projects in the sample have short R&D histories of around three to four years, the full impact of current R&D may only become apparent after a lag of one or two years. Hence, in this study the authors use either $LNR(-1)$ or $LNR(-2)$ in the regression model. The empirical results show that the regression model with $LNR(-1)$ has a better degree of fit than that with $LNR(-2)$.

7. In the studies of Griliches and Mairesse (1990), the depreciation rate of R&D stock was assumed to be 15%. In the present empirical analysis, having used 15%, 20%, and 25% separately, the authors find that the regression model with a 20% depreciation rate has the best fit. Because a lagged R&D variable is included in both the regression model and the calculation of the R&D stock, double counting can pose a problem in terms of specification. To avoid this problem, the authors excluded the current (i.e., one period lagged) R&D expenditure from the R&D stock calculation.

8. *DELEC* is equal to 1 if the S&T projects are in the fields of electronics and information, and otherwise 0. Similar definitions are applied to *DMACH*, *DCHEM*, and *DBIO*.

product innovation for the innovative outputs of an S&T project could be a possible factor affecting the value of patents. The authors evaluate project characteristics oriented toward process or product innovations (*PROD*) for ITRI S&T projects based on a survey of transferred technologies carried out among professional experts in the relevant fields. This is measured by the ratio of the number of product innovation-oriented locally transferred technologies to the total number of locally transferred technologies for each S&T project.

The authors include two firm-specific variables for the participating firms, *SIZE* and *LOCA*, which are designed to control for differences in the scale and location of the firms involved in ITRI S&T projects. According to the selection processes of public hearings, the ITRI has tried to provide the equal opportunity to the potential firms for participating in the S&T projects. It is inevitable that large- and small-firm innovations are promoted under different economic and technological conditions; thus, as compared to small firms, larger firms are likely to be stronger in terms of their research capabilities and human capital, as indicated in Acs and Audretsch (1988). Therefore, the participation of large firms in research projects with ITRI may well be undertaken in a more efficient way and display better performance in terms of innovative outputs. The authors also use *LOCA* as the variable representing the proximity of participating firms to the ITRI in terms of geographical distance. Feldman (1994) stressed that innovative activities tend to be geographically concentrated close to agglomerations of technological infrastructure. The authors expect that R&D projects involving participating firms that are in close proximity to the ITRI are more likely to generate greater innovation as a result of the closer interaction in knowledge transfer or R&D collaboration. Finally, because the impacts on the innovative outputs stemming from *PROD*, *SIZE*, and *LOCA* may vary within different sectors, the interaction terms between these three variables and sector dummies are introduced in the regression models.

C. The Data

The authors exclude some of the nonindustrial-research S&T projects from the data, more specifically, those that focused on testing, S&T management, and so on. Other S&T projects with incomplete data, particularly with regard to detailed labor composition, were supplemented by their final project reports. After screening out the nonqualifying data, the resultant sample comprised of 252 observations, by project-year unit, during which 83 long-term S&T projects were covered.[9] There were approximately 5902 cases of local technology transfer to private firms involved in these annual S&T projects, and the authors traced the way back to the original final project reports of these cases to develop the variables *SIZE* and *LOCA*. The authors also surveyed six experts in the relevant professional fields about the nature of the transferred technologies using questionnaires.[10] The authors asked them to judge whether each transferred technology was considered product innovation–oriented or process innovation–oriented, based on their expertise. Detailed definitions and statistics of the variables used in the regression models are listed in Table 4. The variables, such as R&D expenditure and the monetary value of patent grants (M), are in current dollars.[11]

III. EMPIRICAL RESULTS

Given the discrete nature of patent grant data for the dependent variable of equation (1), one may consider discrete models such as the Poisson distribution or negative binomial model for the estimation. Because there exists an over-dispersion phenomenon in the sample, a negative binomial type II model is

9. Most S&T projects are long-term projects that may last for 3, 5, or even more than 10 years. However, because proposals and budgets for the ITRI have to be approved by the government on an annual basis, the unit of the analysis is in terms of project-year as opposed to project. That is, 83 long-term projects can be disaggregated into 252 annual projects.

10. The authors are grateful to Professor J. H. Tsai of the Department of Telecommunications Engineering, National Taiwan University, Professor K. H. Wei of the Department of Material Sciences, National Chao-Tung University, and the ITRI's Dr. K. C. Chang, Dr. E. L. Wei, Dr. K. E. Weng, and Mr. C. C. Chen for their participation and assistance in this survey.

11. The deflation of R&D spending has been treated differently in previous literature. Mansfield (1984) used a consumer price index deflator, Hall et al. (1986) used an R&D cost deflator, and Pakes and Griliches (1984) and Brouwer and Kleinknecht (1999) used nominal value. Because the authors have been unable to find a good deflator for R&D spending on ITRI S&T projects, they adopted a measure of R&D spending and M in current dollars.

TABLE 4
Variable Definition and Summary Statistics

Variable	Definition	Mean (SD)	Maximum	Minimum
P	Number of foreign patents	3.004 (4.941)	42	1
M	The log monetary value of innovative outputs	1.681 (0.921)	4.157	−0.129
LNR(−1)	The log of R&D spending of each annual project per employee in the previous year	11.097 (0.947)	12.107	8.354
LNK	The logarithm of R&D stock of each annual project per employee	11.180 (0.760)	12.098	7.862
LNL′	Quality-adjusted R&D personnel	5.078 (0.53)	6.334	3.696
PROD	Percentage of the transferred technologies which are product-innovation-oriented to total transferred technologies in each annual project	65.048 (31.867)	100	0
SIZE	The ratio of the number of large participating firms to total participating firms in terms of number of firms in each project. Those firms that have more than 200 employees or more than NT$60 million (about US$2.3 millions in 1999) in assets are defined as large firms	67.823 (27.042)	100	0
LOCA	The ratio of the number of participating firms located in the Hsinchu area to the total number of participating firms in each project. The Hsinchu area covers Hsinchu City and County, Taoyuan County, and Muoli County	35.191 (26.632)	100	0

applied using the maximum likelihood method in model 1.[12] As the dependent variable of equation (2), the monetary value of patent grants (*LNM*), is a continuous variable, the equation is estimated by ordinary least squares using a heteroskedastic-consistent covariance matrix in model 2. Table 5 presents the estimation results.

Eleven out of 21 estimated coefficients are statistically significant in model 1. The authors discuss the detailed results as follows. Neither the contribution of the observed history R&D (*LNR*(−1)) nor the accumulated R&D stock (*LNK*) to current year's successful patent applications (*P*) is statistically significant in model 1. This is an unexpected result. However, it is hard for the authors to do the comparison about the effect of historical R&D expenditures on patenting among the existing literature because their patent production functions are applied for firm/country-level analysis rather than the project-level study. The coefficients of *LN*(*L′*) (1.03) are significantly positive, suggesting that when holding constant all other control variables, a 1% increase in quality-adjusted R&D personnel can promote an increase in patent productivity by around 1.03%. As for the estimated parameters of T_1 and T_2, the empirical results of model 1 suggest that ceteris paribus there was a surge in the patent propensity of S&T projects from the base time period of 1991–93 to the 1994–96 time period, the rate of increase eventually slows down in the final time period of 1997–99.

All of the sector dummy variables' coefficients are insignificant, except for that of *DMACH*, which is significantly positive. It indicates that the propensity to patent for S&T projects in the machinery sector is the highest among the four sectors. Although the ITRI's resources had dominantly distributed to electronics and information sector, the coefficient of *DELEC* is unexpectedly insignificant. Obviously, the sector variation effects derived from this sector are reflected in the other factors, such as the intensity of product innovation and location effect.

Perhaps the most remarkable result displayed in model 1 is the effect on the increase in the number of patents stemming from the nature of the transferred technology. The sum of the estimated coefficients of *PROD*

12. The Poisson regression model is based on the assumption that the conditional mean and variance of the number of patent grants are equal. The essential methods for estimating the negative binomial model are the maximum likelihood method and the quasi-generalized pseudo-maximum-likelihood method (Cameron and Trivedi, 1986). The Hausman test indicates that the results of the negative binomial model estimated by maximum likelihood were better than those estimated by quasi-generalized pseudo-maximum-likelihood; therefore, only the results of the former model are listed as model 1 in Table 5.

TABLE 5
Estimation of the R&D Production Function for ITRI's S&T Projects

	Model 1 (*P*)		Model 2 (*LNM*)	
Variables	Coefficient	SE	Coefficient	SE
C	−7.205	(5.828)	−45.044	(32.703)
LNR(−1)	−0.654	(0.547)	−2.904	(2.949)
LNK	0.768	(0.507)	5.102*	(2.866)
LNL'	1.026**	(0.168)	4.580**	(0.696)
T_1	0.836**	(0.322)	3.556**	(1.657)
T_2	1.084**	(0.343)	4.272**	(1.723)
DELEC	0.883	(0.826)	5.608	(4.481)
DMACH	1.153*	(0.659)	11.229**	(3.381)
DBIO	−0.746	(1.570)	5.741	(8.183)
PROD	0.008**	(0.004)	0.047**	(0.019)
*PROD*DELEC*	−0.016**	(0.005)	−0.076**	(0.026)
*PROD*DMACH*	−0.002	(0.006)	−0.045	(0.030)
*PROD*DBIO*	0.009	(0.012)	0.002	(0.064)
SIZE	−0.004	(0.004)	−0.006	(0.028)
*SIZE*DELEC*	0.011	(0.007)	−0.012	(0.036)
*SIZE*DMACH*	0.001	(0.007)	−0.020	(0.038)
*SIZE*DBIO*	0.020*	(0.011)	0.053	(0.077)
LOCA	0.019**	(0.006)	0.137**	(0.030)
*LOCA*DELEC*	−0.018**	(0.007)	−0.113**	(0.034)
*LOCA*DMACH*	−0.044**	(0.010)	−0.236**	(0.043)
*LOCA*DBIO*	−0.062**	(0.021)	−0.158	(0.131)
No. of observations	252		252	
Log Likelihood	−478.196		−777.125	

Notes: Statistical significance at the 0.05/0.1 level is denoted by ** and *, respectively.

and *PROD*DELEC* is statistically negative and equals to −0.008, which suggests that when holding constant all other control variables, a 1% increase in the level of process innovations from the transferred technologies in ITRI S&T projects of the electronics and information sector may lead to an increase of around 0.008% in the number of patents. Opposite effects appear in the sector of chemicals/materials because the coefficient of *PROD* is significantly positive and in the sectors of machinery and biomedical because the coefficients of *PROD*DMACH* and *PROD*DBIO* are insignificant (i.e., their effects are not significantly different from that in the base sector, i.e., chemicals/materials sector). These findings seem to reflect the successful strategies of ITRI S&T projects to improve the private firms' technological competencies that emphasized more on the development of process innovations in the sector of electronics/information, while focusing on the development of product innovations in the rest of three sectors. To transform what would have been a "niche electronics product" developed by the advanced countries into a standardized product suitable for mass production and easy for patent applications, the ITRI's strategy in this field is rather rational (Mathews, 2002). It is also consistent with the findings of Mansfield (1988), who compared R&D between the United States and Japan and found that the advanced technological production processes from the West could be improved on by adopters at relatively low costs.

The results of model 1 indicate that there seems to be a relationship between S&T project's innovative outputs and the size of the participating firms in the biomedical sector. The sum of the coefficients of *SIZE* and *SIZE*DBIO* is about 0.02, suggesting that when holding constant all other control variables, a 1% increase in the number of large participating firms in ITRI's S&T projects in the biomedical sector will lead to an increase of about 0.02% in the number of patents. Conversely, there are no significant size effects in the rest of three sectors.

All coefficients associated with *LOCA* are significant in model 1. Because most of the private firms in the machinery and biomedical sectors have preexisted far away from the Hsinchu area, their location effects are, as expected, significantly negative. They are −0.03 and −0.04, respectively. On the other hand, the location effects of the firms participating in the S&T projects in both the chemicals/materials and electronics/information sectors are significantly positive, specifically, 0.02 and 0.001, indicating that the increase in the number of participating firms in close proximity to the ITRI (in the Hsinchu area) will enhance their collaborative interactions through face-to-face discussion, seminar attendance, training programs, researcher exchange, and so on, which may result in improving participating firms' absorptive capability and further increasing project's propensity for patenting in these two sectors.

As the innovative output variable for this study is changed from the number of patent grants (P) to the monetary value of patents (M), the number of the significant coefficients is about the same but the estimated effects of model 2 are larger than those in model 1.

The coefficient of the lagged R&D variable, ($LNR(-1)$), still remains insignificant in model 2. What is worth noting, though, is the striking result yielded by the estimated coefficient of R&D stock in model 2. It has changed from insignificant to significant, and is around 5.1, implying that a 1% increase in R&D stock will lead to a 5.1% increase in the monetary value of patent grants. This finding is consistent with the findings of Kondo (1999), who emphasized that the increased technology stock enlarges an invention frontier and enhances patent applications; and the theory of Teece and Pisano (1994) on firm's "dynamic capabilities," which focused that a firm's accumulated technological capabilities may underlie its sustained competitiveness.

Overall, the authors find evidence that when using the monetary value of patent grants developed in this study as an innovation indicator in the R&D production function, the impacts of accumulated R&D stock, high-level R&D personnel, the intensity of process innovations, and the location effects of participating firms on project-level R&D productivity are comparatively stronger than those using the simple patent counts as innovative outputs.

IV. CONCLUSIONS

In contrast to firm/country data analyses, the authors' empirical investigation of the relationship between public R&D and industrial innovations is carried out at the project level. The authors examine the R&D production behaviors of 252 public-funded annual research projects conducted at the ITRI in Taiwan for the period of 1991–99. The analysis developed a new index of innovation outputs by using the concepts of willingness to pay and propensity for patenting to measure the monetary value of patent grants of public research project. Substituting monetary value of patents for simple patent counts as the proxy for innovation outputs in the R&D production function, the authors find the influence of accumulated R&D stock, high-level R&D personnel, the intensity of process innovations, and location effect on project-level R&D productivity have become stronger.

These empirical results will not only shed light on the relevance of econometric work on public R&D but also provide the following policy lessons for other newly industrializing countries seeking to emulate Taiwan's experience in catching-up with advanced technologies: (1) One of technology latecomers' strategies to overcome the problem of resource scarcity is to prioritize public research in a select set of fields (such as electronics and information sector in Taiwan) important to competitive status in a world. (2) To improve the effectiveness of public research, the government of a technology latecomer should not only adopt a strategy to promote the country's long-term technology accumulation but also create a collaborative mechanism with local firms to reach the goals of rapid adoption of new technologies and quick diffusion to as many as firms as possible. (3) The innovation outcome may be more productive if the research projects of the technology latecomer are swayed toward a suitable innovation focus (such as the target at improving manufacturing technology in the information technology–related fields in Taiwan). (4) Because high-quality R&D personnel and geography proximity of the participating firms are also important factors in facilitating the effectiveness of public R&D, public investment in education should be a long-term commitment of the government to ensure a continuous supply of highly capable and skilled R&D personnel. Technology parks and industrial research clusters have been instrumental in achieving the island's impressive performance of technological capability and should continue to be a focus of industrial policy.

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