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Improving the Innovative Capabilities of Taiwan's Manufacturing Industries with University–Industry Research Partnerships

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The experiences gained from Taiwan's university–industry collaborative program are presented by case studies. The framework of the university–industry partnership is presented. Both successful and failed case studies are detailed to extract the underlying understanding required to improve university–industry collaborative programs further. The capabilities of small and medium-sized enterprises, which are the majority of all enterprises in Taiwan, and the various ways of improving their innovative capabilities by effectively using university–industry partnerships, are also discussed. Supporting evidence which indicates that proper partnerships are the most effective means of improving the innovative capabilities of the manufacturing industries are also detailed.

Keywords: Innovative capability; Manufacturing industry; Motivation; University–industry partnership

1. Introduction

Of Taiwan's manufacturing industries, 98% are small and medium-sized enterprises (SMEs). To survive and to thrive, these SMEs have developed unique parallel/open collaborative networks in order to provide the collaboration channels for them to form partnerships within multiple networks. These unique partnerships allow these SMEs to divide an industry/product into much more manageable areas, which in turn lowers the entry barrier for these SMEs and provides an efficient route for them to compete effectively and globally with large foreign manufacturing plants. However, the fierce competition from Mainland China and Southeast Asian countries with low labour costs and abundant natural resources is gradually making Taiwan lose its competitive advantages. It is, thus, important for Taiwan to raise the overall industry competitiveness by innovations. Currently, approximately 90% of the research and development (R&D) budgets of Taiwan's academia and research institutes come from government support. With the increase in headcount and funding of engineering research, Taiwan's rank of number of papers published in the EI (Engineering Index) has risen from 13th place in 1993 to 10th place in 2000. The total number of papers published in SCI ranks number 19. Taiwan, currently ranked 4th when considering the number of patents issued in the USA lags behind only three industrialised developed nations, i.e. USA, Japan and Germany [1]. Despite these apparently very good figures, the majority of the key components or key manufacturing technologies used in Taiwan are imported or have been transferred from abroad, with key manufacturing technologies totalling NT$39.91 billion (US$1 = NT$34, approximately) for 2000. Furthermore, judging performance by using the technological balance of payments index (TBPI), which is the ratio of the value of exported technical goods to the value of imported technical goods, Taiwan has an index of 0.03. Comparing this very small number with that of high technology export countries, such as the USA (2.75 TBPI), Japan (2.34 TBPI), UK (1.80 TBPI), and Germany (0.77 TBPI) [1], Taiwan's TBPI is considered to be very low. It is obvious that problems exist on the linkage and interactions among the industries, academia, and research institutes, otherwise, it is difficult to explain why the good Taiwanese R&D performance, based on EI ranking and issued patents, does not lead to reasonable improvements in innovations and technical capabilities in industries.

In addition to the situations mentioned above, SMEs in Taiwan, which are typically constrained by their own size, generally lack R&D personnel and funding. These constraints translate to difficulty in pursuing systematic R&D and thus lead industries to perform only "incremental innovation" activities that have a "small change here, little change there" limitation in manufacturing technology or product areas. Close to 70% of Taiwan's plentiful R&D personnel are located in academia [1]. How to release the hidden R&D potential from academia and promote university–industry partnerships to

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improve the innovative capabilities of Taiwan's SMEs, is an issue where the government can play a pivotal and key role.

The term "university–industry partnership" can be defined as an innovation-based relationship whereby university and industry sectors jointly contribute to financial, research, human, and infrastructure resources. The main goal of this partnership is to maximise the benefits from R&D [2] and technology, and is much more than simply a contract research mechanism for subsidising industrial R&D. According to the analysis by MTI of university–industry interactions [3], three university–industry interaction modes exist:

1. The membership model which conforms to the pattern of technology-push, and is based upon a fee structure for corporations to sponsor faculty research activities.
2. The relationship model which conforms to the pattern of market-pull, and provides a new focus on market needs in which the interaction is planned, is information-based, and is measured by customer satisfaction.
3. The new partnership model which is rapidly becoming the investment standard for the future. This model focuses upon innovation as the mode of interaction through symbiotic, networked learning.

The first and second models relate to sponsorship of university–industry relations, which have a smaller impact on improving industry innovations and capabilities. Furthermore, these two models are becoming less efficient in reacting to "the rapid reduction of product and R&D cycles due to the rapid change of technology and market development." The third partnership model not only transfers R&D results from academia to industry, but also emphasises the collaborating innovative process between academia and industry, i.e. it pursues a full solution, which has been shown to be most beneficial to industrial innovations and R&D capabilities improvement [4,5].

However, because of differences in organisational culture, research objectives, interests, and problems in R&D, the perceptions between industry and academia do not change. The fundamental reason lies in the fact that industry concentrates more on solutions to specific problems whereas the universities stress long-term research. With this perspective, university–industry partnerships can be classified according to the motivation, as follows:

1. *University motivation* which gives emphasis to obtaining financial support for educational and research missions, broadening the experience of students and faculty, increasing employment opportunities for students, and the ability to test applications in the market place, with state-of-the-art-equipment.
2. *Industry motivation* which emphasises accessing the research infrastructure of the university, accessing expertise, aiding in the renewal and expansion of a company's technology, gaining access to students as potential employees, and increasing the level of precompetitive research, such as leveraging internal research capabilities, leveraging grant funds, and being a source for consultations [6–8].

Since many differences exist between the motivation of universities and industry for forming university–industry collaborations, the interface between the university and industry is a key factor for increasing partnerships and innovations [6,9]. It is much better, both from an university and an industry perspective, to have this interface well defined. In addition, the policy tools which include providing monetary incentives for the formation of university–industry partnerships by financing collaborative research projects, are also convenient tools to facilitate this process [6,9,10].

With rapid market demand change and the rapid complications of technology, it is impossible for industry to finance all necessary R&D tasks and they must contract out non-essential R&D tasks [11,12]. On the other hand, technology development has caused the R&D funds required for academia to increase sharply. With limited budget constraints, it is becoming more difficult for the government to meet the needs of academia. It is this kind of global environment that forces academia today to constantly look for other research funding sources [12,13]. In addition, the technological and industrial policies of the government have been evolving away from grant-based support for innovation towards providing the infrastructure for innovation so as to boost economic performance [14]. All of the above exert a high pressure on the government, the universities, and industry. The universities and industry are interested in commercialising valuable new technologies [15], which is the main thrust that establishes the infrastructure for the development of university–industry partnerships and which makes it easier for this to be promoted by the government.

2. Establishing a Framework for University–Industry Partnerships

As no effective linkage of collaborative R&D exists between the universities and industry in Taiwan, local SMEs are limited by their size in pursuing effective R&D innovations. To determine whether university–industry partnerships can effectively improve the innovation of SMEs, a framework for university–industry partnerships was constructed and is shown in Fig. 1.

1. *Motivation*. Owing to the difference in organisational cultures of universities and industry, the starting point of

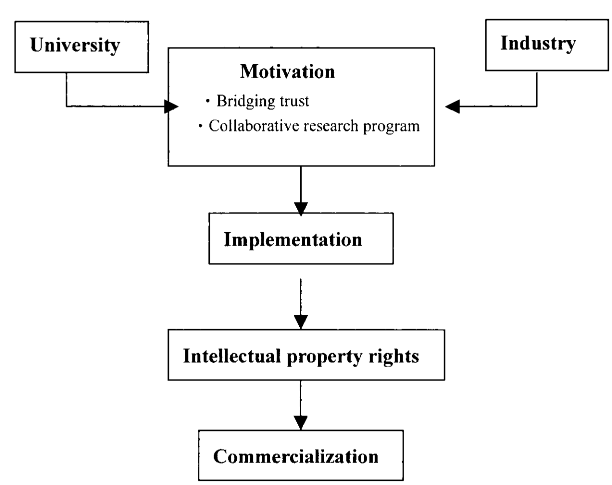

Fig. 1. The framework of an university–industry partnership.

collaboration between these two sides has always been on the potential benefit that may exist. However, significant differences do exist in the motivation for collaboration. It is first necessary to establish mutual trust between the university and industry, and then the convergence of the objectives and interests may be established. The university–industry collaborative program has been found to be a very good catalyst for promoting the formation of university–industry partnerships.

2. *Implementation.* For typical academia to pursue research programs that are both fundamental and practical, a sufficient R&D budget, necessary state-of-the-art equipment, and chances to test the applications within the market place are needed. It is also clear that these needs are easier to meet when the university collaborates with industry. However, the SMEs generally lack qualified R&D personnel and sufficient R&D funds to pursue effective research and development. If a path exists for the SMEs to participate in collaborative R&D by expending a small amount of matching funds, the incentive to participate will then increase significantly. University–industry collaborative projects were found to be an effective vehicle to satisfy these needs as joint contributions that involve financial, research, human, and infrastructure resources, etc. are most efficient and can typically lead to maximum benefit. When executing university–industry collaborative projects, the following elements are strongly encouraged:

(i) *Industry*. It is essential to select appropriate R&D personnel to participate in the R&D project in order to incubate core personnel within the industry that can understand and fully make use of external technology information as well as receive and appreciate R&D results generated from the university–industry collaborative project. Furthermore, it is beneficial to recruit good candidates to participate in the university–industry project in order to speed up the R&D within the industry and to promote interactions between the university and the industry [2,12,16].

(ii) *Academia*. It is important to understand the needs of industry, which can be fostered by pursuing continuous dialogue/communications that lead to a two-way exchange of knowledge and learning between the two sides. It will also be beneficial to organise regular meetings with industry to discuss R&D contents and results in order to establish a strong mutual trust. Furthermore, it will be important to establish a mechanism that can maximise the overall influence of the resources available from industry and the university so as to achieve the maximum benefit of the R&D investment [6,8,12,16].

3. *Intellectual property rights (IPR)*. Many believe that potential conflicts of interest exist between the university's obligation to train as well as to disseminate knowledge through publication, and industry's need to protect the R&D results generated from their sponsored projects. The main conflict comes from the fact that the quality of the academic research has traditionally been judged by the papers published in peer-reviewed journal papers whereas the main performance factor of an industry is its profitability. Because of these background differences, careful balancing of the needs of the country to rapidly diffuse R&D findings, and the desire of industrial sponsors to obtain exclusivity for R&D results, are the most important factors influencing the probability of a successful university–industry project.

4. *Commercialisation*. Commercialisation is the bridge that can cross the university–industry cultural divide [15] and is the ultimate goal for industry when participating in university–industry collaboration. It must be kept in mind that the planning, execution, and intellectual property rights (IPR) are closely related to commercialisation. It is with this understanding that many US universities have set up special commercialisation, licensing, or technology transfer units in order to guide research partnerships with industry from their initial contract negotiations through to their final licensing and royalty arrangements [12]. However, remember that overly emphasising the importance of patents and licensing may not improve the R&D and teaching functions of academia. The key will be for the universities to balance all of the traditional roles/functions and the needs generated by today's rapidly evolving technology world.

5. *Government's role*. It should be noted that the government plays a very important role in all of these steps. The influence and impact of these roles will now be discussed.

Step 1. As perspectives of collaborative R&D between university and industry are different, it is better to have the government serve as the bridge in order to secure the trust of both sides. In addition, the government can promote university–industry collaborative programs by making sure that all related measures are coherent. For example, Taiwan's National Science Council (NSC), currently provides a Principal Investigator (PI) and Co-Principal Investigator (Co-PI) of university–industry projects with NT$20 000 and NT$10 000 per month stipends, respectively, in addition to providing post-doctoral, PhD, and masters level research scholarships. Furthermore, if the industry participating in the university–industry research project hires a PhD level graduate with more than one year's R&D experience on the project, the government agrees to supplement half of the salary for up to two years. Furthermore, the matching fund offered by the industry to university–industry collaborative projects is tax deductible, which can certainly serve as a catalyst to speed up the successful forming of such projects.

Step 2. The university–industry collaborative programs promoted in Taiwan are now structured so that the government supports the majority of the R&D funding, which under current policy, requires the participating company to provide a matching fund of more than 25%, which can be shared by several companies. Before July 2000, the lower limit of the matching fund was set at 15%. The current operating mode for Taiwan's university–industry collaborative projects is to have a government agency, such as the National Science Council, select proper pre-proposals based on project planning; project PI, Co-PI's, R&D teams, potential collaborative enterprises, etc. Once the pre-proposal passes the threshold, the agency will then recommend one or more companies, which are then selected from the enterprises responding to the public announcement of the government's intention to fund such projects, to be reviewed by the PI's on their fitness to become a full R&D team member. Once the full team is formed, the final proposal will be written by the team and then will undergo review by a committee formed by senior members representing industry, academia, and research institutes. The review process constitutes both the document review and the field interview. The decision to go or to reject the project and the supporting fund granted are then determined from the outcome of these reviews. The review opinions are then sent to the PI as guidelines/references for executing the project.

Step 3. The nature of IPRs also affects the incentives for partnerships, as various regulations and traditional values govern how the university can control the diffusion of the IPRs created from public R&D support. For example, preventing exclusive licensing granted by universities to companies participating in the university–industry collaborative project might preclude research financing by firms who see their support benefiting competitors. On the other hand, results created by government-sponsored R&D projects are considered to be public property, and as such are supposed to be diffused as widely as possible. This perspective is in direct contradiction to the desire of enterprises to obtain exclusivity in order to protect their interests [2]. This conflict must be resolved by the government in such cases by carefully reviewing R&D status, industrial characteristics, level of innovations for the projects, etc., for the purpose of setting up guidelines for industry and academia to follow.

Step 4. Even though the commercialisation of the R&D results are executed by industry, the government should not be responsible for setting up corresponding policies, which may include priority or exclusivity to license/transfer the R&D results, priority to bid for government purchase, etc. It is only with the successful establishment of these policies, measures, and guidelines that the R&D results created by university–industry can be fully explored.

This paper examines the status of Taiwan's university–industry collaborative programs and explores the possibility of improving the innovative capabilities of SMEs through university–industry partnerships.

3. Case Studies

The NSC in Taiwan has been very active in promoting university–industry collaborative programs. Eighty-seven projects were funded from 1992 to June 1998. It should be noted that a single project might last two to three years, i.e. a three-year project approved in June 1998 will last until June 2001. There were 148 participating companies during this period and 57 R&D results were transferred from the academic team to companies. As university–industry collaborative programs are mission oriented, the projects approved by the Department of Engineering and Applied Science of NSC (NSCDEAS) are not only the largest in number and in overall funding, but they also serve as the flagship for this important program. It is with this background and understanding, that we use the various projects funded by NSC DEAS as examples for the case studies. A summary of the funding is given in Tables 1 and 2.

Considering the statistics of 69 university–industry collaborative projects approved by NSC DEAS from 1993 to 1998, 119 participating companies sent 480 industrial engineers to join the work led by academic R&D teams. A total of 263 university professors and associate professors served as the PIs or Co-PIs, 1054 PhDs or Masters with practical experience graduated, and the accumulated funding was NT$ 1.698 billion which represented NT$ 1.346 billion from the government and NT$ 352 million from industry as the matching fund. Nine out of the 69 projects were terminated. Four of the nine prematured projects were terminated after one year and the other five were terminated after two years. Within the 60 completed projects, a total of 168 patents, which were taken out in Taiwan and the USA, were applied for. Up to May 2001, a total of 111 patents, with 72 in Taiwan, 32 in the USA, 3 in Germany, 2 in Japan, 1 in the UK and 1 in Canada were approved.

These 69 university–industry projects can be classified into two groups:

1. *Pattern 1 case*. This consists of cases where the whole project was completed and was considered a success.
2. *Pattern 2 case*. This consists of cases where the project was not finished and was considered a failure.

Taking the framework shown in Fig. 1 as the basis, these two patterns will be detailed and examined in the following sections.

3.1 Pattern 1 Case: Successful Projects

Twenty out of the 60 successful projects transferred 48 technologies from the university to the industry and were considered to be the most successful. Taking two case examples from this group, one case study involves a high-tech industry and the other case involves a traditional industry. In addition, two Pattern 1 projects that are not considered to belong to the most successful group as mentioned above, will also be examined to serve as a comparison.

1. Case 1: Diffractive Optical Components and Diffractive Laser Encoders – High-tech Industry

The factors that make this case study successful can be analyzed by the above-mentioned four factors. Starting from (i) motivation, a traditional industry planning to diversify and grow into a high-tech industry finds that the lack of R&D experience and personnel is the main bottleneck. The PI of this project has an abundant high-tech R&D experience as it has served as PI's at IBM Research Division for many years before becoming a faculty member at National Taiwan University. Since the PI has been with National Taiwan University for quite some time, the academic R&D team and the system research laboratory has already been established by the vision of the PI, which translates to significant R&D capabilities. The active promotion of the government towards university–industry programs was one of the main factors that this project was established. Followed by (ii) implementation which has the government providing NT$20.718 million and a collaborative industry matching 20.4% of the fund to invest NT$5.317 million into this project. The industry and academia have planned the applicable range of the technologies that may be derived from this project carefully. The possibility of using new technologies developed to replace traditional technologies

Table 1. Successful case studies.

Case	Involvement	Motivation	Implementation	Intellectual property rights	Commercialisation	Partnership
1. Optical components and laser encoders	Collaborating enterprise	Intention to proceed to diversify into high-tech industry.	University and industry proposed a new systematic R&D innovation method. The project strongly influenced the progress and outlook of the collaborating enterprises. The personnel needed were incubated by the project. The R&D innovations met the industrial needs as well.	Obtained total of 8 patents and tens of international journal papers.	The R&D results were technology transferred to the collaborating enterprise. many of the final products have become worldwide leading technologies. For example, Advanced Vibrometer/Interferometer Device were awarded a US patent and several international phototonics awards. In addition, many of the instruments developed were used in leading international production and R&D organisations.	Good interactions exist between the collaborating enterprise and the university as a new university–industry collaborating project is currently underway.
	Academia	Possesses abundant R&D experience and capabilities, hopes to secure resources needed to advance R&D and to verify R&D results.				
2. High precision rotation indexing tables	Collaborating enterprise	Lack R & D capabilities and are unable to pursue technology transfer of software and machining from international sources; desperately looking for collaboration and technical help.	The R&D resources between the collaborating enterprise and the university are complimentary and shared. Discuss R&D results and exchange opinions regularly. The collaborating enterprise participates more on the practical manufacturing technology side, and less involvement of R&D tasks for future development of the enterprise.	Obtained 1 patent, 6 CAD/CAM software packages, 2 design/manufacturing manuals, and several journal papers.	Technology transferred to collaborating enterprise twice. The R&D results were successfully implemented on the design and manufacturing. The product achieved surpasses the imported high-precision items, which were sold back to the original exporter.	Completed two phases, i.e. 6 years of university–industry collaborating projects. Possesses good partnerships.
	Academia	Desire to obtain research funds to pursue R&D that can be integrated into both theoretical and practical applications.				

Table 1. Successful case studies.

3. High-speed spindles	Collaborating enterprise	All key components of machining tool are imported, of which foreign companies control the source of the high-speed spindles; have strong intentions to identify circumventing measures.	The collaborating enterpriseconsidered the project as a trial effort from the beginning. As the R&D results were good after the first year review, the engineers of the collaborating enterprises were sent in to participate in the project fully.	Obtained 12 patents, and tens of journal papers.	A 20 h.p. spindle was completed. The spindle was running at 24 000 r.p.m. (DN value = 2.0×10^4 mm r.p.m.). The collaborating enterprise commercialised the R&D results. In addition, the high-speed spindle was integrated into the manufacturing machines. A detailed technology transfer process was not completed.	Even though an official technology transfer was not put in place, the partnership between the university and the collaborating enterprises was damaged.
	Academia	Primary investigator (PI) of the project was Chief Engineer of US machine tool company. It was planned that the PI would help the industry to solve the bottleneck created by the lack of key components and to secure more R&D resources.				
4. Wire-cut electrical discharge machines (WEDM)	Collaborating enterprise	A total of 4 SMDs were eager to participate in the wire-cut discharge machine business. However, this plan was limited by the sixe and R&D capabilities of the enterprises involved.	The university served as the communication channel among the collaborating enterprises and encouraged all of the collaborating enterprises to form an alliance to develop.	Secured 2 patents, much technology know-how, and several journal papers.	The R&D results were comercialised. Four of the six global companies that can manufacture WEDM participated in the university–industry project.	The official technology transfer process was not put in place. The partnership between the university and the collaborating enterprises deserves further evaluation.
	Academia	Primary investigator had in-depth experience relating to wire-cut discharge machine and planned to verify his theoretical predictions and R&D results. In addition, the PI intended to secure more R&D funding for the project.	Precompetitive prototypes.			
	Government	Majority of the above 4 cases were funded by the government. In addition, the government served as the communication channel between the university and the collaborating enterprises.	The government funded approximately 80% of the overall project budget. In addition, 20% of the funding was provided by the collaborating enter prises.	Official procedures for the university–industry.	Official procedures for the university–industry.	

Table 2. Unsuccessful studies.

Case	Involvement	Motivation	Implementation	Partnership
5. Intelligent power IC	Collaborating enterprise	Three large companies look for a short-term solution to meet the rapid change of high-tech industries.	Pursue precompetitive R&D. The collaborating enterprises requested to terminate the three-year project at the end of the second year due to rapid change of the industry and the marketplace.	Not sustainable
	Academia	To secure more R&D resources and to purchase new equipment.		
6. Digital temperature controllers	Collaborating enterprise	An SMD specialised in low-tech analog temperature controller planned to obtain digital temperature controller technology by collaborating with the university. The SMD matched 30% of the government funding with an intention to secure exclusive licensing rights.	Without arriving at a set of well-defined and realistic objectives, the project was established with the intention of obtaining R&D resources. Owing to differences in perspectives and lack of mutual trust between the university and the collaborating enterprise, the project was terminated before the start of the last year of the project.	Not sustainable
	Academia	Obtain university–industry collaboration experience and more R&D funding.		
	Government	Majority of the above four cases were funded by the government.	Official procedures for the university–industry collaborating project.	

The following conclusions can be drawn from Tables 1 and 2. They are:

1. The primary objective for all parties of the university–industry collaboration projects was to benefit all. The government served as an important interface to facilitate the communication channel and mutual trust between the university and the collaborating enterprises. The university–industry collaboration project is an important factor in facilitating partnerships.
2. Successful case studies. The collaborating parties possess complementary resources, have mutual trust, and have definite R&D objectives, which integrate well with future development goals of the enterprises. The primary investigators all have excellent R&D track records and have industrial R&D experiences [7,17].
   Unsuccessful case studies. Opposite to the successful case studies.
3. Cases 1 and 2. The collaborating enterprises secure the rights through an official technology transfer channel. The partnership between the university and the collaborating enterprise are maintained well.
   Cases 3 and 4. The collaborating enterprises did not execute the appropriate technology transfer procedures to secure lawful R&D usage rights. The partnership cools down with the completion of the project.

are also examined and explored to modify the overall targets of this project. A systematic R&D innovation methodology was developed and is now rooted to become the underlying R&D structure of the research teams involved. In addition, the participating company used this project to serve as the incubator to train and to recruit the R&D personnel needed for the company to diversify into the high-tech industry of choice. Furthermore, the pursuit of this university–industry project has enabled all personnel participating in the project to understand the planning and future outlook of this company, and has prompted many highly trained personnel including several M.S. and Ph.D. graduates, two post-doctorate fellows, and an university faculty that serves as a co-PI. Examining the (iii) intellectual property rights (IPRs), this case study is also fruitful in terms of patent applications and professional journal papers, which include four U.S. patents, four Taiwan patents, and tens of international journal papers. The (iv) commercialization factor is just as impressive when considering some of the R&D results technology which have transferred to collaborative companies for commercialization. Out of the many commercialized high-tech product, several have won internationally prestigious awards. For example, the Advanced Vibrometer/Interferometer Device (acronym AVID) was awarded a U.S. patent as well as Photonic Spectra's 1998 Circle of Excellence Award for innovative product, the first time a Taiwan company has won this prestigious award. This newly developed instrument has been utilized in many high-tech industrial, academic, and research fields. For example, Professor Kenya Goto of Tokai University in Japan has adopted this instrument to study and to pursue innovative near-field optical storage at a national level project in Japan. The research division of the Seagate Company, a magnetic disk drive company, has also used this instrument for disk drive development. In addition, an innovative true color dot matrix writer (named Sparkle) was also developed within this project, which not only won several photonic awards but also is viewed as the leading technology for anti-counterfeiting applications. This machine has been exported to more than 10 countries worldwide.

This case study completed the first three-year project from 1994 to 1997 and is now in the process of its second three-year project.

2. Case 2: High-Precision Rotation Indexing Table – Traditional Industry

The successful factors for this case study can also be examined from the above-mentioned four guidelines. Considering

(i) motivation, the participating company is a traditional SME with about 30 employees. This company was eager to improve its technology level. However, it lacks the R&D capability needed and cannot obtain either advanced integrated design/manufacturing software packages or manufacturing and metrology technologies. On the other hand, the university faculty involved intended to secure more funding in order to pursue a research that is both fundamental and practical. Since the government served as the bridge to promote this university–industry collaborative project, this project was established successfully. During the (ii) implementation stage, the government funded NT$7.126 million and the company set up a 17.4% matching fund, i.e., NT$ 1.5 million. During the execution of this project, the academic side provided the R&D methodology, the equipment needed and the required R&D personnel. The participating company offered and in some cases donated hardware equipment/manufacturing and practical technology. Both sides worked together on R&D related to design, analysis, manufacturing, and metrology. The resources of the two sides were considered to complement each other. During the execution of this project, the academic research team paid several visits to the company to discuss R&D results and to exchange perspectives in order to make sure a two-way exchange between the university R&D knowledge and industrial practical application was going well. On the (iii) IPRs side, a new style patent was approved. There were five additional new style and one inventive patents which are currently under review. In addition, a total of six CAD/CAM computer software packages and two design/manufacturing manuals were copyright protected. Several domestic and international journal papers were published from the results of the project. Regarding (iv) commercialization, the R&D results were twice technology transferred to the collaborating company and have been successfully adopted into product design and manufacturing. The product developed has gradually replaced other imported high-precision rotation indexing tables. Some of the products have even been exported to Japan and other international markets. As the sub-systems were originally imported from Japan, this achievement and replacement effect is significant.

The university and the company have completed its second three-year university–industry collaborative projects from 1994 to 1997 and then from 1997 to 2000. A year has elapsed without pursuing further collaborative projects. However, the two sides maintain a close relationship. The factors for this status will be further detailed later.

3. Case 3: High-Speed Spindle– Traditional Industry

Taiwan is ranked as the world's fifth largest machine tool exporter. However, the majority of the key components are imported. Considering this case study which involves R&D of high-speed spindles, the PI was a chief engineer in a U.S. machine tool company. When this PI came back to Taiwan to become a faculty member, he determined to help the domestic machine tool company to solve the key component problem once and for all. Again, the government promotion of the university–industry collaborative program propelled the establishment of this project. For this project, the government funded NT$23.67 million and the participating companies offered a 15.5% matching fund, i.e. NT $4.34 million. During the execution of this project, the university was responsible for the principle analysis such as design thinking, materials, structure, heat flow, cooling, lubrication, automatic control, performance verifications, etc. In addition, the university was also responsible for establishing the design and test analysis model as well as the prototype development. On the other hand, the participating enterprises were responsible to help with the fabrication of the experimental components needed and were in charge of testing the prototype on the machine tool. After this project achieved very good R&D results at the end of the first year, the participating enterprise then began to send engineers to actively participate in this university–industry collaborating project.

Five new styles and three inventive patents were approved in Taiwan. In addition, three U.S. patents were approved and another patent application is currently being reviewed. In addition, one new style German patent application and one Japanese inventive patent application were filed. More than ten papers were published in domestic and international journals. On the commercialization side, the university has developed a 20 horse-powered high-speed axial, which can run up to 24,000 rpm by using a steel ball bearing. This high-speed spindle has also been verified in a real machine tool. The participating companies did not apply for a technology transfer after the completion of this project. However, the R&D results have been commercialized and were installed in its own brand of machine tools. The machines equipped with these new technologies have been exhibited domestically as well as internationally and have been marketed in the open market. It is indeed worth further exploring if the dishonest behavior of the participating companies influences the partnership, industry innovation, etc.

4. Case 4: Wire-Cut Electrical Discharge Machine

Four traditional electrical discharge machine (EDM) companies were eager to move into the wire-cut electrical discharge machine (WEDM) industry. However, the size and the R&D capabilities were the bottlenecks. Since a faculty member of the university had been involved with EDM and WEDM for quite some time and had hoped to verify his academic theory and R&D results, the government was happy to be the bridge to cross the gap between the industry and the university. Thus, an university–industry collaborative project was funded. This case study went for three years. The government funding was NT$15.094 million and a 17% matching fund, totaling NT$3.12 million, was provided by four SMEs. The university was in charge of exploring the theoretical and fundamental models to establish the basis for the designs and for machine performance improvement. The participating companies provided practical experience and executed the part of the project that was closely related to practical implementation in order to complement the lack of practical experience of the academic team. The four participating companies took this university–industry collaborative project as their vehicle for communication, which eventually led to the mutual understanding of jointly developing a pre-competitive prototype. All companies then went on to develop their own version of the machine by using the knowledge gained from developing that pre-competitive model. This project became a special type of university–industry partnership as all four participating companies used the joint R&D as a platform for its strategic alliances.

Two circuit patents were approved and much technological know-how was developed based on the R&D results of this project. Many domestic and international journal papers were also published. The patents have been successfully implemented in manufacturing control of the WEDM developed. In addition, the Institute of Mechanical Engineering of Taiwan's Industrial Technology Research Institute (ITRI) has used the R&D results of this project as the basis for them to develop new WEDM. The four participating companies also utilized the R&D results of this project to develop their own version of the WEDM. It is worth mentioning that the four companies participating in this case study were among the 16 elite companies which possess the capabilities to manufacture WEDM according to ITIS [17]. All of these four companies now market WEDM globally and their sales volumes have increased steadily.

Even though the R&D results were successful commercially, the method by which the participating companies did not go through the official technology route to license the technology developed is an important topic worth further exploring by academia, industry, and the government.

3.2 Pattern 2 Cases: Projects Which Failed

Nine out of the 69 university–industry collaborative projects funded by NSC DEAS were terminated before the approved period, which included four projects that terminated after one year and five projects that terminated after the second year. Furthermore, five of these projects were terminated due to an industry technology change and the other projects were terminated due to commercialization problems.

1. Case 5: Intelligent Power IC – Technology Change of High-Tech Industry

A total of three companies participated in this project, all of which were large domestic or international companies. This project was originally funded for three years. The government had funded NT$14.462 million for the first two years. In addition, the collaborative companies provided a NT$2.448 million matching fund. As the research topic of this project belonged to the pre-competitive category and the technology of this high-tech industry changed rapidly, the originally planned R&D targets were found to be incapable of satisfying the market demand near the end of the second year. This deficiency has led to the premature termination as requested by the collaborating companies.

2. Case 6: Concurrent Design and Quality Control of Digital Temperature Controllers – Commercialization Problem

The participating company involved in this case study is a SME, which has its main business derived from representing imported automation components. This company also manufactures lower level analogy temperature control, sensing, and recoding instrument. As it had planned to move into digital temperature control, and the digital technology involved was closely related to many fundamental principles, the technology fault became a threshold too high to overcome without external help. The academic R&D team had planned to secure practical experience by collaborating closely with industry and at the same time secure more R&D funding. This project was set up with the government playing a role of a communication bridge and as a major partner in funding. The project was originally approved for three years with the government funding NT$1.925 million and the participating company offering a NT$ 825,000 matching fund. The high 30% matching fund provided by the participating companies shows the intention of this company to secure exclusive licensing originally. During the execution of this project, the participating company constantly refused to provide the academic R&D team with practical experiences or related data based on trade secret grounds. This constant refusal prevented the industry and the academic side from having an effective two-way communication. In addition, the two sides had some fundamental discrepancies in their roles. For example, the participating company asked the academic team to commercialize the R&D results directly. However, the academic R&D team though its responsibility ended at the completion of the prototype and believed the commercialization/development process was the responsibility of the participating company. All these factors led to the termination of this project at a time when the R&D results showed some potential for further commercialization.

4. Discussions and Suggestions

1. Using the framework shown in Fig. 1 to analyse these case studies leads to the following conclusions:
   (*i*) Both the successful cases and the failed cases indicate that the original motivation for industry and for the university were to secure some benefits through collaboration. The government was able to play a key role in smoothing out the discrepancies in background which existed between the industry and the university. It was also found that the university–industry collaborative program was a key factor in establishing university–industry partnerships.
   (*ii*) Considering the lessons learned from all the case studies, the industries and the universities in the four successful cases were found to complement each other, creating mutual trust, and resulting in a common perspective of overall R&D goals. In addition, the PIs involved had an excellent track record academically and had practical industry R&D experience. On the other hand, the failed case studies showed some common traits which lead to the failure of the projects. For example, the targets of the projects were incapable of satisfying the actual market demand, the participants had a lack of mutual trust, had no common perspectives on research goals, were characterised by ineffective communication, showed mediocre academic performance, and showed a lack of industrial R&D experience by the PIs involved, all of which led to the early termination of the projects. It is thus clear that successful university–industry partnerships must have the following characteristics:
      a) University and industry must establish agreement on well-defined and realistic objectives.

b) Partners must complement each other, balancing out strengths and weaknesses, while generating mutual respect and trust.
c) Partners must have open and continuous communications.
d) The PIs must have appropriate and applicable R&D experience.
e) There must be common goals for the university–industry collaborative projects and for the long-term strategic targets of the participating industry [7,18].

(*iii*) The role of the government while executing the university–industry collaborative program must be considered as the government funds the projects, determines the necessity and percentage of the matching fund, evaluates the proposals, and chooses the potential candidates to form a team, etc. All these involvements have made the government the most suitable to appraise a good proposal, and to select better PIs and Co-PIs. In addition, the proposal review and the approved funding generated from the proposal review were delivered to the PI as supplemental factors to make sure the project ran properly, which improved the success rate of the projects as illustrated by the four case studies chosen from the 60 successful projects out of the whole 69 projects. It should be noted that the procedures and guidelines implemented by Taiwan's NSC agree well with the experiences of other OECD countries. More specifically, a matching fund requirement, as well as generating competition among project participants, can lead to better proposals and better R&D teams. In addition, public financing of partnership initiatives should be designed to increase the market relevance of the project [2].

(*iv*) With regard to IPRs and journal publications, the four successful cases have obtained 21 patents, e.g. six Taiwan inventive patents and six new style patents, seven US inventive patents, one German new style patent and one Japanese new style patent. In addition, more than 30 papers have been published based on the R&D results of these four projects. All these performance indices have shown that the industries and the universities involved in these successful case studies can communicate with each other and have created a mutual trust, which facilitates the operation of the projects. To further promote the collaboration and protect the interests of all the parties, Taiwan's NSC took steps to make sure that its policies facilitate the partnerships. For example, the government does not automatically release the research results to the public for one year after the project ends. A company, which participates in an NSC university–industry collaborative project, can receive priority non-exclusive licensing for a pre-set period after the technology transfer. Where there is only a single collaborative company and the matching fund provided by this company is more than 30%, a certain period of exclusive licensing can be obtained. For case studies 1 and 2, the collaborating companies have completed the technology transfer procedures and have obtained a priority non-exclusive licensing right.

(*v*) Considering the effect on commercialisation for all case studies, the collaborating companies involved in cases 1 and 2 have completed the technology transfer and have commercialised the product for the global market. Even though the companies participating in case studies 3 and 4 did not complete the technology transfer procedures, they had commercialised the product and had begun to deliver the product to the market. Several issues deserve further examination. First, the two cases deal with official technology transfer, where the university and industry have retained strong interactions even after the projects were completed. However, in the two cases where there was no official technology transfer, the partnership between the university and the industry ended or cooled down with the completion of the project. Secondly, when the NSC executed the official technology transfer process previously, the environment and the mentality of the transfer remained passive. This passive atmosphere led to a slow reaction to requests and typically increased a PI's workload once a technology transfer application was applied for. This disruption has certainly significantly reduced the effects of the technology transfer. Thirdly, the arrangements for the IPR created from the government sponsored research projects must be enhanced. A very small number of professors were found to release technology results to companies for commercialisation without official technology transfer procedures. At the same time, there have been a few participating companies that have commercialised the product without official technology transfer and licensing. These adverse examples deserve attention from the government and the university in order to modify the policies to ensure that a well-run system can be set up.

2. There are some similarities among the last three successful case studies which deserve a second look. The academic team infused a new technology and knowledge effectively during the development and during the innovation of the manufacturing technology/key components for the second case study. The university R&D team in the third case study replaced the originally imported machine tool high-speed spindle with their own version of newly developed key components. The fourth case study belongs to the system integration category and is innovative in its technology development, which is more difficult both for the current industry or for government sponsored-help, or privately owned research institutes to pursue.

In all these three case studies, the participating industries adopted a "cyclic incremental innovation process" model for R&D internally as they all belonged to the mature industries group. This model is having difficulty in meeting the challenges enforced by the rapid development of new technology and the wide use of technology in various new fields. The successful cases examined above indeed show that university–industry partnerships can effectively improve the innovation capabilities of Taiwan's SMEs.

3. It becomes clear that the university–industry partnerships discussed above can be beneficial to industrial innovation. Considering the working conditions, the R&D environment, and the salary in today's SMEs, it is difficult to recruit undergraduate or graduate level personnel to participate in the company's R&D. It is thus next to impossible for the manufacturing SMEs to improve their innovation capabilities quickly, or directly transfer the R&D results into products through the commercialisation process. The only plausible approach is to adopt the model demonstrated in case study 1, which forms a strong bond/partnership between industry and the university by having industry send engineers to participate in R&D work first. Then, a long-term partnership can be developed and maintained to prepare/incubate innovation capabilities internally. Once the SME has a stronger R&D capability and a better internal R&D system, it will become easier to recruit better R&D personnel, which will translate to rapid improvement in innovation capabilities.
4. Several drawbacks not discussed above can be further clarified:
   (*i*) Except for case 1, all other five cases belong to the precompetitive category, which may include prototype manufacturing process development, product improvement, etc. The patents developed and secured are all simple inventions or new style patents, which provide improvements to the integration of principle and practical experience. As the majority of the university–industry collaborative projects belong to this kind of precompetitive category, it is more difficult to secure or develop large systems of high value or highly complex/innovative invention patents by using this type of platform.
   (*ii*) Eight of the nine failed industry–university collaborative projects belong to high-tech industries such as semiconductor electronics, opto-electronics, and information technology. For successful projects, i.e. R&D results were technology transferred, and belong to this category as the research goals were in traditional electrical technology know-how or new style patents. Very few innovative invention patents were created in this kind of project.
   (*iii*) The key to improving innovative capabilities effectively lies in establishing long-term university–industry partnerships. However, several observations deserve to be discussed further.
   (*iv*) The majority of the high-tech industry category of university–industry collaborative projects are executed typically for only a three-year or a two-year term. None of the projects continued to the second term, no matter how the university collaborated with the original industry or a new industrial team. The partnership terminated with the end of the project.
   (*v*) The traditional industry category university–industry collaborative projects typically achieved good R&D results and were deemed successful when their performance indices were evaluated. In addition, approximately half of the teams will pursue a second university–industry collaborative project. Nevertheless, even though the industry and the university teams had established a very strong bond, the PI and Co-PI have been reluctant to form a second term of an university–industry collaborative project. After interviewing those PI or co-PIs, an alarming pattern has appeared. All of the responses from these PI and Co-PIs interviewed are consistent. Active involvement in a NSC university–industry project means investing a significant amount of time and energy. However, the incentives offered by NSC and academia are not enough, as their R&D results typically do not receive a corresponding academic recognition/award. For example, the NSC award system does not recognise their active involvement and the accomplishments achieved. In many cases, their strong involvement even produced a negative impact on their academic performance. More specifically, Taiwan's academic circles have adopted the NSC award system as an objective evaluation of their members. Since the NSC award system awards research based on academic principles, the quantity and not the quality becomes the norm and is evaluated as better. Currently, there is not a single award or part of an award system which targets faculty members who have achieved excellent performance indices in an university–industry collaborative project in order to encourage the involvement of university faculty members. All of these combinations have made the reward disproportionate to the efforts invested by the PI or Co-PI of the university–industry collaborative projects.
5. Some suggestions for improving the innovative capabilities of Taiwan's SMEs are given below:
   (*i*) It should be noted that support for precompetitive R&D is necessary, but insufficient. Effective and innovative ways are required in order to enhance industry's innovation performance [19].
   (*ii*) The funding/measures from the government must be classified by innovation level, i.e. not by the kind of industry. The innovation should be the major performance index used to evaluate a university–industry collaborative project so as to improve the partnerships and to improve industry innovative capabilities.
   (*iii*) For high-tech and industry seeing rapid technology change, it is not beneficial to fund precompetitive R&D. This is especially true for the kind of industry-university collaborative projects discussed here. It is probably better to encourage university–industry collaborative projects to target industrial level R&D, i.e. it is more rational for the government to support this kind of partnership. In addition, Taiwan is expecting to join the World Trade Organization (WTO) soon and the practice enforced by the WTO will certainly have an impact on government sponsored or fostered research. For example, the WTO regulation limits the

level of government sponsored R&D to less than 75% of the overall costs in industrial research. Also, for precompetitive development activity, the government share may not exceed 50% of the costs [20]. To observe and follow these guidelines, the policies and measures related to Taiwan's university–industry collaborative programs discussed above must be adapted appropriately.

These suggestions towards government sponsored R&D, participation conditions for academia and industry, can be summarised as shown in Fig. 2.

(*iv*) Even though some drawbacks exist in the promotion and execution of university–industry partnerships as discussed above, the government, academia, and industry still lack an overall understanding of the current implications. The main reason for this is that no detailed and complete review of the university–industry collaborative program as a whole and of each of the individual project exists up to this date. This paper is probably the first research targeted along this direction. It is clear from the several case studies presented in this paper that more research is needed. Some of the topics which deserve more examination include:

a) How the results of the industry-university collaborative projects and the partnerships established influence the university, the industry, and the overall innovation capabilities.
b) How to maximise the benefit of the limited government resource towards the innovation and competitiveness of the SMEs.
c) To understand the primary benefit for the academic R&D team that participates in the university–industry collaborative project, where evaluations must be studied from the perspective of the university, the faculty members and their R&D, the readiness of the graduates, etc.
d) How well the SMEs can improve their innovation and R&D capabilities by sharing and complimenting their resources with those of academia. Once these evaluations are performed, feedback to the government, academia, and industry can then be used to enhance and improve the effectiveness of the university–industry collaborative program. It is suggested that evaluation and feedback mechanisms be introduced into the structure shown in Fig. 1 to make sure that the university–industry partnerships are complete and effective.

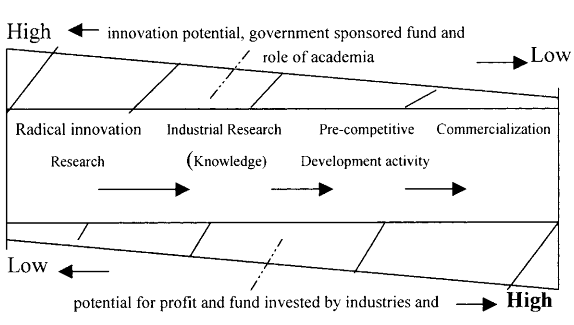

Fig. 2. The suggested relationship between the maturity of the industry and government sponsored R&D projects.

5. Conclusions

With Taiwan's enterprises primarily consisting of SMEs, the R&D model adopted, no matter whether it is developed internally or developed as a result of collaboration with government sponsored research institutes, follows a cyclic incremental innovation mode. This type of R&D model lacks the radical innovation capabilities and is more difficult to integrate/interact with the advanced technology of related fields, which translates to a disincentive towards the long-term R&D of SMEs and prevents the rapid growth of industrial technologies. These obstacles hinder the global competitiveness of SMEs. The case studies in this paper clearly indicate that properly releasing the R&D capabilities accumulated within the university and linking this unleashed capability of R&D personnel and also industrial research can significantly raise the overall level of the enterprises, including generating new ideas, developing new methodologies, and new technology information. With this kind of mechanism, the industry can gradually be equipped with the capability to access external knowledge, to build up the internal capability to understand and apply the external knowledge, and to provide the R&D personnel with the capabilities required to receive the results generated from the university–industry collaborative program. The data compiled and the framework examined in this paper clearly demonstrate that, with proper use, the university–industry collaborative program can improve the innovative capabilities of Taiwan's SMEs. However, it is also clear that with the special social and industry structures of the nation, the government must change from its current passive supporting role to a more proactive role in order to foster and create an excellent R&D environment for the full cooperation between industry and the university. Some of the tasks required may include establishing a framework of incentives for collaboration between academia, research facilities, and companies, and maintaining the strength of the university research base. It is believed that with the full implementation of the tasks discussed above, a long-term partnership between the industry and the university can be established.

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