Innovation Systems and Policy Instruments: The Application of S&T Indicators

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***Abstract*--To enhance country competitiveness, we can improve the function of national innovation system and the exercise of policy instruments for S&T indexes. Despite the great importance to national development, scholars have paid little attention to this policy agenda, in particular the understanding of the linkages of national systems, policy instruments and S&T indexes. In this study using data from WEF and IMD, we draw on the questionnaire survey and Fuzzy Delphi methods to explore such linkages in Taiwan. We identify the missing linkages in Taiwan's national innovation systems, based upon which policy implications are drawn out.**

I. INTRODUCTION

Technological innovation can transform the competitiveness of a country, thereby promoting economic growth. In this era of knowledge-based economies and globalization, nations have been devoting considerable efforts to the management of creative knowledge and innovation system in the economy [3], [9], [36], [45], [52], [59].

Innovation systems are networks and organizations involved in searching and exploring, including universities, public research facilities, government, and any agency involved in innovation [41], [48]. The aim is to facilitate the creation, dissemination, and application of knowledge to enhance efficiency and ensure the on-going development of innovative systems. One example is the exercise of policy instruments for the development of Science and Technology (S&T).

Governments encourage national S&T development using a variety of mechanisms such as subsidies, incentives, and restrictive policies. Funding R&D can be particularly effective in promoting innovation to enhance national competitiveness. S&T indexes can help to clarify the status of S&T development [16], [21], [23], [35], [50] to determine whether goals are being reached and identify the strengths and weaknesses in the current system.

Despite the importance of these measures, few scholars have examined this policy agenda, in particular the links between national systems, policy instruments and S&T indexes. In the 《Oxford Handbook of Innovation》, the study of innovation systems emphasizes the functions and activities (causes and key factors) within those systems [38] or focuses on data survey about the achievements within the system [10], [52].

Many studies have explained how policy instruments induce transformation and change in innovation systems [2], [17], [43], [49], [58]; however, most of these works focus on the importance of interactive-learning and learning from the impact of the environment All of the above studies mention the lack of a systematic study regarding the link between innovation systems and policy instruments. Establishing this link could alter the direction of policy measures, thereby improving national competitiveness.

Since the 1970's, the Taiwanese innovation system has been characterized by the government's implementation of policies to promote technology-based industries. This has included the recruitment of outstanding scientific and technological personnel from abroad and cultivating the type of personnel required by these industries. The Ministry of Economic Affairs (MEA) has funded public facilities to promote research and the National Science Council (NSC) has established science parks to augment the development of technology-based industries. After 30 years of development, Taiwan has built a distinct innovation system [1], [27] typified by the success of the Hsinchu cluster for creative entrepreneurs.

Nonetheless, the innovation system in Taiwan must be re-configured to ensure its continuing development, and S&T indexes are an effective means of evaluating the efficacy of the system. In the next section, we review the background of innovation systems, policy instruments, and S&T indexes. In Section 3, we outline the research methods including data sources, data selection, and analysis. In Section 4, we explore the linkage between S&T competitiveness with policy instruments using a case study. In the final section, we draw conclusions and present the practical implications as well as suggestions for future research.

II. THEORETICAL BACKGROUND

The purpose of this study is to build a model examining S&T indexes as the link between innovation systems and policy instruments.

A. Innovation systems

Freeman [18] first mentioned the concept of a national system of innovation after studying the qualitative aspects of Japanese development after the Second World War. He noted four particular features of the Japanese system: the role of the Ministry of International Trade and Industry (MITI); the role of R&D strategies in Japanese firms; the role of education and training; and the conglomerate structure of industry which combined policy, R&D, training, and tech-investment. That study described a national system of innovation as a network of institutions in both the public and private sectors with the common aim of initiating and diffusing new technology.

Over the years, scholars have labored to explain the various functions and processes involved in innovation. Porter [57] cited innovation as one factor associated with the creation of national competitiveness. Lundvall & Borrás [41] claimed that innovation is the process of interactive learning that generates or reinterprets the knowledge required for R&D, production, and marketing. Nelson [48] stated that innovative efforts require economic incentives such as R&D or seed funding as well as resources of new knowledge or talent. Nelson also called for acceleration in the rate of knowledge diffusion to create opportunities through sectorial cooperation. Etzkowitz & Leydesdorff [11] presented the triple helix of university-industry-government relations to share resources and information in order to improve efficiency and the development of S&T. Edquist [10] defined a system of innovation as follows: all important economic, social, political and organizational factors that influence the development, diffusion, and use of innovation.

Carlsson & Stankiewicz [5] and Galli & Teubal [20] stated that the goal of an innovation system is the development, diffusion, and use of innovations. Johnson [34] claimed that the function of innovation is to explore problems and provide suggestions about knowledge creation, learning, experimentation, and imitation. Numerous methods of supporting innovation have been contrived, such as providing tax incentives, investing resources (funding), directing efforts through regulations and standards, identifying areas in need of innovation (technical feasibility, opportunity for commercialization and supplementary resources), accelerating the circulation of information and resources, stimulating or creating markets, reducing uncertainty, and clearing up factors that could prevent innovation.

The development of S&T and innovation requires the organized integration, cooperation and exchange of information between universities, industry, and research institutions. The Organization for Economic Co-operation and Development (OECD) [52] defined innovation systems as follows: “the result of numerous interactions by a community of actors and institutions, which together form what are termed national innovation systems.” Technology advancement and innovation is an integrated process that must be examined systematically. The OECD [54] further pointed out that innovation and the creation/application of new knowledge are important issues and act as a way for the government and the enterprises to enhance competitiveness. Investments in knowledge production and diffusion can also help to bring about a high-income human resource market and increase production [55].

For developed countries, investments in innovation can enhance competitiveness, while developing economies can use innovation to strengthen competitiveness as well as industry value-added activities in addition to labor-intensive production. S&T indexes, such as company linkages, company-university-public research linkages, company knowledge & tech-diffusion, and flow of talent, can be used to measure and evaluate the results of innovation systems. This type of knowledge-flow has become the basis from which to formulate innovation systems.

The OECD [56] claimed that in an increasingly complex innovation landscape, government and stakeholders require constant policy co-ordination and investment at the local, regional, and national levels. The function of government has been transformed from policy-supply to policy-demand. Policy-making plays a key role through the adoption of regulations, standards, pricing, consumer education, taxes, and other public policies for innovation.

B. S&T innovation policy instruments

Scholars have provided different definitions for policy instruments, governing instruments, and tools of government.

Hood [24] claimed that policy instruments are administrative processes that governments use to make policy objectives workable. Howlett [25] stated that when a government wishes to implement policy goals, there are diverse policy tools and techniques that can be implemented. Schneider & Ingram [64] claimed that policy instruments appear as a type of action map with a given target to motivate people to change their behavior in order to settle public issues or achieve policy goals. Linder & Peters [37] defined policy tools as mechanisms used to achieve policy goals. Salamon [63] pointed out that policy tools are identifiable methods through which collective action is structured to address public problems.

UNESCO [66] stated that policy instruments constitute a set of ways and means of putting a given policy into practice. Sagasti [62] stated at a UN conference that, “policy instruments are the means employed by those who exercise power and authority to influence the decisions made by other agents.” According to Sagasti [62] policy instruments are the means of governance or policy goal achievement, with the aim of inducing or motivating individuals, firms, or organizations to behave in accordance with the regulations or guidelines of governmental policy. Sagasti [62] described the structure of policy instruments as policy, legal devices, organizational structure, operational mechanisms, and effects, which are not necessarily operated by order but could use tools of single or mixed levels according to the purposes of authorities.

Scholars have presented many opinions regarding the various types of policy instruments. Schneider & Ingram [64] distinguished authority tools, incentive tools, capacity tools, symbolic and hortatory tools, and learning tools. McDonnell & Elmore [44] listed mandates, inducements, capacity-building tools, and system-changing tools. Howlett & Ramesh [26] categorized instruments as voluntary, compulsory, and mixed. Salamon [63] claimed that the multiple classification of tools is entirely appropriate because different classifications highlight different facets of the tools.

In order to analyze STI (science, technology and innovation) policy instruments, UNESCO [65] developed analytic units which distinguished policy instruments into three groups: the structure of national STI systems, legal frameworks, and operational instruments for promoting S&T

activities. Sagasti [62] asserted that policy instruments are meant to build S&T capacities and infrastructure, regulate technology imports, shape technological behavior and the S&T performance of firms, and provide support for the S&T activities of firms. Rothwell & Zegveld [61] provided a comprehensive classification of policy instruments, which included 12 types within three categories: supply, demand, and infrastructure. The supply side involves policy tools such as public enterprises and research laboratories, the demand side involves R&D contracts and the infrastructure side deals with grants and patents. These items are connected with S&T programs, making them an important policy instrument of governments with regard to S&T development. Examples of such implementations include Singapore's Technopreneurship 21 program, Japan's S&T Basic Plan, Korea's BK21 programs, China's 12th Five-Year Plan (2011-2015), and the Science and Innovation Investment Framework 2004-2014 of Britain.

Governments have different targets and objectives; therefore, there is no single mode that could be followed. UNESCO [66] claimed that the framework of policy instruments could be used as reference to determine the feasibility of policy tools. Linder &Peters [37] considered using market, regulatory, voluntary or mixed types of policy tools in accordance with national capacity and the function of policy sub-systems.

Sagasti [62] suggested that the performance of S&T policy instruments could be evaluated according to five dimensions: the categories of decisions they affect, the types and numbers of agents influenced, cost/benefit ratios, impact on the actual behavior of agents, time lags, and the capacity to adapt and evolve over time.

C. S&T indexes

S&T indexes are an important reference for national foresight and the execution of S&T policy. According to the OECD [50] S&T indexes are a series of data responding to the current status of the S&T system, which includes the structure of the system, economic and social relationships, to help personnel understand the ratio of accomplished targets

S&T indexes can be used for the evaluation of policy, S&T programs, and organization. In policy evaluation, the function of S&T indexes is to review the factors that influence the achievement of policy goals. The design of indicators is initiated by policy vision and goal setting. More clear goals provide more specific indexes for objective evaluation. For the evaluation of programs, we used indicators of strategy, technology, efficiency, efficacy, commercialization, and human talent which according to research purpose. As for evaluating the performance of the organization, we used a range of indexes based on the mission of specific organizations. For example, Taiwan has designed six sets of main indicators for organizational evaluation: organizational development, resource capacity, management & execution, performance of R&D, performance of R&D cooperation, and achievements of distinguishing R&D. Each indictor is given a different weight based on the mission of the organization.

The OECD is a leader in R&D statistics research and published the Frascati Manual in an attempt to establish a set of definitions, standard operation methods and standard procedures for R&D surveys which included R&D, technology balance of payments, and statistics survey of innovation. In addition, the OECD [49] published the Oslo Manual to provide a set of methods for the collection of survey data related to tech-innovation. This method became a reference for the measurement of industrial innovation activities. In 1997, the 2nd edition was published with the addition of indexes of firm innovation. The follow-up sixth edition of the Frascati Manual was published in 2002, expanding the R&D survey to the service industry. The third edition of the Oslo Manual also outlined methods for using innovation indexes.

The EU has also been studying indexes of national innovation capacity. The PRO INNO EUROPE publishes periodical survey data and revises the indexes according to changes in international trends [14]. In 2009, the European Innovation Scoreboard revised four categories with 25 indexes into three categories: enablers, firm activities and output (which includes 29 S&T and non-S&T sub-indexes). These could be used for the comparison and analysis of innovative systems in EU member countries and provides a reference for reviewing the processes and systems of national innovation [13].

The other important indicators for reference are the 《Global Competitiveness Index》 of the World Economic Forum (WEF) and IMD's《World Competitiveness Yearbook》. The WEF divided 110 indictors into 3 categories and 12 sub-items, and assigned weights in accordance with the stages of national economic development. When developing the world innovation rankings, the IMD collects data (70% from secondary statistics resources and 30% from questionnaires). Each indicator \ has a different weight and is periodically revised a coincidence with current circumstances.

During the mid-1990's, the OECD recognized that different indictors should be designed for different policy goals which truly respond and measure the results of performance of innovation and the knowledge economy [55].

Colecchia [8] claimed that there are two ways of measuring innovation: invention-oriented and diffusion-oriented. Invention-oriented innovation should be performed in labs and guided by consumers. The invention-oriented indictors should focus on the interaction of consumers and the flow of human resources and knowledge. Both scientific & non-scientific development and applicable technology can be seen as innovation. Therefore, Colecchia [8] claimed that we should emphasize measurement and analysis of how to link science, technology, and innovation.

The OECD [56] stressed that a one-size-fits-all method for evaluating S&T development is no longer suitable. Systems of S&T evaluation should be amended in accordance with international trends. Evaluation is required to promote the effectiveness and efficiency of policies and could be helpful for creating an innovative environment and improving social welfare. Scholars have echoed these sentiments, declaring that to improve the improving measurements of innovation requires measurements of links, results, and impact evaluation [60].

III. RESEARCH METHOD

This study sought to build a model to link innovation systems and policy tools through the use of S&T indexes. We therefore selected S&T indictors and used a questionnaire for the collection of data. We used the fuzzy Delphi method to analyze problems prone to subjectivity.

A. S&T index selection

A four-step process was used for indicator selection. We first obtained indicators from the WEF and IMD as primary data and selected suitable S&T indictors from among these. Second, we sorted out S&T innovation indictors in accordance with the stages of innovation development. Third, we sorted indicators from governmental R&D projects. Fourth, we integrated the sifted indicators into the national innovation system to construct a holistic technological innovation system.

B. Pre-Questionnaire and Interview

This study selected 28 indicators of S&T innovation. We then developed a questionnaire and sent it to experts to validate the indicators of S&T innovation.

Before sending the formal survey, we prepared a pre-questionnaire to make sure every item was clearly defined [41], [74]. Each item included seven options from agree to strongly disagree. The questionnaire was divided into three parts: the first part had 28 items related to the indexes of innovation systems. The second part was concerned with the indictors of program performance. The third part had items concerning the indictors of efficiency & effectiveness and how to promote the efficiency of innovation systems. The questionnaire included 24 pages. We utilized the assistance of three experts in the preparation of the pre-test and interviewed each expert for approximately 30 minutes, after which we analyzed the responses to confirm the importance of the items. The results of the pre-test demonstrate that each expert required too much time to think about how to fill out the questionnaire, suggesting that we should provide additional information. These experts also suggested a number of revisions to the wording.

C. Revision and survey

After revision, we sent the questionnaire to scholars of business management and committee members who had been executors or reviewers of the government's S&T programs. The revised questionnaire included 18 pages covering two issues: the importance of S&T innovation indicators and which performance indicators should be included. We also explained the content of the questionnaire over the telephone.

The questionnaire was sent out twice. In the first round, only 16 copies were returned because filling out the questionnaires proved too time consuming. During the second round we retrieved 12 copies and analyzed questionnaires to make sure that the scholars had reached consensus about every agendas.

D. Analysis

This study used the fuzzy Delphi method (FDM) for survey analysis. FDM is better way of collecting experts' opinion than traditional Delphi method. [33], [46].

FDM is suitable for a small number of experts, providing a systematic means of achieving a consensus among experts [6], [7], [33].

FDM has been widely applied for surveys of public policy, technological forecasting, education, and project planning. FDM is a method of making expert forecasts and group decisions by seeking consensus in the judgments of experts. FDM was developed to deal with uncertain data through the application of fuzzy theory during the decision-making stages [33], [47], [75].

The FDM questionnaire provides threshold values, weights, and ranking. Threshold values can be used as a sign of whether or not a consensus has been reached and help to understand the priority and importance of various issues according to weight and ranking.

This study used the same analysis method as Büyüközkan & Ruan [4] involving the following three steps: 1) determine the alternatives and evaluation criteria, 2) identify the evaluation base, and 3) determine the aggregated fuzzy weight of the criteria. First, experts were asked to provide evaluation data and whether they had reached consensus for each indicator. We then assessed the important items and indicators according to opinion of experts. To set the threshold values, we presumed a value of 0.2; i.e., the convergence of criteria must include more than 80% of the participants, for the criteria of programs, we use the option"important" as a threshold and then checked the table of fuzzy triangular numbers obtaining a solution weight of 067.

We further classified the indictors in accordance with four targets of S&T development: human talent, patents, patent output and patent industrialization. We designed a table with connecting S&T indexes and policy tools using the four targets. We then sorted out the policy tools according to the corresponding targets to show the relationship between innovation and policy tools.

IV. RESULTS

A. Indicators of Taiwanese competitiveness

The results of the questionnaire confirmed that the indicators of all of the government programs and 28 indexes exceed the level of significance and all of the weights exceed

0.67, except for the indictor labeled science degrees, which is within the normal range with a weight of 0.62. We also evaluated the measurement and classification indices according to stage input, process, output, and outcome analysis structure (see Table 1). In addition, the indicators university/industry collaboration in R&D, university-industry cooperation, and public and private sector ventures belong to the input and process stage. The indicators of each stage are outlined in the Table 1.

B. Indicators of stage input

The weight of business expenditure on R&D was the highest at 0.83. This was followed by university-industry collaboration in R&D at 0.82. Development and application of technology was .0.81. The availability of scientists and engineers and quality of scientific research institutions were the same at 0.8. The three indicators with the lowest weights were funding for technology at 0.74 and R&D personnel in business per capita at 0.73. In addition to input resources and personnel, university-industry collaboration is an important indicator for S&T development.

C. Indicators of stage process

The value of capacity for innovation is 0.81. the weight for factors falling under FDI and technology transfer and knowledge transfer have the same value 0.79, which shows that it is increasingly important that firms adopt high-tech through innovation or open-innovation to transfer knowledge to promote S&T development.

D. Indicators of stage output

The weight of intellectual property rights was 0.81, followed by patent grants at 0.74. The indicators Scientific articles and the number of patents in force had weights of 0.71 and 0.67, respectively. This shows that with the number of scientific articles and patents in Taiwan, scholars should pay more attention to the protection of intellectual property rights and the number of patent grants for the sake of the country.

E. Indicators of stage outcome

The index value of availability of latest technologies was 0.82, innovative capacity was 0.78, and high-tech exports and ratio of high-tech exports were both 0.74. This means that with the low-margins in the high-tech industry, continued development will require new technology to enhance technology transfer, facilitate advancements in industrial technology and cultivate the innovation capacity of Taiwan.

F. S&T competitiveness and innovation systems

To link S&T competitiveness with innovation systems, we sorted through the above 28 indexes of the stages of innovation development to obtain 14 indicators which we then combined with the inter-factors of innovation systems: government-university, government-public research facilities, government-industry, university-industry, industry-public research facilities and university-public research facilities. Those indexes represent the status of innovation system and highlight the focal point for the promotion of operational effectiveness and the application of policy (see Table 2). We explain the six inter-factors with 14 indexes in Table 2.

TABLE 1. INDICATORS TAIWANESE COMPETITIVENESS

Input	Process	Output	Outcomes
● Total expenditure on R&D ($) ● Total expenditure on R&D (%) ● Business expenditure on R&D ($) ● Business expenditure on R&D (%) ● Funding for technological development ● Total R&D personnel nationwide ● Total R&D personnel nationwide per capita ● Total R&D personnel in business enterprise ● Total R&D personnel in business per capita ● Science degrees ● Availability of scientists and engineers ● Basic research ● Development and application of technology ● Quality of research institutes ● Technological cooperation 1 ● University-industry collaboration in R&D ● Public and private sector ventures	● Technological cooperation ● University-industry collaboration in R&D ● Public and private sector ventures ● Knowledge transfer ● Innovative capacity ● FDI and technology transfer	● Scientific articles ● Patent applications ● Patents grants ● Patents utilities ● Intellectual property rights	● High-tech exports($) ● High-tech export (%) ● Capacity for innovation ● Availability of latest technologies

Note1: The indicator: Technological cooperation, University-industry collaboration in R&D and Public and private sector ventures, which belong to input and process stages at same time

TABLE 2. S&T COMPETITIVENESS AND INNOVATION SYSTEM

Dimansions	S&T Indexes													
	Scientific articles	Quality of research institutes	Knowledge transfer	Patent applications	Patents grants	Patents utilities	Innovative capacity	Availability of latest technologies	FDI and technology transfer	Capacity for innovation	Intellectual property rights	Availability of scientists and engineers	High-tech exports($)	High-tech export (%)
government-university	•	•	•								•			
government-public-research facilities	•	•	•	•	•	•	•	•			•			
government-industry		•	•	•	•	•	•	•	•	•	•			
university-industry			•		•	•	•	•	•	•	•	•		
industry-public research facilities			•		•	•	•	•	•	•	•	•		
university-public research facilities	•	•	•								•			

Government-university includes four indexes. Academics usually focus on published scientific articles but Taiwan has enough publications. However, we should improve the quality of research institutes and engage international R&D collaboration to promote S&T innovation system with international standards.

Government-public research facilities include nine indexes. In addition to the number of patents, the government could use indexes like innovation capacity, the availability of latest technologies, and encourage research institutions in the development of new technologies and R&D cooperation which could introduce latest technologies for development of firms and industries.

Government-industry includes ten indexes. This shows that the Taiwanese government places great emphasis on advancing S&T industries. These indicators encourage inter-firm co-research, strengthen firm's innovation capacity and introduce latest technologies to promote industrial development more effectively than output of patents.

University-industry includes nine indexes. Recently university-industry cooperation has become a key factor in promoting industrial development. Pre-tech transfer, technology transfer, and the introduction of the latest technologies can all help firms to invest in production and industrial development.

Industry-public research facilities include nine indexes that seek to enhance international cooperation to improve the standards of research institutes and encourage the formation of alliances between research institutes.

University-public research facilities include four indexes that emphasize the transfer of knowledge between universities and research institutes, interflow of personnel to improving R&D capability.

G. Linking S&T Competitiveness and Policy Tools

This study classified indexes in accordance with the four targets of human talent, patent output, patent industrialization and new emerging technology. We then combined the current 11 government programs including the National Science Council (NSC) funding for research projects, industry-university cooperative research projects, the technology development program of the Ministry of Economic Affairs (MEA), and National Science and Technology Programs (NSTP). We divided these indicators according to the process of S&T development, which includes the four stages of basic research, applied research, technological development, and commercialization. We dealt with S&T competitiveness using the relationship between policy tools and the links between innovation systems and policy tools (see Table 3). This study used recent research projects from Taiwan as examples to explain the S&T indexes.

H. NSC funding for research projects

The purpose of the NSC is to provide university and research institutes with the funding required for research projects and to improve S&T development. The funding projects are in basic and applied research. The assessments of the results of R&D are based on the number of scientific articles, patent applications, the accumulation of innovation capacity, and the promotion of S&T achievements through knowledge transfer.

I. MEA technology development program

The purpose of the MEA is to make use of R&D capacities and facilities from universities to take advantage of prospective, innovative industrial technology in order to create opportunities in emerging industries. Funding is provided for technological development. The major assessments of the results of R&D are human talent incubation and the number of patent applications & grants. Another objective it to encourage scholars to provide fruitful results in R&D through knowledge transfer and IP protection mechanisms.

J. NSC industry-university cooperative research projects

The aim of the NSC is the fulfillment of precursor & pragmatic tech and applied knowledge by integrating research resources from universities and research institutes and also considering the demands of the private sector, in order to encourage firms to actively participate in co-research with other scholars, develop latent capacity, attract talent, and increase in service performance and added value in production. Results can be evaluated through the input of funding and research personnel to promote tech development and application. This project could be used to encourage technological cooperation between industry and scholars and to protect IP and knowledge transfer through the transfer of tech-rights.

K National Science and Technology Programs

The aim of the National Science and Technology programs is to address the country's major socioeconomic issues. The NSTP integrates Taiwanese R&D resources up and downstream to boost national competitiveness. The NSTP requires long-term and clearly defined goals, involving advanced technologies to make a significant contribution to industrial development and national social welfare. The evaluation of NSTP is based on R&D and the cultivation of tech talent. These measures are meant to encourage R&D cooperation between universities and research institutes using practicable plans for technological development and perfecting IP protection mechanisms.

L. Case study

This study selected Taiwan's weaker S&T indexes to demonstrate the proposed linking model. Graph 1 is the average ranking of Taiwanese S&T indexes for the period from 2007~2011. In graph 1, higher values indicate a weaker index. The average ranking of Taiwanese competitiveness for the period from 2007~2011 was 14 which means that a ranking of indicators below 14 represents under-development.

TABLE 3. LINKING OF S&T COMPETITIVENESS AND POLICY TOOLS

		Policy Tools										
		NSC funding for research projects	Technology development program of scholars of MEA	Technology development program of research institutes of MEA	Technology development program of industry of MEA	ITDP	Small Business Innovation Research funding projects	NSC industry-university cooperative research projects	Funding for IPR projects of Industrial Development Bureau	Funding for human Talent projects of Science Park	Funding for SME incubation projects	NSTP
Emerging Technology	Scientific articles	•								•		
	Total expenditure on R&D ($)											
	Total expenditure on R&D (%)				•	•	•					
	Funding for technological development			•	•	•	•	•			•	•
	Business expenditure on R&D ($)											
	Business expenditure on R&D (%)											
	Quality of research institutes	•	•	•	•							•
	Development and application of technology			•	•	•	•	•			•	
Patents Output	Patent applications		•	•	•	•	•					
	Patents grants		•	•	•	•	•					•
	Patents utilities											
	Intellectual property rights		•	•	•	•	•	•	•			
Patents Commercializiltion	University-industry collaboration in R&D											
	Knowledge transfer	•		•	•	•	•	•				•
	Capacity for innovation	•	•	•	•	•	•	•				•
	Innovative capacity		•	•	•	•	•		•			
	Technological cooperation			•	•	•	•	•			•	
	Availability of latest technologies			•	•	•	•					
	Public and private sector ventures				•	•	•					
	FDI and technology transfer				•	•						
	High-tech exports($)				•	•						
	High-tech export (%)				•	•						
Human Talent	Total R&D personnel nationwide		•	•	•	•	•	•		•		•
	Total R&D personnel nationwide per capita											
	Total R&D personnel in business enterprise				•	•	•					
	Total R&D personnel in business per capita											
	Availability of scientists and engineers			•	•	•	•					•
	Science degrees									•		

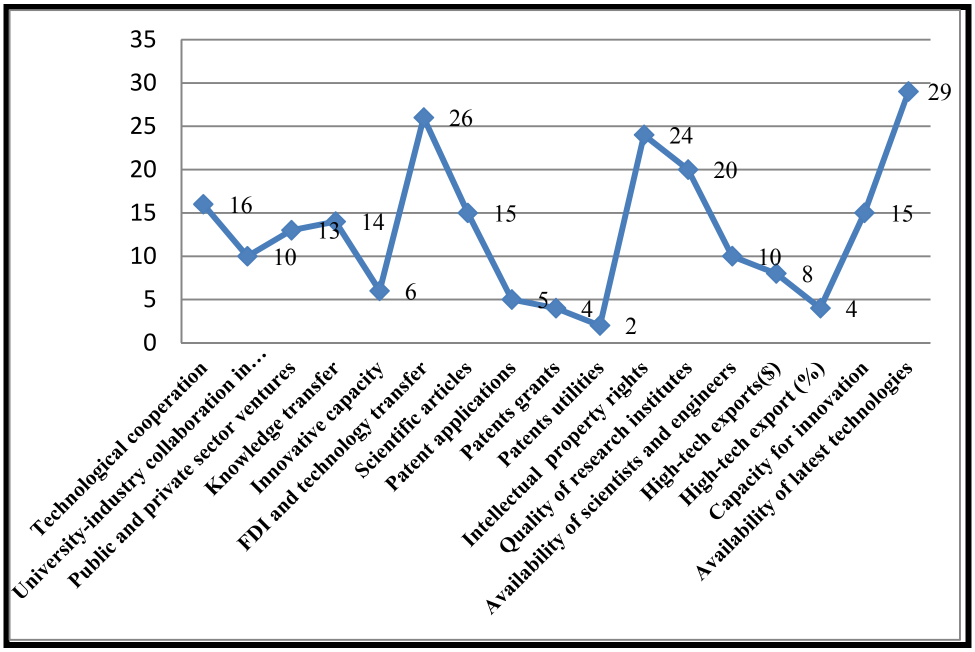

Figure 1. The Average Ranking of Taiwanese S&T Indexes of 2007-2011

The ranking of quality of research institutes and FDI and technological transfer were 20 and 26 respectively, which means that if we improve the ranking of these indicators, we could promote Taiwanese competitiveness. In the following, we explain how to link S&T indexes with innovation systems and policy tools to improve S&T competitiveness.

M. Quality of research institutes

According to the WEF (2010) definition, the indicator quality of research institutes refers to the performance of a country's research institutes in specialized fields. The average ranking of Taiwan's research institutes was 20 for the period from 2007~2011. To strengthen the performance and ranking of this index, we proceeded with the following measures:

Taiwanese competitiveness belongs to the stage input indicators, which means we can obtain direct results between the output and the input of resources. The table of six inter-factors related to S&T competitiveness and innovation systems indicated that we could put more effort into government-university, government-public research facilities, government-industry, and university-public research facilities. The government could plan for the deployment of resources in support of these four different inter-factors for R&D. The base policy targets on a industrial development by, thereby promoting the quality of those research institutes.

After reviewing Taiwanese funded projects in the table of S&T competitiveness and policy tools, we found available projects including NSC funding for research projects, MEA technology development programs, and the NSTP.

The government should invest resources according to the purpose of the projects. As an example, NSC funding is for university and research institutes to improve S&T development. Thus, we suggest increasing the percentage of total expenditure on R&D to improve the quality and the ranking of research institutes to strengthen S&T competitiveness.

Taiwan's research institutes have been playing a key role in tech-development, particularly in the semiconductor industry. Promoting the quality of research institutes in these and other research institutes could directly improve industrial technology.

N. FDI and technological transfer

FDI and technological transfer measure the transfer of the latest technologies through foreign direct investment. The average ranking of FDI and technological transfer was 26 during the period 2007~2011. Taiwanese competitiveness is far below the average ranking at 14. To strengthen the performance and ranking of this index, we proceeded through the following measures:

This index belongs to stage process, which means that we obtain indirect result from input resources; therefore, the process has the function of connecting input-output or input and outcome.

The table of six inter-factors of S&T competitiveness and innovation systems indicated that we could put more effort into government-industry, university-industry, and industry-public research facilities. This means that the government has limited leverage and needs scholars or research institutes to influence industry. Nonetheless, the government could deploy resources for encouraging R&D and tech-transfer using the above 3 inter-factors as a reference.

After reviewing Taiwanese funded projects in the table of S&T competitiveness and policy tools, we found available projects including the following: MEA technology development program and MEA leading new product funding projects.

The ITDP is meant to upgrade industry, enhance the value of industry, encouraging firms to invest in tech innovation, encourage firms to get involved in high-risk technological R&D, planning long-term global strategies in advance, elaborating to efforts of industrial R&D with IP protection and interflow of personnel e D, ant, growing start-up companies for new products and services. Thus, we suggest increasing funding to improve the quality and ranking of FDI and technological transfer.

FDI and the transfer of technology are used to introduce the latest technologies, which is a key factor in the development of S&T competitiveness. The host country requires particular capabilities and infrastructures, which nonetheless, still presents many challenges.

V. DISCUSSION AND CONCLUSION

Innovation systems have the function of integrating resources and mechanisms to encourage innovation and drive S&T competitiveness. Policy tools operate in coordination with the government's goal of S&T development to get this result. S&T indexes provide an objective assessment scale of R&D performance. All three are important factors in promoting national S&T competitiveness and require more cohesive linking. Nonetheless, there tends to be a lack of cohesiveness, which results in a reduction in competitiveness. No previous study has provided a model to combine the effectiveness of these measures. This study sought to link innovation systems and policy tools with S&T indexes to promote S&T competitiveness.

We began by sorting out 28 innovation indexes using data from the IMD and WEF, then distributing questionnaires to determine the appropriateness of the indexes using consensus determination and weight analysis of FDM. We then categorized the indexes into the stages of input, process, output, and outcome and outlined the value and meaning of the indexes. Second, we combined S&T indexes with six dimensions of innovation systems and identified the indexes concerned with each dimension. We also classified 28 indexes with four targets: emerging technology, output of patents, patent commercialization, and human talent, which was combined with the main Taiwanese S&T projects (policy tools) for innovation system, S&T indexes, and policy tools linking model. Third, we analyzed the quality of research institutes and FDI and technological transfer and made suggestions as to the means to improve the ranking. We then checked six dimensions of the innovation system model to identify the key points for implementing government policy and suggested directions of input resources and the use of policy tools to enhance national S&T competitiveness.

The main contribution of this study was the development of a model linking innovation systems and policy tools. It is our hope that this model can be used as a reference by the government. This study also classified indexes into different stages of S&T development. According to our results, policy-maker could ask concerned administrators to draw up a strategy and provide resources for the promotion of national competitiveness. This study also helps to link government S&T projects with policy tools, which is good for the promotion of competitiveness. Further links could be made with performance indicators from the main S&T projects, which could be used as a reference for improving the results of S&T projects.

One limit of this study is that we did not present a full discussion about applying different indexes and mechanisms for different domains and stages of S&T research. This will require more data to build a model applicable for the assessment of indexes for different domains and stages of S&T research. For future studies, we suggest probing the results more deeply for other indicators and revise indicators in response to the status of innovation systems. Moreover, this study did not discuss policy tools of mechanisms for application across the pre-, mid-, post-policy implementation, partly because different government administrations support different S&T projects in Taiwan and partly because we are still lacking an objective means of evaluating projects after they are finished. It is our hope that appropriate auxiliary models and assessment methods will be implemented in the future.

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