行政院國家科學委員會專題研究計畫　成果報告

台灣高競爭力科技發展策略之研究

計畫類別：個別型計畫
計畫編號：NSC91-3013-P-009-001-
執行期間：91 年 04 月 01 日至 92 年 10 月 31 日
執行單位：國立交通大學科技管理研究中心

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報告類型：完整報告
報告附件：國外研究心得報告
處理方式：本計畫可公開查詢

中　華　民　國 93 年 6 月 1 日

國家科學委員會專題研究計劃

台灣高競爭力科技發展策略之研究

MCDM Approach to Technology Development Strategies

for High Competitiveness of Taiwan

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2003 年 10 月

台灣高競爭力科技發展策略之研究研究計畫中英文摘要

一、計畫中文摘要

科技發展策略的擬定與執行，前後有相當程度的時間落差且對未來影響深遠，在瞬息萬變的市場競爭下，由於無法認知環境變遷要素為動態之變動狀態，使科技發展策略之決策與動態環境變動狀態間出現時間落差，或難以預測，導致原科技發展策略無法適時對應、效能降低。本計劃首先採用歐盟所提出的「創新計分版」作為指標，以最適合的資料包絡分析(Data Envelopment Analysis, DEA)模式建構科技發展策略投入產出效率之分析模型，針對台灣科技發展策略執行效率加以分析。第二部分根據層級分析法(Analysis Hierarchy Process, AHP)的層級架構，針對國家創新系統建立多準則評估體系，本體系分為三層級（Tri-Tiered）：第一層為標的（Goal），為國家競爭力之提昇；第二層為層面（Aspects），為國家創新系統之八個分析觀點；第三層為目標/準則（Objects/Criteria），為本計劃針對八個分析觀點中的細項進行分割型模糊積分之多準則評估體系探討過去政府對 IC 產業引進、扶植等過程所施行的科技發展策略群組是否有顯著的影響效果；計劃結果可作為政府制訂創新/技術政策參考。

關鍵字：科技發展策略、國家創新系統、創新政策、創新計分版、資料包絡分析、層級分析法

二、計畫英文摘要

Decision making and practice of S&T policy are crucially for both government and private sectors, but they usually suffer from high volatility in dynamic environment of international competition. The first objective of this research is to propose the Data Envelopment Analysis model for efficiency measuring of Taiwan S&T policy.

The second objective of this research is to develop an empirically based framework for formulating and selecting Innovation Policy. The government is usually facing complex decision scenarios. Traditional decision making methods are failed to satisfy the government's need in this regard. Thus, a hierarchy multi-criteria decision-making (MCDM) method for evaluating the Innovation Policy is proposed in this study. Finally, in order to show the practicality and usefulness of this model, an empirical study of Taiwan IC industry are demonstrated.

Key Words: S&T policy, National Innovation System, Innovation Policy, Innovation Scoreboard, Data Envelopment Analysis, Analysis Hierarchy Process.

計畫綱要

PART 1 Comparative Performance of Major OECD Member National Innovation Systems: A Data Envelopment Analysis Approach

PART 2 The Innovation Policy Priorities in Industry Evolution: The Case of Taiwan's IC Industry

PART 3 Fuzzy Integral MCDM Approach for Evaluating the Effects of Innovation Policies: The Case of IC Design Industry in Taiwan

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附錄 出國差旅心得報告

PART 1

Comparative Performance of Major OECD Member National Innovation Systems: A Data Envelopment Analysis Approach

Comparative Performance of Major OECD Member National Innovation Systems: A Data Envelopment Analysis Approach

Abstract: Real difficulties occur in measuring and comparing technological accumulation across firms, sectors and nations. National Innovation Systems (NIS) performance is also difficult to measure. However, due to the growing demands from public and private policy-makers for better information, progress has been made in both NIS measurement and conceptualization. This paper attempts to shed light on the economic theory regarding the performance of major OECD member NISs by presenting comparative analyses based upon nation-level data for 1996-1997, measured using the Data Envelopment Analysis (DEA) approach. It is possible to make useful international comparisons amongst OECD nations in change-generating activities for the major NIS institutions.

Keywords: National innovation systems; Data envelopment analysis; Science and technology policy; Performance measuring; Research and development.

1. Introduction

The last ten years have witnessed rapid economic development in Asia, and the spread of market liberation around the world. In the 21st century, increasing pressure from globalization will force enterprises to face a higher level of global competition. The related impacts from the computing explosion, communications and media technologies convergence, and international deregulation, are reshaping the world economy in a manner not seen at any time in history. There are three levels of global competition, the firm level, the industrial level, and the national level. For advanced nations, the competition among different nations rests in their educational systems, R&D infrastructure, environmental and trade regulations, and macroeconomic and microeconomic policies. The direct involvement of government in commercial technology developments has not been the major policy focus for these advanced nations.

For developing nations, to strengthen the global competitive advantage for national firms and maintain stable economic growth for the nation, national governments must develop effective economic and industrial policies to insure sustained competitive advantage and continued economic growth. In addition to the common macroeconomic and microeconomic policies, direct government involvement in technological acquisitions and development is necessary. Science and Technology (S&T) are now strategic resources to be deployed as effectively as possible [1]. To achieve this goal, any S&T policy should be based on nation-specific S&T frame conditions [2]. In economic reality, however, the S&T

policies of different nations exhibit certain common attributes [3].

The most important nation-specific frame conditions for any sectoral S&T policies are the national institutional conditions for technological innovations. This institutional infrastructure is often referred to as a "National Innovation System (NIS)". This term is defined as: "the network of institutions in the public and private sectors whose activities and interactions initiate, modify and diffuse new technologies" [4]. Since the studies by Freeman, several other studies on NIS have been published (Lundvall, 1992; Nelson, 1993; Patel & Pavitt, 1994). All of these studies tried to understand regional innovative capabilities in relation to the various institutions that were present in the nations under study (Janszen & Degenaars, 1998).

Real difficulties occur in measuring and comparing technological accumulation across firms, sectors and nations (Patel & Pavitt, 1994). As we have seen, the activities that contribute to technological accumulation are complex and varied, encompassing basic research in universities at one end of the spectrum, and routine thinking in production, at the other. NIS performance is therefore also difficult to measure. However, due to the growing demands from public and private policy-makers for better information, progress has been made in both NIS measurement and conceptualization. This paper attempts to shed light on the economic theory involved major OECD member NISs by presenting a comparative analyses based upon nation-level data for 1996-1997, measured using by Data Envelopment Analysis (DEA). The DEA technique, first proposed by Charnes et al. (1978), is now known as an evaluation technique for the performance analysis of various entities, whose production activities are characterized by multiple inputs and outputs (Sueyoshi et al., 1999). It is possible to make useful international comparisons among OECD nations on the change-generating activities of the major NIS institutions.

This paper is organized as follows. Section 2 describes, in detail, the NIS concept, the elements of NIS and the variables used for their measurement. Section 3 summarizes the DEA technique. Section 4 applies the DEA technique to evaluate the performance of major OECD member NISs based upon nation-level data for 1996-1997. The conclusion is documented in Section 5.

2. National Innovation Systems

2. 1 National Innovation Systems Concept

The conceptual development of a national innovation system, sector, or particular technology orientation has largely been the work of economists and other technologically advanced scholars that adhered to an evolutionary theory of economic growth (Freeman, 1988; Lundvall, 1988, 1992; Nelson, 1988, 1993; Carlsson, 1995; Edquist, 1997; Mowery & Nelson, 1999). These scholars emphasized interactive learning between knowledge producers and users in generating innovations and the role of the nation state in this process. They also argued that an institutional framework plays an important role for interactive learning that leads to innovations.

There are several definitions of the "NIS" concept. As Lundvall (1992) illustrated, there is a broad definition, that encompasses all interrelated institutional actors that generate, diffuse and exploit innovations, but also a narrow definition, that includes organizations and institutions involved in searching and exploring, e.g. R&D departments, technical institutes and universities.

Having developed historically, NISs vary and should indeed vary greatly from one nation to another (Ergas, 1987). Lundvall (1992) assumes that basic differences in historical experience, language and culture will be reflected in five important factors in each NIS:

a. The way in which firms are organized can have important consequences for the interaction between different departments, the flow of information and the learning process. All of these factors can affect the innovative capability of firms.

b. Inter-firm cooperation is the second important factor. This takes a variety of forms including user-producer interactions; network relationships in industrial districts which facilitate the informal exchange of technical know-how; and various forms of cooperation that are becoming increasingly important in knowledge-intensive industries.

c. The public sector as a competent user of innovations; and as formulator of the regulations and standards, which influence the rate and direction of innovation.

d. The institutional set-up of the financial sector, which finances innovation. This is significant because investments in innovation imply more uncertainty than ordinary investments, and involve a longer learning process for consumption and production than for known products.

e. The resources, competencies and organization of the R&D system. This includes public sector research directly funded by government (in universities and government laboratories), as well as industrial research carried out by firms and research associations.

All of these factors give rise to a certain institutional structure. In aspects more closely related to what is actually called the innovation systems, the previously stated characteristics can be seen, for instance, in the way firms are organized, the way firms deal with one another, the public sector's role and the way in which S&T and R&D systems are organized (Cooke et al., 1997).

2. 2 Elements of National Innovation Systems

Our analysis embraces a cross-nation approach to evaluating the performance of major OECD member NISs. To this effect, the various NIS elements are organized into three groups: inputs, moderators, and outputs (Naierowski & Arcelus, 1999).

a. Inputs: As with any other sector of the economy, the inputs, directly responsible for the present and future development of a nation's NIS, are labor and capital. The first relates to the sources of technology and the potential for each nation to develop NIS by itself, to acquire it from abroad or to involve private industry in this endeavor. The second reflects the state of the human component of R&D. This is accomplished by assessing:

    i. The current state of the human contribution to NIS through an analysis of each nation's R&D employment structure; and

ii. Each nation's current state of involvement in the development of future human resources (Dahlman, 1994), as consumers and developers of technology, through the level of investment in future human capabilities.

b. Moderators: Nationwide in nature, representing elements of the nation's socio-economic structure impacting the relationship between the inputs and outputs. The elements embrace the accumulated S&T capability, cultural characteristics, patterns of technological development, and size, in terms of people or economic wealth.

c. Outputs: The NIS ultimate contribution to the national economy, namely its output toward technological progress via increase in productivity. Three sets of outputs might be identified, denoted by solutions, knowledge base and productivity. Solutions consist of various types of patent counts, widely used in spite of their potential pitfalls (Pavitt, 1985), as a manifestation of relatively short-term R&D strategies aimed at "investment in solution" (Basberg, 1987). Such strategies reflect the R&D involvement of the world community in each nation, as well as national efforts in their own nation and abroad. The "knowledge base" evaluation is more long term (FMS, 1989) in nature and deals with the building of the nation's R&D knowledge base. It includes publication and citations counts, which can be used as indicators of NIS output. The third output, productivity, represents the effect of technology development strategies on the economic base of a nation. Technology efforts are expected to lead to improvements in the economy (Porter, 1990; Maital et al., 1994).

3. Data envelopment analysis

DEA, as developed by Charnes et al. (1978) and extended by Banker et al. (1984) is a technique for measuring the relative performance of decision making units (DMUs) on the basis of the observed operating practice in a sample comparable DMUs. DEA has usually been applied to analyzing the relative productive efficiency of DMUs in multiple incommensurate input variable and multiple incommensurate output variable settings (Post & Spronk, 1999).

3. 1 Data envelopment analysis models

The performance measurement of major OECD members' NIS was calculated using various DEA models in this study. These models are detailed in Appendix A. The following models and their efficiency scores for each nation were calculated.

a. Simple efficiency (Charnes et al., 1978 [CCR]; Banker et al., 1984 [BCC]) refers to efficiency scores (technical and scale efficiencies) calculated using the basic CCR and BCC models for each nation.

b. Ranked efficiency (RCCR) (Andersen and Petersen, 1993) is the efficiency score calculated by the reduced CCR model for each nation.

3. 2 Strengths and shortcoming of Data envelopment analysis

When applying the DEA technique to the performance measurement for various entities, the following methodological strengths and shortcomings were considered.

a. Strengths

i. DEA can incorporate important features related to NIS elements (e.g., Total number of researchers, number of patents and gross domestic expenditure on R&D) into its analytical framework;

ii. The NIS contribution must be evaluated using NIS multiple- objectives.

b. Shortcomings

i. DEA may often produce many efficient DMUs although we searched for a single DMU as the best performer.

DEA has become a popular technique for evaluating the relative efficiencies of DMUs within a relatively homogenous set. This study represents one of the more comprehensive DEA technique applications. Using a variety of DEA models allows for additional insight and determines the consistency of the result.

4. Performance evaluation of major OECD members' NISs

4. 1 Data collection

The data for the DEA models included both input and out factors. The input used to evaluate the performance of the NIS consisted of five factors: Gross domestic expenditure on R&D, degree of involvement in R&D by the private business sector, total number of researchers, total education expenditure as a percentage of GDP and inward direct investment flows. The outputs were comprised of the number of national patent applications, the number of patents granted by the U.S. Patent and Trademark Office, number of citations received by scientific publications, number of scientific publications, and productivity growth-trend growth in GDP per hour worked. All of these inputs and outputs are characterized and summarized in Table 1.

To consider the consistency of the nation-level data, we attempted to evaluate the performance of 23 member NISs under the OECD for 1996-1997. A good rule-of-thumb in applying DEA involves including a minimum set of data points in the evaluation set (e.g., the number of inputs multiplied by the number of outputs, Boussofiane et al., 1991) to discriminate better between efficient and inefficient units. In our study with a total of five input and five output factors, a good minimum set was 20 data points. We have 46 data points. Table 2 is composed of descriptive statistics that includes the means and standard deviations for each of the input and output factors for each of 2 years examine in this study.

4. 2 Empirical results

We conducted a major OECD members' data evaluation that included the overall average, technical and scale efficiency analysis and a brief evaluation of the nation rankings.

The CCR and BCC efficiency results are shown in Table 3. At least 19 different nations were considered technically-or scale-efficient in at least 1 of the 2 years under consideration. Seven nations were efficient for entire 2 years. The NIS performance or competitiveness was evaluated through analysis of the average efficiencies. The average efficiencies from the CCR and BCC model increased during 1996 and 1997. The differences in average CCR and BCC efficiency scores point to some varying returns to scale in the data set. That is, the relationships among the input and output values depended upon the magnitude of the data set. The A&P model results were consistent with the CCR and BCC models. The A&P model also provides the ranking scores for these nations. The slight upward trends in both percentage of efficient nations and average efficiency scores mean that the major OECD member nation NISs operations were becoming more efficient and competitive. Yet, with less than half of the nations in this sample still not obtaining an efficiency score equal to 1, there is ample room to increase their efficiency.

Table 4 represents the scale efficiency results. Nearly 73.91% of the examined nations were scale efficient, with an average scale efficiency score of 0.9160 in 1996. Nearly 86.96% were scale efficient, with an average scale efficiency score of 0.9552 in 1997. There was an upward trend in both percentage of efficient nations and average scale efficiency scores. The scale category returns for IRS, CRS and DRS were 6, 17, and 0 nations in 1996. The scores were 3, 20, and 0 nations in 1997.

Using the A&P ranking model, the most efficient nations for the two years were Finland, U.S, Ireland, Norway, and Switzerland (appearing in the top eight ranks for two years in the A&P model). The least efficient nations included Mexico, Spain, Italy, Austria, Canada, and Hungary (appearing in the bottom eight ranks for two years in the A&P model). The efficiencies (or inefficiencies) and rankings may be due to circumstances beyond the nations' S&T operations management policy.

4. 3 Discussions

If a nation were chosen as representing the paradigm for the coming shift in

NIS, that nation would be Ireland. In the 1990s the Irish, in part by joining the European Union and in part on their own, removed restrictions on trade, immigration, and commercial activity. They also invested in communications networks and telecommunications infrastructure, without dictating how that infrastructure should be used. The Irish Industrial Development Agency has introduced a maximum 12.5 % corporate tax rate for all business activities, including e-commerce, signaling a future for stable and acceptable tax rates. The Irish took advantage of the time zone difference between the U.S and Dublin. It has become the electronic hub (e-hub) for the new "Euro land." (Ohmae, 2000)

In contrast, Spain has suffered from late industrialization and companies have operated within a protected market for a long time. Spanish firms are usually small and focused on traditional sectors compared to the European companies. Spanish companies have faced a less stimulating environment with a smaller demand for goods and services with high technological content. Furthermore, only 11% of the Spanish firms were innovative. The R&D expenses of companies accounted for 0.4% of the Spanish GDP while in Europe it is about 1.2%. Only 25% of the innovative firms developed R&D activities internally. However, these firms do not usually cooperate with the public sector or other companies. The public system in Spain is very significant and constitutes the principal source of knowledge: About

80% of Spanish researchers belong to the public sector. This number falls to 50% in other European nations. Spain lags behind the rest of the European nations in innovation.

5. Conclusions

The NIS performance evaluation is important for public and private policy-makers. This paper attempted to shed light on the economic theory behind the performance of major OECD member NISs by presenting a comparative analysis based on nation-level data for 1996-1997, measured using the Data Envelopment Analysis (DEA) approach. Various DEA models provide diverse and complementary insights into evaluating the overall efficiencies and factors that may influence NIS efficiency. The results showed that the overall mean efficiencies and scale efficiencies of major OECD member NISs increased during 1996 and 1997. This confirms the notion of increasing competitiveness and improving S&T resource utilization by many nations. The most efficient nations during this two-year study were Finland, the U.S., Ireland, Norway, and Switzerland..

The DEA technique and data used in this study had a number of limitations. The first is the bias toward larger nations. Although this bias is not necessarily bad from a DEA perspective, which seeks to consider nations with more homogeneous characteristics, our generalization of the results to smaller nations must be evaluated. In addition, data variations in the input and output sample might provide varying results. The data variables selected were not exhaustive.

This paper makes a number of contributions. It provides some initial analysis on NIS performance, an economic view of NIS and identifies factors that may influence the NIS input and output. There are several areas worthy of future consideration. A nation’s social and political characteristics may impact NIS performance. Why Finland, the U.S., Ireland, Norway, and Switzerland are much more efficient, and why Mexico, Spain, Italy, Austria, Canada, and Hungary are inefficient should be discussed further. This paper proposed a technique for evaluating NIS performance. This research could be used as a guide for public and private policy-makers to conduct additional investigations into improving their S&T resource utilization.

Table 1

Input (I), Output (O) variables measuring the NIS elements

Type	Variables	Name	Descriptions	Data source
I	GERD	Gross domestic expenditure on R&D	A measure of R&D expenditures incurred within a given country during a given period	OECD, Main Science and Technology Indicators, Nov. 2001
I	BRD	Degree of involvement in R&D by the private business sector	Ratio of business-to-government expenditures on R&D	OECD, Main Science and Technology Indicators, Nov. 2001
I	TR	Total researchers (FTE)	A measure of a nation's state of involvement in R&D	OECD, Main Science and Technology Indicators, Nov. 2001
I	EDU	Total education expenditure as a percentage of GDP	A measure of the investment in a nation's human resource	UNESCO, 2001
I	IDI	Inward direct investment flows (Billions of US Dollars)	A measure of the increasing importance of foreign sources of technology in the composition of a nation's NIS	OECD, Science, Technology and Industry Scoreboard , 2001
O	NPA	National patent applications	A measure of the combined effort of the local and international community in the nation's "investment in solutions"	OECD, Main Science and Technology Indicators, 1999
O	PAUS	Patents granted in USP	A measure of the excellence and important of the innovation	TAF Special Report All Patents, All Types Jan. 1977-Dec. 2001
O	CIT	Number of citations received by scientific publications	A measure of the perceived (by others) quality of a nation's create the "knowledge base"	Institute for Scientific Information, NSIOD 1981-1999
O	PUB	Number of scientific publications	A measure of the nation's ability to create the "knowledge base"	Institute for Scientific Information, NSIOD 1981-1999
O	PRO	Productivity growth-trend growth in GDP per hour worked	A measure of the effect of technology development strategies on the economic base of a nation	OECD, Science, Technology and Industry Scoreboard, 2001

Table 2

Descriptive statistics for 23 nation samples

Type	Variables	Name	1996		1997	
			Mean	SD	Mean	SD
I	GERD	Gross domestic expenditure on R&D	20183.491	43040.600	21331.731	46153.654
I	BRD	Degree of involvement in R&D by the private business sector	1.572	0.987	1.658	0.992
I	TR	Total researchers (FTE)	121203.261	229147.571	128827.217	251581.269
I	EDU	Total education expenditure as a percentage of GDP	5.797	0.799	5.671	0.814
I	IDI	Inward direct investment flows (Billions of US Dollars)	10.139	17.527	12.287	21.891
O	NPA	National patent applications	82969.783	81050.689	97315.217	82036.984
O	PAUS	Patents granted in USP	5121.565	14889.220	5208.957	14985.301
O	CIT	Number of citations received by scientific publications	201634.348	418550.353	139230.826	279438.861
O	PUB	Number of scientific publications	29034.000	52750.731	29814.217	52122.994
O	PRO	Productivity growth-trend growth in GDP per hour worked	1.930	1.149	1.933	1.152

Table 3
DEA results

Nation [DMU]	CCR [1996]	CCR [1997]	BCC [1996]	BCC [1997]	A&P [1996]	A&P [1997]
Australia	0.1378	0.8575	**1**	0.8575	1.0001 (10)	0.8575 (18)
Austria	0.7250	0.7956	**1**	0.8005	0.7242 (19)	0.7956 (19)
Belgium	**1**	**1**	**1**	**1**	1.1435 (9)	1.1425 (10)
Canada	0.9611	0.9271	0.9611	0.9271	0.9611 (16)	0.9271 (17)
Denmark	0.8027	**1**	**1**	**1**	0.8027 (18)	1.0513 (13)
Finland	**1**	**1**	**1**	**1**	1.5481 (1)	1.5454 (3)
France	0.7242	**1**	**1**	**1**	1.1686 (8)	1.0095 (15)
Germany	0.9881	**1**	0.9881	**1**	0.9881 (12)	1.0246 (14)
Hungary	0.7091	0.7460	0.7091	0.7460	0.7091 (20)	0.7460 (20)
Italy	0.6742	0.6798	0.6742	0.6798	0.6742 (7)	0.6798 (1)
Ireland	**1**	**1**	**1**	**1**	1.1873 (21)	2.5446 (21)
Japan	0.9977	**1**	0.9977	**1**	0.9977 (11)	1.4198 (5)
Korea	0.7127	**1**	**1**	**1**	1.2614 (5)	1.2000 (9)
Mexico	0.5803	0.4496	0.5803	0.4496	0.5803 (23)	0.4996 (23)
Netherlands	**1**	0.2899	**1**	0.6726	0.9875 (13)	1.0676 (12)
New Zealand	0.9649	0.9613	**1**	0.9613	0.9649 (15)	1.2153 (6)
Norway	**1**	**1**	**1**	**1**	1.4566 (4)	1.2053 (8)
Poland	**1**	**1**	**1**	**1**	1.4827 (3)	0.6726 (22)
Spain	0.6290	0.5454	0.6290	**1**	0.6290 (22)	0.9613 (16)
Sweden	0.8247	**1**	0.8247	**1**	0.8247 (17)	1.1079 (11)
Switzerland	**1**	**1**	**1**	**1**	1.2098 (6)	1.2116 (7)
U.K	0.9845	**1**	0.9845	**1**	0.9845 (14)	1.4616 (4)
U.S	**1**	**1**	**1**	**1**	1.5122 (2)	1.6178 (2)
Average efficiency	0.8442	0.8805	0.9282	0.9171	1.0347	1.1289
Percent efficient (%)	34.7826	60.8696	60.8696	65.2174	--	--

( ): Nations' ranking under A&P model.

Table 4

Scale efficiency of major OECD member's NIS for the period 1996-1997

Nation [DMU]	Scale efficiency [1996]	Scale efficiency [1997]	RTS [1996]	RTS [1997]
Australia	0.1378	**1**	IRS	CRS
Austria	0.7250	0.9939	IRS	IRS
Belgium	**1**	**1**	CRS	CRS
Canada	**1**	**1**	CRS	CRS
Denmark	0.8027	**1**	IRS	CRS
Finland	**1**	**1**	CRS	CRS
France	0.7242	**1**	IRS	CRS
Germany	**1**	**1**	CRS	CRS
Hungary	**1**	**1**	CRS	CRS
Italy	**1**	**1**	CRS	CRS
Ireland	**1**	**1**	CRS	CRS
Japan	**1**	**1**	CRS	CRS
Korea	0.7127	**1**	IRS	CRS
Mexico	**1**	**1**	CRS	CRS
Netherlands	**1**	0.4309	CRS	IRS
New Zealand	0.9650	**1**	IRS	CRS
Norway	**1**	**1**	CRS	CRS
Poland	**1**	**1**	CRS	CRS
Spain	**1**	0.5454	CRS	IRS
Sweden	**1**	**1**	CRS	CRS
Switzerland	**1**	**1**	CRS	CRS
U.K	**1**	**1**	CRS	CRS
U.S	**1**	**1**	CRS	CRS
Average efficiency	0.9160	0.9552	--	--
Percent efficient (%)	73.91	86.96	--	--

Appendix A. Data envelopment analysis models

This section provides a review of basic DEA and some cross-efficiency and ranking extensions to the DEA models used to evaluate the performance of OECD members' NIS.

A. 1 CCR and BCC models

Productivity models were traditionally used to measure the efficiency of systems. Typically, DEA productivity models for a given DMU use ratios based on the amount of output per given set of inputs. In this case, a DMU is a nation. DEA allows for the simultaneous analysis of multiple inputs to multiple outputs, a multi-factor productivity approach. Using the notation of Doyle and Green (1994), the general efficiency measure used by DEA is best summarized by Eq. (A1).

$$E_{ks} = \frac{\sum_{y} O_{sy} \, v_{ky}}{\sum_{x} I_{sx} \, u_{kx}} \qquad \text{(A1)}$$

where E_{ks} is the efficiency or productivity measure of nation *s*, using the weights of test nation *k*; O_{sy} is the value of output *y* for nation *s*; I_{sx} is the value for input *x* of nation *s*; v_{ky} is the weight assigned to nation *k* for output *y*; and u_{kx} is the weight assigned to nation *k* for input *x*.

In the basic DEA ratio model developed by Charnes et al. (1978) (CCR model), the objective was to maximize the efficiency value for a test nation *k* from among a reference set of nation *s*, by selecting the optimal weights associated with the input and output measures. The maximum efficiencies were constrained to 1. The formulation is represented in Eq. (A2).

$$\text{Max} \qquad E_{kk} = \frac{\sum_y O_{ky}\, v_{ky}}{\sum_x I_{kx}\, u_{kx}}$$

$$\text{subject to: } E_{ks} \leq 1 \quad \forall \quad \text{Nations } s \tag{A2}$$

$$u_{ks},\ \ v_{ky} \geq 0$$

This nonlinear programming Eq. (A2) is equivalent to Eq. (A3) (Charnes et al. 1978):

$$\text{Max} \qquad E_{kk} = \sum_y O_{ky}\, v_{ky}$$

$$\text{subject to: } E_{ks} \leq 1 \quad \forall \quad \text{Nations } s \tag{A3}$$

$$\sum_x I_{kx}\, u_{kx} = 1$$

$$u_{kx},\ \ v_{ky} \geq 0$$

The transformation is completed by constraining the efficiency ratio denominator from Eq. (A2) to a value of 1, represented by the constraint $\sum_x I_{kx}\, u_{kx} = 1$. The Eq. (A3) result is an optimal simple or technical efficiency value (E^*_{kk}) that is at most equal to 1. If $E^*_{kk} = 1$, then no other nation is more efficient than nation *k* for its selected weights. That is, $E^*_{kk} = 1$ has nation *k* on the optimal frontier and is not dominated by any other nation. If $E^*_{kk} \leq 1$, then nation *k* does not lie on the optimal frontier and there is at least one other nation that is more efficient for the optimal set of weights determined by (A3). Eq. (A3) is executed *s* times, once for each nation. The first method in the analysis uses the CCR model to calculate the simple efficiency.

The dual of the CCR formulation is represented by Eq. (A4):

$$\min \quad \theta \tag{A4}$$

subject to:

$$\sum_s \lambda_s I_{sx} - \theta I_{sx} \leq 0 \quad \forall \quad \text{Inputs } I$$

$$\sum_s \lambda_s O_{sy} - O_{ky} \geq 0 \quad \forall \quad \text{Outputs } O$$

$$\lambda_s \geq 0 \quad \forall \quad \text{Nations } s$$

the CCR model has an assumption of constant returns to scale for the inputs and outputs. To take into consideration variable returns to scale, a model introduced by Banker et al. (1984) (BCC) is utilized. The BCC model aids in determining the scale efficiency of a set of units (which is a technically efficient unit for the variable returns to scale model). This new model has an additional convexity constraint defined by limiting the summation of the multiplier weights (λ) equal to 1, or:

$$\sum_s \lambda_s = 1 \tag{A5}$$

the using the CCR and BCC models together helps determine the overall technical and scale efficiencies of the airport respondents and whether the data exhibits varying returns to scale.

A. 2 A&P models

A DEA-ranking model is a variation of the CCR model proposed by Andersen and Petersen (1993). In this model, the test unit is eliminated from the constraint set. The new formulation is represented by (A6).

$$\text{Max} \quad E_{kk} = \sum_{y} O_{ky} v_{ky}$$

$$\text{subject to: } E_{ks} \le 1 \quad \forall \quad \text{Nations } s \ne k \qquad \text{(A6)}$$

$$\sum_{x} I_{kx} u_{kx} = 1$$

$$u_{kx}, \quad v_{ky} \ge 0$$

Eq. (A6), which we call the reduced CCR (RCCR) formulation, allows for technically efficient scores to be greater than 1. This result allows for a more discriminating set of scores for technically efficient units and thus can be used for ranking purposes.

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PART 2

The Innovation Policy Priorities in Industry Evolution: The Case of Taiwan's IC Industry

The Innovation Policy Priorities in Industry Evolution: The Case of Taiwan's IC Industry

Abstract: This paper explores the innovation policy priorities in industrial evolution. This issue has not been discussed in most of the literature. Taiwan has devoted considerable resources to the IC industry. Resources have been aimed at promoting research and development-based industrial activity and economic growth. This paper chose the Taiwan IC industry for an empirical study on the innovation policy priorities in industry evolution. Many of the policy tools for innovation were found different in the four phases. An 'Environment side' policy was exhibited as vital for the initial phase of industry evolution. Government involvement in the later phase of industry evolution is not necessary. However, to maintain domestic technology capacity, the government should focus its industrial development strategy onto innovation for the next generation technological R&D. 'Environment side' policy should play a vital actor once again. In the above shifting pattern, policy establishments were pulled by the industry needs for evolution.

Keywords: Innovation policy; industry evolution; policy priorities; IC industry.

1. Introduction

Schumpeter Dynamics pointed to new technology as a future omnipotent panacea. To be able to continue 'business as usual', new technology is an indispensable element that could also contribute to the self-destruction of businesses [1]. Theoretically, innovation is the engine for national technological development. However, innovation has excessively high risks and the return is uncertain. Intervention by the government is essential [2].

Public policy, in turn, provides direction and coordination to the National system of innovation [3-5]. The public role has the following aspects: it provides infrastructure in fields like education, technology transfer, incubators, and so on. It should act as a large-scale buyer of innovative products and services in the public sector (e.g., energy, traffic systems, city renewal, defense, and health care). It promotes prestigious projects like high-energy, astro-physics, manned space flight, and so on [1].

Innovation policy includes science and technology (S&T) and industry policy [2]. There are significant differences among countries, according to the individual national policy style [6]. Innovation policy research has been discussed in several nations (e.g., [2, 7-11]). The other stream involves cross-national perspectives on innovation policy (e.g., [12, 13]). Many of the determinants are more different across nations than within a nation. Government policy, legal rules, capital market conditions, factor costs, and many other attributes make these differences important.

Limited resources, coupled with seemingly unlimited demand for development, means that policies must be made regarding the allocation of scarce resources. During the past decades governments sought more ways of transparently dealing with the problem of scarcity. The public was given a role in determining priorities [14]. While the need for priority setting in the context of limited resources is not questioned, there are both theoretical and practical debates on the most appropriate ways to determine priorities. Quantitative methods such as cost-effectiveness, cost-benefit, and disease analysis burden differ in their methodologies. However, each uses what is considered relevant data (e.g., epidemiological or economic evidence) to determine priority [15].

Industry life cycle and shakeout theories provide the theoretical foundations for how an industry typically evolves from an early ‘fluid’ state into one that is highly specific and rigid [16]. It is well recognized that the magnitude and rapidity at which industry evolution can occur depends partly on the industry’s technological opportunities. In this perspective, these opportunities are themselves usually a lagged function of breakthroughs in science and technology [17]. However, industry evolution might depend on a wide range of factors besides technological development and opportunities. It also depends strongly on the interaction between education, knowledge diffusion, structural flexibility, innovation, and competition [18, 19]. For developing nations, to strengthen their global competitive advantages for industries and maintain stable economic growth for the nation, governments must develop effective innovation policies to insure sustained competitive advantage and continued economic growth. In addition to the common macroeconomic and microeconomic policies, direct government involvement in technological acquisitions and development is necessary. In this regard, there is an apparent need to explore the innovation policy priorities in each phase of industry evolution.

It is generally recognized that the public sector was a determinant in the development of

Taiwan's IC industry in creating leading innovative institutions and shaping cooperation and coordination between public research and development (R&D) centers and enterprises, resulting in a different policy demand for Taiwan. It is essential for policy makers to understand the innovation policy priorities for each phase of industry evolution. This paper chose the IC industry in Taiwan as an empirical case because it is an appropriate representative for this subject. The Taiwan IC industry performance is excellent and mature. Based on Rothwell and Zegveld's [20] framework for innovation policies, this paper proposes a model to explore innovation policy priorities using an empirical case in the evolution of Taiwan's IC industry. To facilitate exploring the innovation policy priorities for Taiwan's IC industry, published or archived data analysis (e.g., [21, 22]), questionnaire survey (e.g., [23]), and in-depth interviews (e.g., [22]) were used.

This paper is organized as follows. Section 2 summarizes the innovation policies and Industry evolution. Section 3 reviews, the Taiwan's IC industry and how the government provided incentives to promote private sector investment in the IC industry. Methodologies applicable to the proposed model will be described in Section 4. Section 5 explores the priorities for innovation policies in the evolution of Taiwan's IC industry. The conclusion is documented in Section 6.

2. Innovation policies and industry evolution

2. 1 Innovation policy

Innovation policy includes S&T and industry policy. Science policy is the most supply-side-oriented and the least direct of these policies. Technology policy is the most difficult to define because technological research varies significantly in the continuum from relatively mono-disciplinary scientific research to multidisplinary commercial innovation. S&T policy aims to enhance the basic and applied research capacities of nations, it basically supply-side oriented. The industrial policy is generally perceived as an instrument to reinforce industry competitiveness. Industry policy formation is based upon demand-side considerations [2]. However, innovation policy oriented toward appropriate new product ideas, production processes, and marketing concepts can produce, at minimum, temporary competitive advantages [24].

The search for appropriate policy tools is not easy. Macro measures are not effective; thus, proposals like a general R&D tax credit are pointless. Policies must be designed to influence particular economic sectors and activities. In this regard, the essential policy problem is to augment or redesign institutions rather than to achieve particular resource allocations [25]. A list of possible innovation policies given by Rothwell and Zegveld [20] is summarized in Table 1. The various policies are organized into three categories:

A. Supply: Provision of financial, human resource and technical assistance, including the establishment of S&T infrastructure.

B. Environment: Taxation, patent policies and regulations, such as measures that establish the legal and fiscal framework in which an industry operates.

C. Demand: Central and local government purchases and contracts, notably for innovative products, processes and services.

Through these three categories, this paper provides a model to analyze the innovation policy priorities in industry evolution.

2. 2 Industry evolution

An historical perspective is basic to understanding both the existing and future economic conditions. Not surprisingly, biological metaphors have frequently been employed in this context. Thus terms resonant with biological connotations, such as ‘life cycle’ and ‘evolution’, have become familiar in the literature of economics (see [26, 27]). The notion of an industry life cycle has been most influential and applied, in various ways, to industry evolution interpretation. This subject is reviewed in the following before considering two major weaknesses. The first weakness is a uni-directional, almost deterministic view of change that fails to acknowledge the possibility that unpredictable events can fundamentally alter the course of an industry’s development. The second weakness is an implicit assumption that private sector companies are the sole agents of economic change. This assumption is difficult

Table 1 Classification of innovation policy tools

Category	Policy tool	Descriptions
Supply side	Public enterprise	Innovation by publicly owned industries, setting up of new industries, pioneering use of new techniques by public corporations, participation in private enterprise
	Scientific and technical development	Research laboratories, support for research associations, learned societies, professional associations, research grants
	Education	General education, universities, technical education, apprenticeship schemes, continuing, and further education, retraining
	Information	Information networks and centers, libraries, advisory and consultancy services, databases, liaison services
Environment side	Financial	Grant loans, subsidies, financial sharing arrangements, provision of equipment buildings or services,, loan guarantees, export credits
	Taxation	Company, personal, indirect and payroll taxation, tax allowances
	Legal regulatory	Patents, environmental and health regulations, inspectorates, monopoly regulations
	Political	Planning, regional policies, honor or awards for innovation, encouragement of mergers of joint consortia, public consultation
Demand side	Procurement	Central or local government purchases and contracts, public corporations R&D contracts, prototype purchase
	Public services	Purchases, maintenance, supervision and innovation in health service, public building, construction, transport, telecommunications
	Commercial	Trade agreements, tariffs, currency regulations
	Overseas agent	Defense sales organizations

Source: [20]

to sustain in a world of states and blocs where international boundaries represent discontinuities between different policy environments.

In various guises in this literature shows us that in the early phases of an industry's life cycle demand is fragmented across a variety of individual product variants that are produced primarily by young firms [28-32]. In this phase there is no extraordinary comparative advantage to incumbency. Rather, there is a considerable amount of entry and exit into the industry and market uncertainty is high. Young firms are attracted by the ease of competing on novel product variants. This is what Geroski [33] refers to as technological opportunities. In the later phases, dominant product designs become established and firms that do not adhere to these tend to go bankrupt or drop out into small niche markets. Learning from incumbent firms becomes incremental and cumulative with increasing returns on economic scale, raising barriers to entry. One result is an industry 'shakeout' leading to increased market concentration and lower uncertainty [32]. Depending on the prime theoretical orientation, industry shakeout is explained as the result of either decreased entry or increased exit.

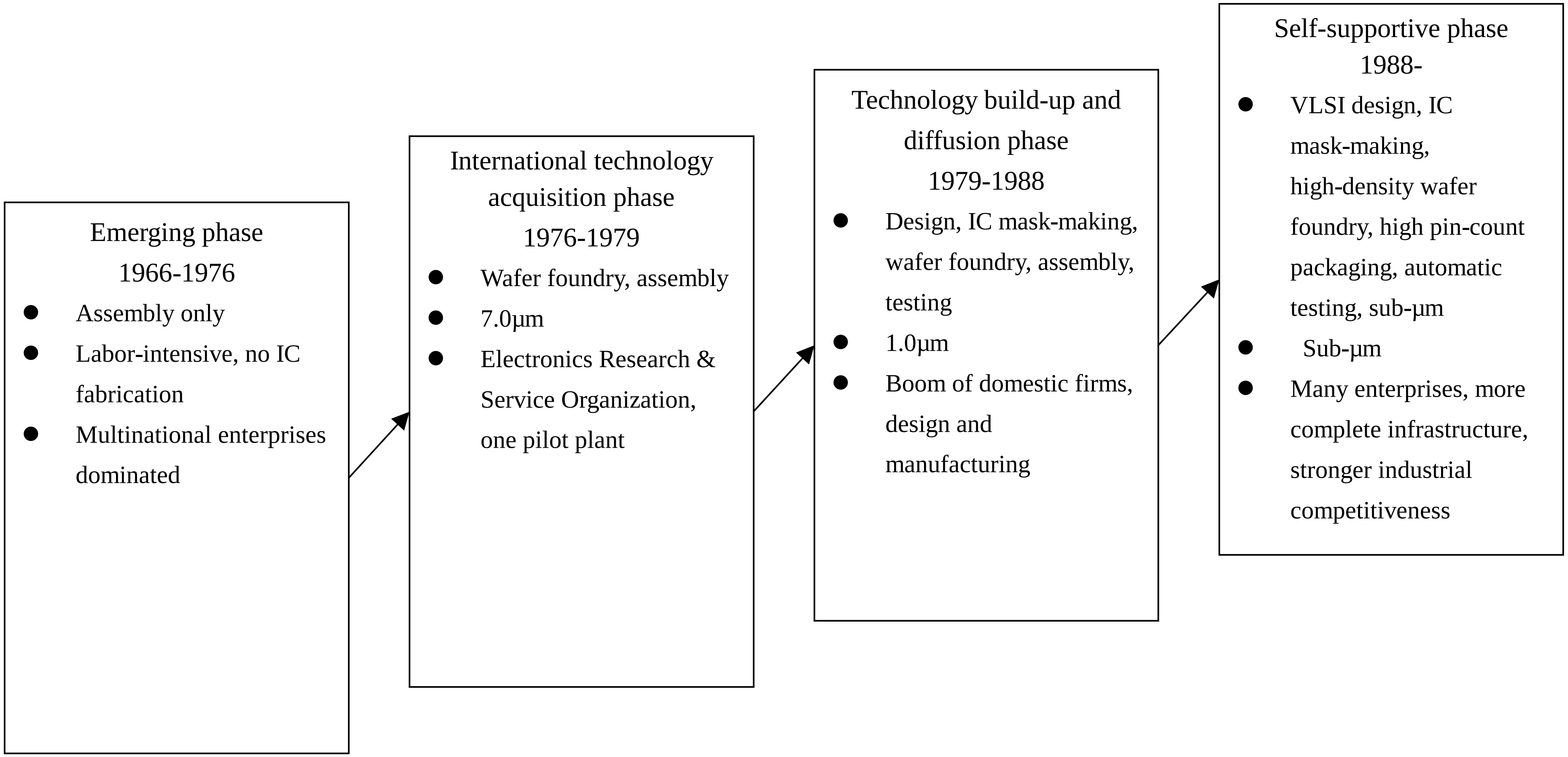
Presented here are some findings from the literature review. The determinants and conditions in each phase of industry evolution are different. The priorities for innovation policy did exist. To strengthen the competitive advantages for industries and maintain economic growth for the nation, direct (or indirect) government involvement in industry evolution is necessary. Moreover, no case involving Asian developing countries has been reported in the literature. This paper proposes a model to explore the innovation policy priorities in each phase of industry evolution using Taiwan's IC industry as the case study.

3. Taiwan's IC industry: an overview

Over the past decades, Taiwan's economy has transformed from traditional industry into a high technology industry. Although recessions have intervened, hundreds of billion dollars were invested into the development of high-tech products such as computers, multi-media, peripherals networks, and so on. Above all, with the boom in IC manufacturing, Taiwan has grown into one of the largest manufacturers in the global market. The structural evolution of the IC industry in Taiwan can be divided into four phases (see Figure 1) [34]. There are several competent actors that supported Taiwan's IC industry: the government, Industrial Technology Research Institute (ITRI), National Chaio Tung University (NCTU), National Tsing Hua University (NTHU), etc.

The foremost role played by the Taiwan government in developing its IC industry was to acquire technology from abroad and perform in-house pioneer research through a series of national research projects. A series of government funded Electronics Industry Development Projects were executed by the Electronic Research & Service Organization (ERSO). The government concentrated on technological supplies and stimulated demand by helping enterprises across the industry spectrum speed up commercialization of theses technologies to meet specific market segments. ITRI is a national-level, government-sponsored non-profit institute for applied research in Taiwan. In selecting various means for transferring enterprise technologies, ITRI took into account the status of its technologies, the requirements and the existing technological capacities of the private sector. ITRI also spun off an entire IC manufacturing operation to create several new enterprises, such as: United Microelectronics Corp (UMC), and Taiwan IC Manufacturing Co (TSMC). The government established the Hsinchu Science-based Industrial Park (HSIP) in 1980, to engage in building a brand new high-tech industry and upgrade current industrial technologies. HSIP is entirely government oriented, for instance, developed on public land with infrastructure facilities; efficiently supported one stop service; automated customs services, on-job training; domestic, and international network; investment incentives and benefits [35]; etc. NCTU and NTHU are both advanced academic institutes in Taiwan,

Figure 1 The structural evolution of the IC industry in Taiwan



Source:[34]

especially in electronics and information. They furnish this industry with talent enforcement activities, high quality human resource and research and development support. Through these efforts, Taiwan's overall IC production was valued at $17.4 billion in 2002. In 2001, there were more than 100 design enterprises in Taiwan. There are 20 firms producing wafers, over 40 enterprises involved in packaging and some 30 enterprises devoted to testing. The clustering phenomenon has occurred at HSIP.

4. Remarks on methodologies

Based on Rothwell and Zegveld's [20] framework for innovation policies, this paper proposes a model for innovation policy priorities in the evolution of Taiwan's IC industry (see Table 1). This framework is helpful to illustrate and explain the innovation policy priorities in industry evolution. With this framework important priorities can be observed and evaluated.

To facilitate exploring innovation policy priorities using an empirical case in the evolution of Taiwan's IC industry, several methodologies will be introduced. Data analysis of the published or archived data is widely utilized in the literature as an objective method for corroborating proposed models and hypotheses (e.g., [21-22]). The questionnaire survey is a multi-purposed approach capable of measuring either substantial or intangible indicators (e.g., [23]). The in-depth interview is a judgment-based approach that can help researchers to know the holistic system and the insider's operations, which are important for identifying critical drivers and interrelationships (e.g., [22]).

5. Exploring the innovation policy priorities in the evolution of Taiwan's IC industry

5. 1 Sample and questionnaire

A questionnaire survey study was selected to provide information about the 12 tools used in the three types of policies (see Table 1) in Rothwell and Zegveld's [20] framework. This information was used to explain the innovation policy priorities in the evolution of Taiwan's IC industry. Stakeholders in this industry were asked to describe their perceptions of the 12 tools in three types of policies and how they impact on Taiwan's IC industry using a 5-level scale (1 = significant negative effect, 2 = negative effect, 3 = no effect, 4 = positive effect, 5 = significant positive effect). Of 200 questionnaires sent out, 81 valid returns were collected calls, as 40.5% valid return rate. In this survey, the majority of the respondents were managers at foreign-owned enterprises, locally owned enterprises, R&D institutions, academic institutions, and local government officials in Taiwan. Of 81 valid questionnaires, 46 were from enterprises, 21 were from R&D institutions, 8 were from academic institutions, and 6 were from government officials. The descriptive statistics are shown in Table 2.

Table 2 Descriptive statistics for replies

Category	Policy tool	Phase			
		1.	2.	3.	4.
Supply side [a]		3.657 (0.972) [b]	3.241 (0.976)	3.500 (0.902)	3.194 (0.808)
	Public enterprise	2.691 (0.768)	2.568 (0.907)	2.679 (0.849)	2.766 (0.763)
	Scientific and technical	3.975	2.519	3.864	3.370

	development	(0.632)	(0.823)	(0.770)	(0.679)
	Education	4.309	4.222	3.802	3.617
		(0.861)	(0.880)	(0.660)	(0.663)
	Information	3.654	3.580	3.728	3.025
		(0.777)	(0.739)	(0.689)	(0.851)
Environment side		4.071	3.707	3.444	3.383
		(0.702)	(0.864)	(0.904)	(0.764)
	Financial	4.383	3.963	4.222	3.531
		(0.624)	(0.697)	(0.570)	(0.709)
	Taxation	4.099	3.642	3.309	3.358
		(0.644)	(0.926)	(0.903)	(0.841)
	Legal regulatory	3.926	3.260	3.333	3.222
		(0.721)	(0.833)	(0.822)	(0.775)
	Political	3.877	3.963	2.914	3.420
		(0.714)	(0.798)	(0.745)	(0.705)
Demand side		2.873	2.991	2.812	2.380
		(0.991)	(0.927)	(0.979)	(0.822)
	Procurement	2.321	2.518	2.331	2.346
		(0.834)	(0.792)	(0.812)	(0.727)
	Public services	3.815	3.901	3.383	2.370
		(0.937)	(0.889)	(0.874)	(0.843)
	Commercial	3.037	3.099	3.062	2.802
		(0.954)	(0.846)	(0.827)	(0.797)
	Overseas agent	2.321	2.506	2.506	2.000
		(0.819)	(0.882)	(0.882)	(0.725)

Note: [a] In each questionnaire, the grades of the policy tools in one category are averaged into the category's grade.

[b] The number in the bracket is the standard deviation.

5. 2 Empirical results

After the questionnaire collection was completed in April 2003, this paper used one-way ANOVA (parametric method) and the Kruskal-Wallis (K-W) test (nonparametric method) to examine the four phases exhibited the 12 policy tools. The results are shown in Table 3. Using one-way ANOVA and the K-W test, the means and medians [36] were significantly different for 9 policy tools for the four phases at the 0.05 significance level.

Table 3 ANOVA and Kruskal-Wallis test results for 12 policies for the four phases.

	Significance levels of ANOVA [b]	Significance levels of K-W test [b]
A. Supply side [a]	0.000	0.000
A. 1. Public enterprise	0.499	0.443
A. 2. Scientific and technical development	0.000	0..000
A. 3. Education	0.000	0.000
A. 4. Information	0.000	0.000
B. Environment side	0.000	0.000
B. 1. Financial	0.000	0.000
B. 2. Taxation	0.000	0.000

B. 3. Legal regulatory	0.000	0.000
B. 4. Political	0.000	0.000
C. Demand side	0.000	0.000
C. 1. Procurement	0.327	0.545
C. 2. Public services	0.000	0.000
C. 3. Commercial	0.267	0.136
C. 4 Overseas agent	0.000	0.000

Note: [a] In each questionnaire, the grades of the policy tools in one category are averaged into the category's grade.
[b] The difference is significant at the 0.05 level.

Pairwise comparisons were used to determine the priority for the four phases on the 12 policy tools (see Table A. 1). It was indicated that phases 1 and 3 were significantly superior to phases 4 and 2 for 'Scientific and technological development'. Phases 1 and 2 were significantly superior to phases 3 and 4 for 'Education'. The priority for the four phases for 'Financial' was ranked phase 1, phase 3, phase 2, and phase 4. However, phases 1, 3 and phases 3 and 2 were not significantly different. Both 'Taxation' and 'Legal regulatory' might be given precedence in phase 1 over the other phases. The priority for the four phases for 'Political' was ranked phase 2, phase 1, phase 4, and phase 3. However, phases 2 and 1 were not significantly different. The priority for the four phases for 'Public services' were ranked phase 2, phase 1, phase 3, and phase 4. However, phases 2 and 1 were not significantly different.

The Tukey multiple comparisons test was applied to produce a ranking to indicate the sequence for the three categories for the four phases, respectively (see Table 4-7). The priority for the three category effects on phases 1, 2, and 4 were ranked as 'Environment side', 'Supply side', and 'Demand side'. The priority for the three category effects on phase 3 were ranked as ‘Supply side’, ‘Environment side’, and ‘Demand side’. However, ‘Supply side’ and ‘Environment side’ were not significantly different.

Table 4 Results of Tukey test for Phase 1 in three categories

i-variable	j-variable	Mean difference (i-j)	Significance levels of ANOVA [b]	Multiple comparisons [c]
A [a]	B	-0.414	0.000	(B, A)
	C	0.784	0.000	(A, C)
B	A	0.414	0.000	(B, A)
	C	1.198	0.000	(B, C)
C	A	-0.784	0.000	(A, C)
	B	-1.198	0.000	(B, C)

Note: [a] A: Supply side; B: Environment side; C: Demand side.
[b] The difference is significant at the 0.05 level.
[c] (A, B) means that Supply side has significantly higher grade than Environment side at 0.05 significant level.

Table 5 Results of Tukey test for Phase 2 in three categories

i-variable	j-variable	Mean difference (i-j)	Significance levels of ANOVA [b]	Multiple comparisons [c]
A [a]	B	-0.485	0.000	(B, A)
	C	0.216	0.019	(A, C)
B	A	0.485	0.000	(B, A)
	C	0.701	0.000	(B, C)
C	A	-0.216	0.019	(A, C)
	B	-0.701	0.000	(B, C)

Note: [a] A: Supply side; B: Environment side; C: Demand side.
[b] The difference is significant at the 0.05 level.
[c] (A, B) means that Supply side has significantly higher grade than Environment side at 0.05 significant level.

Table 6 Results of Tukey test for Phase 3 in three categories

i-variable	j-variable	Mean difference (i-j)	Significance levels of ANOVA [b]	Multiple comparisons [c]
A [a]	B	0.001	0.617	
	C	0.701	0.000	(A, C)
B	A	-0.001	0.617	
	C	0.627	0.000	(B, C)
C	A	-0.701	0.000	(A, C)
	B	-0.627	0.000	(B, C)

Note: [a] A: Supply side; B: Environment side; C: Demand side.
[b] The difference is significant at the 0.05 level.
[c] (A, B) means that Supply side has significantly higher grade than Environment side at 0.05 significant level.

Table 7 Results of Tukey test for Phase 4 in three categories

i-variable	j-variable	Mean difference (i-j)	Significance levels of ANOVA [b]	Multiple comparisons [c]
A [a]	B	-0.188	0.012	(B, A)
	C	0.815	0.000	(A, C)
B	A	0.188	0.012	(B, A)
	C	1.003	0.000	(B, C)
C	A	-0.815	0.000	(A, C)
	B	-1.003	0.000	(B, C)

Note: [a] A: Supply side; B: Environment side; C: Demand side.
[b] The difference is significant at the 0.05 level.
[c] (A, B) means that Supply side has significantly higher grade than Environment side at 0.05 significant level.

5. 3 Discussions

Through a series of analyses, the innovation policy priorities in the evolution of Taiwan's IC industry could be discussed using the four phases.

A. Emerging phase

An 'Environment side' policy is vital for the emerging industry evolution phase. The government also focused on 'Scientific and technical development' and 'Education'. Taiwan's IC industry began in 1966 when General Instrument Microelectronics established a IC packaging business in Taiwan. Later, multinational corporations such as Philips, Texas Instruments, and RCA started packaging operations. Fewer domestic firms entered this field. All were labor intensive. In this phase, Taiwan had only IC assembly technology capability. This was in accordance with cost-driven and export-oriented goals. To strengthen domestic technological capacity, NCTU opened a IC laboratory to foster advanced technology development and high quality human resources in this field. An 'Environment side' policy is vital for the initial industry evolution phase. There is no extraordinary comparative advantage to incumbency. Rather, there is a considerable amount of entry and exit into the industry and market uncertainty is high. To attract more domestic participation in this industry the government initiated several policies (e.g., export credits, subsidies, and tax allowances) for it.

B. International technology acquisition phase

The priority for the three category effects on this phase were ranked as 'Environment side', 'Supply side', and 'Demand side'. 'Political', 'Public service', and 'Education' were executed seriously in this phase. The integrated circuit (IC) was introduced in the late 1950s by Texas Instruments. Their small size, low power consumption, rapid operating speed and reliability led to dramatic changes in the market. To take advantage of this transition, the Taiwan government opted to develop IC design and manufacturing technology to breed the related industries. However, the fast development of IC technology in leading countries lead to a technology gap that made it difficult for Taiwan to independently develop commercialized IC technology. First, the private sector in Taiwan was too weak to afford the large, risky investment in R&D. Second, the private firms, basically cost-driven, were unwilling to invest in long-term R&D. They preferred to invest in areas with immediate returns regardless if the area was technology or labor intensive. Finally, acquiring technology from abroad and in-house pioneer research required hundreds of professionals, experienced engineers and scientists with intensive training. International technology acquisition strategies were therefore initiated to reinforce domestic R&D competence. ITRI was charged with acquiring generic technology and disseminating it to domestic firms. NCTU and NTHU also furnished this industry with talent enforcement activities, high quality human resource and R&D support.

The government decided to establish an industrial park entirely devoted to high-tech industries, the Hsinchu Science-based Industrial Park (HSIP). HSIP was given infrastructure, back-up services and the intellectual climate for R&D. HSIP was the first high-tech industry development center in Taiwan.

C. Technology build-up and diffusion phase

A ‘Supply side’ policy is vital for this phase. During this phase, ITRI’s technology advanced from 7.0 μm to 3.5μm. Photo mask production equipment setup was completed in 1981. After this, ITRI began to supply masks to domestic IC firms and to its own pilot plant. This greatly reduced the time needed to introduce new products. At the same time, ITRI continued to develop photolithography to complement its high-density process. Very Large Scale Integration (VLSI) Technology Development Project also took place between 1983 and 1988. The IC pilot plant was upgraded into a VLSI model plant. In this phase, the authority adopted technology diffusion strategies to develop a domestic IC industry. In 1980, ITRI spun off an entire IC manufacturing operation to establish a new firm, UMC. This was the first private IC manufacturer in Taiwan. In 1987, TSMC, with capital from the government, private investors and Philips Inc., was established to provide design houses with IC foundry services. The establishment of TSMC allowed huge investments in manufacturing facilities. This policy stimulated rapid growth in the number of independent design firms in Taiwan. In this phase, ITRI also sent personnel to private firms as consultants, transferred entire departments to private companies, spun off research groups to establish new firms and implicitly encouraged personnel shifts.

This was complemented by the innovative capacity of firms to absorb and adapt these technologies and apply them in a productive way with significantly lower costs. The government concentrated on ‘Supply’ of technologies and stimulated ‘Demand’ by helping firms across the industry spectrum to speed up the commercialization of these technologies to meet specific market segments [37].

D. Self-supportive phase

The priority for the three category effects on this phase were ranked ‘Environment side’, ‘Supply side’, and ‘Demand side’. However, the innovation policy priorities were not significant. This exhibited that government involvement in the later phase of industry evolution is not necessary. This leads to increased market concentration and lower uncertainty.

However, with the present severe competition in the global IC industry, product life cycles have been severely shortened, profit margins are extremely low and huge investments are required in R&D and advanced production facilities. Taiwan must actively nurture the technological and innovative capabilities of its engineers and skilled professionals. To keep strengthening the national competitive advantages in the global market, the government might maintain traditional technology acquisition and pioneer research and coordinate cooperative research and strategic alliances. Strenuous efforts should be made to elevate domestic technology capacity and to encourage cross-licensing. Consequently, the government should focus its industrial development strategy onto innovation for the next generation technological R&D. This is the reason that 'Environment side' policy plays a vital actor once again.

6. Conclusions

This paper chose Taiwan's IC industry for an empirical study to explore the innovation policy priorities in each phase of industry evolution. This paper proposed a model for analyzing this theme. An analysis series was used to facilitate exploring innovation policy priorities in industry evolution. Related improvement recommendations were made for the authorities in Taiwan.

There were many coincidences between the findings by this paper and the actual situation. The innovation policy priorities in each phases of industry evolution were confirmed. The determinants and conditions in each phase of industry evolution make the differences important. This study exhibited that ‘Environment side’ policy is vital for the initial phase of industry evolution. A considerable amount of entry and exit occurs into the industry and market uncertainty is high. Government involvement in the later phase of industry evolution is not necessary. This phase has increased market concentration and lower uncertainty. However, the government might maintain domestic technology capacity; the government should focus its industrial development strategy onto innovation for the next generation technological R&D. ‘Environment side’ policy should play a vital actor once again. This case study contributes to the literature on the innovation policy priorities in industry evolution by providing a practical case from Asian developing countries, previously neglected in the literature.

Based on these findings, policies might be made regarding the allocation of scarce resources. From the above pattern shifting, policy establishments were pulled by the needs for industry evolution. Moreover, a lesson is provided for those countries that want to speed up the pace of industrialization and shorten the lag behind industry leaders.

Acknowledgements

The authors gratefully acknowledge the support received from Ya-Ju Shih and Peng-Ting Chen at the Institute of Management of Technology at National Chiao Tung University, Fu-Ching Yang at the Taiwan IC Manufacturing Company, Chih-Peng Liu at the Winbond Electronics Corporation, and Hsin-Jou Chiu at the AU Optronics Corporation.

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35 Investment incentives and benefits are: tax incentives, protection of investors’ rights, government’s participation in investment, capitalization of technical expertise, capital raising, low-interest loan and R&D encouragement.

36 The K-W test is a nonparametric test for the null hypothesis that *k* samples from possibly different populations actually originate from similar populations, at least as far as their central tendencies, or medians, are concerned. The test assumes that the variables under consideration have underlying continuous distributions.

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Table A. 1 Results of pairwise test for four phases

	i-variable	j-variable [a]	Mean difference (i-j)	Significance levels of ANOVA [b]	Multiple comparisons [c]
A. 1. Public enterprise	1	2	0.124	0.741	
		3	0.001	0.924	
		4	-0.001	0.924	
	2	1	-0.124	0.741	
		3	-0.111	0.722	
		4	-0.198	0.769	
	3	1	-0.001	0.924	
		2	0.111	0.722	
		4	-0.001	0.924	
	4	1	0.001	0.924	
		2	0.198	0.769	
		3	0.001	0.924	
A. 2. Scientific and technical development	1	2	1.457	0.000	(1, 2)
		3	0.111	0.722	
		4	0.605	0.000	(1, 4)
	2	1	-1.457	0.000	(1, 2)
		3	-1.346	0.000	(3, 2)
		4	-0.852	0.000	(4, 2)
	3	1	-0.111	0.722	
		2	1.346	0.000	(3, 2)
		4	0.494	0.000	(3, 4)
	4	1	-0.605	0.000	(1, 4)
		2	0.852	0.000	(4, 2)
		3	-0.494	0.000	(3, 4)
A. 3. Education	1	2	0.001	0.924	
		3	0.506	0.000	(1, 3)
		4	0.691	0.000	(1, 4)
	2	1	-0.001	0.924	
		3	0.420	0.004	(2, 3)
		4	0.605	0.000	(2, 4)
	3	1	-0.506	0.000	(1, 3)
		2	-0.420	0.004	(2, 3)
		4	0.185	0.770	
	4	1	-0.691	0.000	(1, 4)
		2	-0.605	0.000	(2, 4)
		3	-0.185	0.770	
A. 4. Information	1	2	0.000	0.999	
		3	0.000	0.999	(1, 4)
		4	0.630	0.000	
	2	1	0.000	0.999	
		3	0.000	0.999	
		4	0.630	0.000	(2, 4)
	3	1	0.000	0.999	
		2	0.000	0.999	
		4	0.630	0.000	(3, 4)
	4	1	-0.630	0.000	(1, 4)
		2	-0.630	0.000	(2, 4)
		3	-0.630	0.000	(3, 4)

Table A. 1 Results of pairwise test for four industrial clusters (Cont'd)

	i-variable	j-variable [a]	Mean difference (i-j)	Significance levels of ANOVA [b]	Multiple comparisons [c]
B. 1. Financial	1	2	0.420	0.000	(1, 2)
		3	0.161	0.711	
		4	0.852	0.000	(1, 4)
	2	1	-0.420	0.000	(1, 2)
		3	-0.259	0.072	
		4	0.432	0.000	(2, 4)
	3	1	-0.161	0.711	
		2	0.259	0.072	
		4	0.691	0.000	(3, 4)
	4	1	-0.852	0.000	(1, 4)
		2	-0.432	0.000	(2, 4)
		3	-0.691	0.000	(3, 4)
B. 2. Taxation	1	2	0.457	0.003	(1, 2)
		3	0.790	0.000	(1, 3)
		4	0.741	0.000	(1, 4)
	2	1	-0.457	0.003	(1, 2)
		3	0.333	0.070	
		4	0.284	0.189	
	3	1	-0.790	0.000	(1, 3)
		2	-0.333	0.070	
		4	-0.001	0.924	
	4	1	-0.741	0.000	(1, 4)
		2	-0.284	0.189	
		3	0.001	0.924	
B. 3. Legal regulatory	1	2	0.667	0.000	(1, 2)
		3	0.593	0.000	(1, 3)
		4	0.704	0.000	(1, 4)
	2	1	-0.667	0.000	(1, 2)
		3	-0.001	0.924	
		4	0.001	0.924	
	3	1	-0.593	0.000	(1, 3)
		2	0.001	0.924	
		4	0.111	0.722	
	4	1	-0.704	0.000	(1, 4)
		2	-0.001	0.924	
		3	-0.111	0.722	
B. 4. Political	1	2	-0.001	0.924	
		3	0.963	0.000	(1, 3)
		4	0.457	0.001	(1, 4)
	2	1	0.001	0.924	
		3	1.050	0.000	(2, 3)
		4	0.543	0.000	(2, 4)
	3	1	-0.963	0.000	(1, 3)
		2	-1.050	0.000	(2, 3)
		4	-0.506	0.000	(4, 3)
	4	1	-0.457	0.001	(1, 4)
		2	-0.543	0.000	(2, 4)
		3	0.506	0.000	(4, 3)

Table A. 1 Results of pairwise test for four industrial clusters (Cont'd)

	i-variable	j-variable [a]	Mean difference (i-j)	Significance levels of ANOVA [b]	Multiple comparisons [c]
C. 1. Procurement	1	2	-0.198	0.697	
		3	0.000	0.999	
		4	-0.001	0.924	
	2	1	0.198	0.697	
		3	0.198	0.697	
		4	0.173	0.709	
	3	1	0.000	0.999	
		2	-0.198	0.697	
		4	-0.001	0.924	
	4	1	0.001	0.924	
		2	-0.173	0.709	
		3	0.001	0.924	
C. 2. Public services	1	2	-0.001	0.924	
		3	0.432	0.013	(1, 3)
		4	1.444	0.000	(1, 4)
	2	1	0.001	0.924	
		3	0.519	0.001	(2, 3)
		4	1.531	0.000	(2, 4)
	3	1	-0.432	0.013	(1, 3)
		2	-0.519	0.001	(2, 3)
		4	1.012	0.000	(3, 4)
	4	1	-1.444	0.000	(1, 4)
		2	-1.531	0.000	(1, 2)
		3	-1.012	0.000	(1, 3)
C. 3. Commercial	1	2	0.000	0.999	
		3	0.000	0.999	
		4	0.235	0.629	
	2	1	0.000	0.999	
		3	0.000	0.999	
		4	0.235	0.629	
	3	1	0.000	0.999	
		2	0.000	0.999	
		4	0.235	0.629	
	4	1	-0.235	0.629	
		2	-0.235	0.629	
		3	-0.235	0.629	
C. 4. Overseas agent	1	2	-0.185	0.938	
		3	-0.185	0.938	
		4	0.321	0.086	
	2	1	0.185	0.938	
		3	0.000	0.999	
		4	0.506	0.001	(2, 4)
	3	1	0.185	0.938	
		2	0.000	0.999	
		4	0.506	0.001	(3, 4)
	4	1	-0.321	0.086	
		2	-0.506	0.001	(2, 4)
		3	-0.506	0.001	(3, 4)

Note: [a] 1: Phase 1; 2: Phase 2; 3: Phase 3; 4: Phase 4.
[b] The mean difference is significant at the 0.05 level.
[c] (1, 2) means that Phase 1 has significantly higher grade than Phase 2 at 0.05 significant level.

PART 3

Fuzzy Integral MCDM Approach for Evaluating the Effects of Innovation Policies: The Case of IC Design Industry in Taiwan

Fuzzy Integral MCDM Approach for Evaluating the Effects of Innovation Policies: The Case of IC Design Industry in Taiwan

Abstract: The aim of this paper is to develop a 'technological system' based on framework for formulating and evaluating the effects of innovation policies. Policy makers usually face fuzzy decision scenarios. Traditional decision making methods fail to satisfy policy makers' needs in this regard. A hierarchical fuzzy integral multi-criteria decision-making (Fuzzy integral MCDM) approach for evaluating the effects of innovation policies is proposed in this paper. To show the practicality and usefulness of this approach, the case on Taiwan integrated circuit (IC) design industry is demonstrated. The results show that single policy might be executed with other policy tools to achieve multiplicative effects. Moreover, 'political' policy tool is the most effective one. This demonstration also shows that the proposed model is valid.

***Keywords**: Technological system; Innovation policy; Fuzzy integral Multi-criteria decision making (MCDM); Taiwan IC design industry.*

1. Introduction

Schumpeter Dynamics pointed to new technology as a future omnipotent panacea. To be able to continue 'business as usual', new technology is an indispensable element that could also contribute to the self-destruction of businesses (Krupp, 1995). Theoretically, innovation is the engine for national technological development. However, innovation has excessively high risks and the return is uncertain. Intervention by the government is essential (Shyu and Chiu, 2002).

Public policy, in turn, provides direction and coordination to the national system of innovation (Freeman and Soete, 1997; Galli and Teubal, 1997; Nelson, 1993). The public role has the following aspects: it provides infrastructure in fields like education, technology transfer, incubators and son on. It should act as a large-scale buyer of innovative products and services in the public sector (e.g., energy, traffic systems, city renewal, defense and health care). It promotes prestigious projects like high-energy and astro-physics, manned space flight and so on (Krupp, 1995).

In industrial technological development the main performer is industry. The strategy for developing technology might be divided into in-house development, technological cooperation (with academia, inter-industry, or research institutes, for example), and technology transfer. The role that government plays is as the sponsor to build better infrastructure to facilitate industrial research and development (R&D) activities.

Limited resources, coupled with seemingly unlimited demand for development, means that policies must be made regarding the allocation of scarce resources. During the past decades governments sought more ways of transparently dealing with the problem of scarcity.

The public was given a role in determining priorities (Tisdell, 1981). While the need for priority setting in the context of limited resources is not questioned, there are both theoretical and practical debates on the most appropriate ways to determine priorities. Quantitative methods such as cost-effectiveness, cost-benefit and disease analysis burden differ in their methodologies. However, each uses what is considered relevant data (e.g., epidemiological or economic evidence) to determine priority (Reichenbach, 2002). The significance of evaluating the effects of policies is therefore rising.

The Taiwan integrated circuit (IC) design industry began in 1973 when IC technology was first introduced. The IC industry hit the growth stage in 1990. This industry benefited from certain critical developments: policy oriented projects for introducing RCAs and sub-micron technology to develop basic knowledge. A Common Design Center architecture for setting up a knowledge sharing mechanism between the industrial sector and research units. In July 1983, the National Science Council (NSC) teamed up with the Ministry of Education, the Industrial Technology Research Institute (ITRI), and nine universities to implement the Multi-Project Chip program and establish the Chip Implementation Center in 1993 for manpower training. Foundry establishment that combines the existing design, packaging and testing industries into a vertically integrated system, together with flourishing information technology industries that give a better edge in terms of production cost and market flexibility. The Hsinchu Science-Based Industrial Park’s support and attraction for IC ventures helped to form an effective cooperation network. In 1999, 127 IC design companies mushroomed to amass NT$74.2 billion in total revenue, second only to the United States. Entering the 21st century, the global IC industry will open up the third industrial revolution under the driving force of 3C (computer, consumer electronics and communication) applications and SOC (system on a chip) technology. The last 5 years have seen the impact of this budding SOC technology. New business models are evolving out of the old professional designers: silicon intellectual property providers, design foundries, design service providers and system design integrators. All governmental, industrial and academic segments have coordinated trying to promote the establishment of R&D teams to form business units for implementing 3C integration programs. Policy makers should realize what policies should be executed to create a favorable industrial environment.

It is generally recognized that the public sector was a determinant in the development of Taiwan's IC design industry in creating leading innovative institutions and shaping cooperation and coordination between public research and development R&D centers and enterprises, resulting in a different policy demand for Taiwan. Because of the limited resources and coupled with seemingly unlimited demand for development, it is essential for policy makers to understand the innovation policy effects for industry. This paper chose the IC design industry in Taiwan as a case because it is an appropriate representative for this subject. The Taiwan IC design industry performance is excellent. This paper attempts to develop a ‘technological system’ based on framework for formulating and evaluating the effects of innovation policies (Rothwell and Zegveld, 1981) for IC design industry in Taiwan. A hierarchical fuzzy integral multi-criteria decision-making (Fuzzy integral MCDM) approach is proposed. To show the practicality of this model, an illustrative case was taken as a verifiable approach.

This paper is organized as follows. Section 2 describes, in detail, the technological system and the elements of innovation policies. Hierarchical analytic process and evaluation methods are presented in Section 3. Section 4 applies the proposed Fuzzy integral MCDM for evaluating the effects of innovation policies in the Taiwan IC design industry. Discussions and conclusions are documented in Section 5.

2. Technological System and Innovation Policies

2. 1 The notion of the technological system

In the past, classical economists considered technology as the external variable in the macroeconomic growth of a nation. To this extent, the connection between technological change and economic growth has been rarely analyzed and less known. Carlsson and Stankiewiez (1991) believed that the growth of a national economy could not be effectively explained by ignoring the role of technology in economic growth. According to their historical analysis, technological innovation plays an important role in national economic growth (Autio and Hameri, 1995). The national innovative performances derive from the confluence of particular institutional, social and cultural characteristics. In this regard, two concepts have been developed: the national system of innovation (Lundvall, 1992; Nelson, 1993) and the technological system (Antonelli and De Liso, 1993).

The latter (which is used in this paper) can be defined as a network formed through the interaction of many agencies in specific technical fields. This interaction produces, expands and uses such technology. This network ranges from businesses, R&D infrastructure, educational agencies, to policy-making bodies. The system focuses mainly on the circulation of knowledge and competence, instead of products or services. As the technological system is regarded as an intermediate structure that connects the knowledge-based department and the businesses within it, the quality of which causes the opportunity for using initiative technology to vary considerably. According to Carlsson and Stankiewiez (1995), two hypotheses on technological systems were stated:

A. The analysis conducted on a system basis rather than the individual unit in the system, emphasizing the interactive and interdependent relationship between agencies within the system. The system function focuses on technical acquisition, spillover, strengthening and scattering.

B. The technological system is dynamic not static. Because the roles of each unit that form the system change, therefore, the dynamic viewpoint is introduced to effectively draw the facts.

There are four constituents in a general analysis of a technological system.

A. The nature of the knowledge and spillover mechanisms

The nature of the knowledge involved in any technical field determines the likelihood for spillover and the spillover mechanisms. Suppose that the nature of the knowledge in a certain technical field is tacit. That knowledge will be transferred through the teaching and guidance of instructors. Therefore, high competence is required in the person that actually receives this knowledge. In the case when the nature of the knowledge is explicit, that knowledge may be transferred through reading. Knowledge is easier to obtain through reading. If the important knowledge is stored in individual units in the system instead of structurally stored in the system, more and diverse media for knowledge transmission is required and the average competence of the receiver must match the embodied knowledge.

B. Receiver Competence

Receiver competence means the ability to select, develop and receive the global technological portfolio that represents the Prime Mover of technological development and the acceptance of certain agencies or firms in the global technological chains within certain agencies or firms. Generally, higher competence in these agencies or firms is required and must be achieved through investment in R&D. With such activities undertaken, these agencies or firms may upgrade their competence and generate the spillover effect within that industry at a certain level. The issues on who is involved first in technological development, the roles that the agencies within the system play in the technological development and receiving, and technology policy process must be considered when analyzing receiver competence.

C. Connectivity

Technology or related knowledge spillover normally depends on the connectivity between the agencies within the system. The denser and greater the connectivity in the technological system, the better the obtained technological spillover.

Overlapping and diversified connectivity exists within each system. In general, three types of connectivity exists:

i. The connection between consumers and suppliers;

ii. The technical issue and answer connectivity;

iii. The non-official connectivity between various bodies.

The participants, public and regional connectivity characteristics are normally involved in a technological system.

D. Pluralistically Innovative Mechanisms

The vitality of a technological system relies on the number of competitors and the challenges entailed. If the similarity in products or services supplied by competitors in the industry is higher and the resistance to change is stronger, the makers might continue to invest in the existing business until the business profits fade away. Under such circumstances, the number of competitors in the industry will decrease due to lessening profits, resulting in lowering the opportunity to develop a global technological portfolio. It is essential to create a pluralistic mechanism to prevent technological system from collapsing. The most important issue is to review the degree of closed or openness in the technological system, the vision of the members within the system, the influence from past experiences, the encouragement resulting from new competitor, and the roles that agencies and technological policies play.

A technological system refers to a hierarchical, multidimensional network of public and private institutions interacting nonlinearly in a given historical context. The result is the creation of economic growth as a consequence of the dynamic interaction between different sub-systems. All governmental, industrial and academic segments have coordinated to promote the establishment of Taiwan's IC design industry in creating leading innovative institutions and shaping cooperation and coordination between public research and development R&D centers and enterprises. The technological system is appropriate for building a hierarchical system for evaluating the effects of innovation policies in Taiwan IC design industry.

2. 2 Innovation policies

Science, technology and innovation policies (in the narrow sense) are specific parts of what could be labeled more broadly as 'innovation policies'. Science policy is the most supply-side-oriented and the least direct of these policies. Technology policy is the most difficult to define because technological research varies significantly in the continuum from relatively mono-disciplinary scientific research to multi-disciplinary commercial innovation. However, innovation policy, oriented toward appropriate new product ideas, production processes, and marketing concepts, can produce, at minimum, temporary competitive advantages (Jacobs, 1998).

The search for appropriate policy tools is not easy. Macro measures are not effective; thus, proposals like a general R&D tax credit are pointless. Policies must be designed to influence particular economic sectors and activities. In this regard, the key policy problem is to augment or redesign institutions rather than to achieve particular resource allocations (Nelson and Winter, 1977). A list of possible innovation policies given by Rothwell and Zegveld (1981) is summarized in Table I. The various policies are organized into three categories: supply, environment and demand.

A. Supply: Financial, human resources and technical assistance provisions including the establishment of an S&T infrastructure.

B. Environment: Taxation, patent policies and regulations, such as measures that establish the legal and fiscal framework in which an industry operates.

C. Demand: Central and local government purchases and contracts, notably for innovative products, processes, and services.

Policies to promote technological advance are playing a significant role in the economic growth strategies of most developed and developing nations. A broad concept of innovation policies implies a new perspective on a wide set of policies. Specifically, the concept calls for new national development strategies with co-ordination across these policy areas. When it comes to supporting IC design industry in Taiwan through different kinds of policy there is a consensus on the need to focus on long-term competence building in firms and in society as a whole. It is essential to policy makers to realize the significance of evaluating the effects of policies. Innovation policies are therefore appropriate tools for evaluating their effects on Taiwan's IC design industry.

3. Hierarchical Analytic Process and Evaluation Methods

3. 1 Building a hierarchical system for evaluating the effects of innovation policies

This paper establish a hierarchy system for evaluating the effects of innovation policies through scenario writing and brainstorming (see Fig. 1). Step 1 includes overall goals. Four aspects (nature of knowledge and spillover mechanisms, receiver competence, connectivity, and pluralistically innovative systems) for achieving goals were also considered in step 2. And then, we consider three criteria in nature of knowledge and spillover mechanisms, four criteria in receiver competence, three criteria in connectivity, and four criteria in pluralistically innovative systems with respect to our consideration aspects that are evaluated and selected outranking listed in step 3. All criteria considered are measured by evaluators. Finally, the innovation policies will be initiated based on our results.

3. 2 Determination of evaluation criteria weights

There are many methods that can be employed to determine weights (Hwang and Yoon, 1981), such as the eigenvector method, weighted least square method, entropy method, AHP, as well as linear programming techniques for multi-dimension of analysis preference (LINMAP). The selection of method depends on the nature of the problems. This paper will use the fuzzy geometric mean method to determine the criteria weights.

Saaty (1980) originally introduced the Analytic Hierarchy Process (AHP) to systematically cope with complex problems in social system. He used the principal eigenvector of the comparison matrix to find the comparative weight among the criteria of the hierarchy systems. If we hope to compare a set of *n* criteria pair-wise according to their relative importance (weights), then denote the criteria by $C_1, C_2, ..., C_n$ and their weights by $w_1, w_2, ..., w_n$. If $w = (w_1, w_2, ..., w_n)^T$ is given, the pair-wise comparisons may be represented by matrix ***A*** of the following formulation:

$$(A - \lambda_{\max} I)w = 0 \tag{1}$$

Eq. 1. denotes that ***A*** is the matrix of pair-wise comparison values derived by intuitive judgment for ranking order. The procedure for AHP can be summarized in four steps:

Step 1: Set up the decisions system by decomposing the problem into a hierarchy of interrelated elements.

Step 2: Generate input data consisting of pair-wise comparative judge of decision elements.

Step 3: Synthesize the judgment and estimate the relative weight.

Step 4: Determine the aggregating weights of the decision elements to arrive at a set of ratings for the alternatives/ polices.

3. 3 Obtaining synthetic utility value

Fuzzy number: Since Zadeh (1965) proposed the fuzzy set theory and Bellman and Zadeh (1970) subsequently described the decision-making methods in fuzzy environments, an increasing number of studies have dealt with uncertain fuzzy problems by applying fuzzy set theory. Similarly, this paper includes fuzzy decision-making theory, considering the possible fuzzy subjective judgment during evaluation process.

According to Dubois and Prade (1978), a fuzzy number $\tilde{A}$ is a fuzzy subset of a real number, and its membership function is $\mu_{\tilde{A}}: R \rightarrow [0,1]$, where x represents the criterion and is described by the following characteristics: (1) $\mu_{\tilde{A}}(x)$ is a continuous mapping from R to closed interval [0, 1]; (2) $\mu_{\tilde{A}}(x)$ is a convex fuzzy subset; and (3) $\mu_{\tilde{A}}(x)$ is the normalization of a fuzzy subset, which means that there exists a number x_0 such that $\mu_{\tilde{A}}(x) = 1$.

According to the characteristics of triangular fuzzy numbers and the extension principle put forward by Zadeh (1975), the operational laws of two triangular fuzzy numbers, $\tilde{A} = (a_1, a_2, a_3)$ and $\tilde{B} = (b_1, b_2, b_3)$, are as follows:

1. Addition of two fuzzy numbers $\oplus$.

$$(a_1, a_2, a_3) \oplus (b_1, b_2, b_3) = (a_1 + b_1, a_2 + b_2, a_3 + b_3) \tag{2}$$

2. Subtraction of two fuzzy numbers Θ.

$$(a_1, a_2, a_3) \Theta (b_1, b_2, b_3) = (a_1 - b_3, a_2 - b_2, a_3 - b_1) \tag{3}$$

3. Multiplication of two fuzzy numbers $\otimes$.

$$(a_1, a_2, a_3) \otimes (b_1, b_2, b_3) \cong (a_1 b_1, a_2 b_2, a_3 b_3) \tag{4}$$

4. Multiplication of any real number k and a fuzzy numbers $\otimes$.

$$k(a_1, a_2, a_3) = (ka_1, ka_2, ka_3) \tag{5}$$

5. Division of two a fuzzy numbers $\oslash$.

$$(a_1, a_2, a_3) \oslash (b_1, b_2, b_3) \cong (a_1 / b_3, a_2 / b_2, a_3 / b_1) \qquad (6)$$

Linguistic variables: Zadeh (1975) suggested that it is very difficult for conventional quantification to express reasonably those situations that are overtly complex or hard to define; thus the notion of a linguistic variable is necessary in such situations. A linguistic variable is a variable whose values are words or sentences in a natural or artificial language, and we use this kind of expression to compare two criteria by linguistic variables in a fuzzy environment as ‘absolutely important’, ‘very strongly important’, ‘essentially important’, ‘weakly important’, and ‘equally important’ with respect to a fuzzy five-level scale. The use of linguistic variables is currently widespread, and the linguistic effect values of innovation policies found in this paper are primarily used to assess the linguistic ratings given by evaluators. Furthermore, linguistic variables are used as a way to measure the performance value of innovation policies for each criterion as ‘very low’, ‘low’, ‘fair’, ‘high’, and ‘very high’. This paper applies the triangular fuzzy numbers to express the fuzzy scale as above.

Fuzzy weights for the hierarchy process: Buckley (1985) was the first to investigate fuzzy weights and the fuzzy weights and the fuzzy utility for the AHP technique, extending AHP by the geometric mean method to derive the fuzzy weights. In Saaty (1980), if **A**= [a_{ij}]is a positive reciprocal matrix, then the geometric mean of each row r_i can be calculated as $r_i = \left(\prod_{j=1}^{m} a_{ij} \right)^{1/m}$. Here Saaty defined $\lambda_{\max}$ as the largest eigenvalue of **A** and the weight w_i as the component of the normalized eigenvector corresponding to $\lambda_{\max}$, where $w_i = r_i / (r_1 + ... + r_m)$.

Buckley (1985) considered a fuzzy positive reciprocal matrix $\tilde{A} = [\tilde{a}_{ij}]$, extending the geometric mean technique to define the fuzzy geometric mean of each row $\tilde{r}_i$ and fuzzy weight $\tilde{w}_i$ corresponding to each criterion as follows:

$$\begin{aligned} \tilde{r}_i &= (\tilde{a}_{i1} \otimes ... \otimes \tilde{a}_{im})^{1/m}; \\ \tilde{w}_i &= \tilde{r}_i \otimes \left(\tilde{r}_1 \oplus ... \oplus \tilde{r}_m \right)^{-1} \end{aligned} \tag{7}$$

Ranking the fuzzy measure and aggregation: Sugeno (1974) introduced the concepts of fuzzy measure and fuzzy integral, generalizing the usual definition of a measure by replacing the usual additive property with a weaker requirement.

Definition 1. Let *X* be a measurable set that is endowed with properties of σ-algebra, where $\aleph$ is all subsets of *X*. A fuzzy measure *g*, defined on the measurable space $(X, \aleph)$, is a set function $g. \aleph \to [0,1]$, which satisfies the following properties: (1) $g(\phi) = 0, g(X) = 1$ (boundary conditions); (2) $\forall A, B \in \aleph$, if $A \subseteq B$ then $g(A) \le g(B)$ (monotonicity); (3) for every sequence of subsets of *X*, if either $A_1 \subseteq A_2 \subseteq ...$ or $A_1 \supseteq A_2 \supseteq ...$, then $\lim_{i \to \infty} g(A_i) = g(\lim_{i \to \infty} A_i)$ (continuity).

As in the above definition, $(X, \aleph, g)$ is said to be a fuzzy measure space. Furthermore, as a consequence of the monotonicity condition, we can obtain:

$$\begin{cases} g(A \cup B) \geq \max\{g(A), g(B)\} \\ g(A \cup B) \leq \min\{g(A), g(B)\} \end{cases} \tag{8}$$

while the two strict cases of measure g as

$$\begin{cases} g(A \cup B) = \max\{g(A), g(B)\} \\ g(A \cup B) = \min\{g(A), g(B)\} \end{cases} \tag{9}$$

are called possibility measure and necessity measure, respectively.

Definition 2. Let $(X, \aleph, g)$ be a fuzzy measure space. Then the Choquet integral of a fuzzy measure $g.\ \aleph \rightarrow [0,1]$ with respect to a simple function h is defined by

$$\int h(x) \cdot dg \cong \sum_{i=1}^{n} \left[h(x_i) - h(x_{i-1}) \cdot g(A_i)\right] \tag{10}$$

with the same notions as above, and $h(x_{(0)}) = 0$.

From the beginning of the application of fuzzy measures and fuzzy integrals to multi criteria evaluation problems, it has thought there was dependence between criteria. Keeney and Raffia (1976) advocated the multi attribute multiplicative utility function, called the non-additive multi criteria evaluation technique, to refine situations that do not conform to the assumption of independence between criteria (Ralescu and Adams, 1980; Chen and Tzeng, 2001). This paper applied Keeney's non-additive multi criteria evaluation technique using Choquet integrals to derive the fuzzy synthetic utilities of each innovation policy for criteria as follows.

Let g be a fuzzy measure that is defined on a power set $P(x)$ and satisfies definition 1. The following characteristic is evidently,

$$\forall A, B \in P(X), A \cap B = \phi \Rightarrow g_{\lambda}(A \cup B) = g_{\lambda}(A) + g_{\lambda}(B) + \lambda g_{\lambda}(A) g_{\lambda}(B) \quad \text{for} \quad -1 \le \lambda \le \infty$$

(11)

where set $X=\{x_1, x_2, ..., x_n\}$, and the density of fuzzy measure $g_i = g_{\lambda}(\{x_i\})$ can be formulated as follows:

$$g_{\lambda}(x_1, x_2, ...x_n) = \sum_{i=1}^{n} g_i + \lambda \sum_{i1=1}^{n-1} \sum_{i2=i1+1}^{n} g_{i1} \cdot g_{i2} + ... + \lambda^{n-1} \cdot g_1 \cdot g_2 \cdots = \frac{1}{\lambda} \left| \prod_{i=1}^{n} (1 + \lambda \cdot g_i) - 1 \right| \quad \text{for}$$

$-1 \le \lambda \le \infty$ (12)

For an evaluation case with two criteria, *A* and *B*, one of three cases as following will be sustained, based on the above properties:

Case 1: if $\lambda > 0$, i.e., $g_{\lambda}(A \cup B) > g_{\lambda}(A) + g_{\lambda}(B)$, then this implies *A* and *B* have multiplicative effect.

Case 2: if $\lambda = 0$, i.e., $g_{\lambda}(A \cup B) = g_{\lambda}(A) + g_{\lambda}(B)$, then this implies *A* and *B* have additive effect.

Case 3: if $\lambda < 0$, i.e., $g_{\lambda}(A \cup B) < g_{\lambda}(A) + g_{\lambda}(B)$, then this implies *A* and *B* have substitutive effect.

Let h be a measurable set function defined on the fuzzy measurable space $(X, \aleph)$ and suppose that $h(x_1) \geq h(x_2) \geq ... \geq h(x_n)$, then the fuzzy integral of fuzzy measure $g(\cdot)$ with respect to $h(\cdot)$ can be defined as follows (Ishii and Sugeno, 1985).

$$\begin{aligned} \int h \cdot dg &= h(x_n) \cdot g(H_n) + [h(x_n - 1) - h(x_n)] \cdot g(H_{n-1}) + ... + [h(x_1) - h(x_2)] \cdot g(H_1) \\ &= h(x_n) \cdot [g(H_n) - g(H_{n-1})] + h(x_{n-1}) \cdot [g(H_{n-1}) - g(H_{n-2})] + ... + h(x_1) \cdot g(H_1) \end{aligned} \quad (13)$$

where $H_1 = \{x_1\}, H_2 \{x_1, x_2\}, ..., H_n = \{x_1, x_{2,} ..., x_n\} = X$. In addition, if $\lambda = 0$ and $g_1 = g_2 = ... = g_n$ then $h(x_1) \geq h(x_2) \geq ... \geq h(x_n)$ is not necessary.

On the other hand, the result of the fuzzy synthetic decisions reached by each alternative is a fuzzy number. Therefore, it is necessary that the nonfuzzy ranking method for fuzzy numbers be employed during the comparison of the innovation policies. In the past, the procedure of defuzzification has been to locate the value of best nonfuzzy performance (BNP). Methods of such defuzzified fuzzy ranking generally include the mean of maximal, center of area (COA), and α-cut (Zhao and Govind, 1991; Tsaur et al., 1997; Tang et al., 1999). Utilizing the COA method to determine the BNP is simple and practical, and there is no need to introduce the preferences of any evaluators. The BNP value of the triangular fuzzy number (LR_i, MR_i, UR_i) can be found by the following equation:

$$BNP_i = [(UR_i - LR_i) + (MR_i - LR_i)]/3 + LR_i, \forall i \quad (14)$$

For those reasons, the COA method is used in this paper to rank the order of importance of

$\sum_{k=1}^{m}$

each criterion. According to the value of the derived BNP, the evaluation of each innovation policy can proceed. When the criteria are not necessary mutually independent, we use factor analysis and the nonadditive fuzzy integral technique to find the synthetic utilities of innovation policies, and to observe the order of the synthetic utilities in different λ values.

4. Evaluating the Effects of Innovation Policies in Taiwan's IC Design Industry

This paper proposes a case study on 171 samples from the Taiwan IC design industry, the academic institutions and the government policy makers for evaluating the effects of innovation policy to show the practicability and usefulness of the proposed method. The data for this paper were collected at the end of 2002 in Taiwan. 325 managers in this industry, academic institutions and government policy makers were contacted by telephone to explain the purpose of this paper and get their cooperation. Two hundred thirty-four contacted individuals agreed to participate in this study and received a mailed questionnaire. A total of 171 valid questionnaires were returned. The majority of the respondents worked in R&D, strategy management division, academic institution industry analysis, NSC, or the Ministry of Economic Affairs in Taiwan. The innovation policy evaluation process is demonstrated as follows:

A. Determining the criteria weights: The weights of various criteria, objectives and aspects were found using the AHP method and are shown in Table II.

B. Estimating the performance matrix: The evaluators could define their own individual range for the linguistic variables employed in this study according to their subjective judgments within a scale of 0-9. This paper could thus employed the average value method to integrate the fuzzy judgment values of different evaluators regarding the same evaluation criteria. In other words, fuzzy addition and fuzzy multiplication were used to solve the average fuzzy numbers for the performance values of effects under each criteria shared by the evaluators for innovation policies. Let $\tilde{h}_{ij}^{k}$ represent the fuzzy performance score by the *k*th evaluator of the *i*th innovation policies under the *j*th criterion. Since the perception of each evaluator varies according to their experience and cognition, and thedefinitions of linguistic variables also vary, we apply the fuzzy geometric mean method to integrate the fuzzy performance score $\tilde{h}_{ij}$ for *m* evaluators (see TableIII). This is ,

$$\tilde{h}_{ij} = (\tilde{h}_{ij}^{1} \otimes ... \otimes \tilde{h}_{ij}^{m})^{1/m} \qquad (15)$$

Moreover, this paper also apply the COA defuzzification procedure to compute the BNP values of fuzzy performance score $\tilde{h}_{ij}^{k}$, as shown in Table IV.

C. Calculating the fuzzy synthetic utilities: We have conducted the synthetic utilities of each policies using different λ value (-1, 0, and 1) representing the properties of substitution between criteria (see Table V). The variation of synthetic utilities in different λ value can be found. For each policies, the synthetic utilities decrease with respect to λ and rapidly decrease in λ=0. While λ= -1, the substitutive effect exists. We can rank the fuzzy synthetic utilities, as follows: P8 ϕ P2 ϕ P6 ϕ P5 ϕ P7 ϕ P4 ϕ P3 ϕ P9 ϕ P11 ϕ P1 ϕ P12 ϕ P10[1]. While λ = 0 (nonadditive

[1] P8 ϕ P2 means that P8 is better than P10.

fuzzy synthetic utilities) We can rank as follows: P8 ϕ P2 ϕ P6 ϕ P5 ϕ P7 ϕ P4 ϕ P3 ϕ P9 ϕ P11 ϕ P1 ϕ P12 ϕ P10. While λ=1, the additive effect exists. We can also rank the fuzzy synthetic utilities, and the order is the same as the former.

5. Discussions and Conclusions

Through a series of evaluation, the effects of innovation policies for IC design industry in Taiwan could be found. It indicates that single policy might be executed with other policy tools to achieve multiplicative effects (while λ=1, the additive effect exists). During the past decades, the innovation policies of the industrialized countries at national level appeared to be rather diverse and complex ones. Programs of government departments as well as those submitted by their clientele used to contain a host of different scenarios, objectives and measures. So, it is real difficult to accomplish government's end by one policy. Public awareness of the functional interdependences between the various policies has been significantly increasing.

The results also showed that political, scientific and technical development, taxation, financial, and legal regulations are top 5 effective policy tools for the Taiwan IC design industry. Four of them are environmental side policies. Environment side policies are vital for the initial phase of industry evolution. There is no extraordinary comparative advantage to incumbency. Rather, there is a considerable amount of entry and exit into the industry and market uncertainty is high.

In the initial phase, to attract more domestic participation in this industry the government initiated several policies (e.g., export credits, subsidies and tax allowances) for it. However, the fast development of IC design technology in leading countries lead to a technology gap that made it difficult for Taiwan to independently develop commercialized IC design technology. First, the private sector in Taiwan was too weak to afford the large, risky investment in R&D. Second, the private firms, basically cost-driven, were unwilling to invest in long-term R&D. They preferred to invest in areas with immediate returns regardless if the area was technology or labor intensive. Finally, acquiring technology from abroad and in-house pioneer research required hundreds of professionals, experienced engineers and scientists with intensive training. International technology acquisition strategies were therefore initiated by the government to reinforce domestic R&D competence. ITRI was charged with acquiring generic technology and disseminating it to domestic firms. NCTU and NTHU also furnished this industry with talent enforcement activities, high quality human resource and R&D support.

This paper successfully applies the fuzzy integral technique to deal with the policy making problem if the criteria are not independent. In real MCDM problems, where the criteria are not necessarily mutually independent, if we apply the simple additive aggregate method to derive the final synthetic utility, it will overestimate when the criteria have substitutive properties, or underestimate when the criteria have multiplicative properties. This paper addressed innovation policies issue using a more rational and objective approach. A fuzzy integral MCDM method was presented to fulfill this purpose. A case study on the Taiwan IC design industry was based on the results from a generalized model that evaluates the effects of innovation policies in a fuzzy environment demonstrated the validity of this model.

Table I Classification of government policy tools

Category	Policy tool	Descriptions
Supply side	Public enterprise	● Innovation by publicly owned industries, setting up of new industries, pioneering use of new techniques by public corporations, participation in private enterprise
	Scientific and technical development	● Research laboratories, support for research associations, learned societies, professional associations, research grants
	Education	● General education, universities, technical education, apprenticeship schemes, continuing and further education, retraining
	Information	● Information networks and centers, libraries, advisory and consultancy services, databases, liaison services
Environment side	Financial	● Grant loans, subsidies, financial sharing arrangements, provision of equipment buildings or services,, loan guarantees, export credits
	Taxation	● Company, personal, indirect and payroll taxation, tax allowances
	Legal regulatory	● Patents, environmental and health regulations, inspectorates, monopoly regulations
	Political	● Planning, regional policies, honor or awards for innovation, encouragement of mergers of joint consortia, public consultation
Demand side	Procurement	● Central or local government purchases and contracts, public corporations R&D contracts, prototype purchase
	Public services	● Purchases, maintenance, supervision and innovation in health service, public building, construction, transport, telecommunications
	Commercial	● Trade agreements, tariffs, currency regulations
	Overseas agent	● Defense sales organizations

Source: Rothwell R, Zegveld W. 1981. *Industrial innovation and public policy: preparing for the 1980s and the 1990s*. Frances Printer: London.

Table II The criteria weights for evaluating innovation policies

Aspects / objectives/criteria	BNP
Nature of knowledge and spillover mechanisms	
Knowledge system	0.305 (9)[a]
Nature of knowledge	0.208 (13)
Spillover mechanism	0.491 (1)
Receiver competence	
Prime mover	0.156 (14)
Creating key mechanism	0.463 (2)
Conquering the marketing failure/hindrance mechanism	0.221 (11)
Roles of agencies and S&T policy	0.357 (4)
Connectivity	
The significance of the regional concentration	0.331 (6)
The relationship between end users and suppliers	0.348 (5)
The connectivity of technical problems and answers	0.325 (7)
Pluralistically innovative systems	
The vision of members within the systems and its characteristics	0.360 (3)
Similarity of the competitors	0.311 (8)
Barriers of accession and dropout	0.231 (10)
International impact	0.210 (12)

[a] The number in the bracket is the order of importance (BNP weights) of each criterion.

Table III Fuzzy performance score of innovation policies with respect to criteria

Innovation policies	BNP values of Criteria						
	C11	C12	C13	C21	C22	C23	C24
P. 1 Public enterprise	(0.83, 1.21, 2.64)	(0.78, 1.49, 2.27)	(1.02, 1.76, 2.85)	(3.65, 4.76, 6.20)	(4.12, 5.21, 6.40)	(3.93, 6.16, 8.89)	(3.78, 6.12, 8.78)
P. 2 Scientific and technical development	(4.73, 6.34, 8.51)	(3.55, 4.10, 4.72)	(5.13, 6.77, 9.03)	(4.07, 5.01, 6.29)	(4.87, 6.41, 9.33)	(2.57, 3.12, 3.96)	(4.47, 5.47, 7.04)
P. 3 Education	(5.43, 6.78, 8.77)	(5.38, 6.67, 8.43)	(5.38, 6.45, 8.26)	(1.58, 2.15, 3.37)	(1.02, 1.93, 3.43)	(1.12, 2.03, 3.64)	(1.92, 3.14, 4.89)
P. 4 Information	(5.64, 6.27, 7.73)	(5.65, 6.49, 7.91)	(4.75, 5.69, 7.34)	(3.86, 4.45, 5.64)	(4.56, 5.17, 5.99)	(4.36, 5.58, 7.04)	(2.66, 3.68, 5.21)
P. 5 Financial	(0.92, 1.56, 2.40)	(0.85, 1.48, 2.28)	(3.02, 4.16, 5.53)	(4.09, 5.19, 6.36)	(4.76, 5.96, 7.38)	(2.45, 3.17, 4.03)	(5.45, 6.24, 7.38)
P. 6 Taxation	(1.27, 2.09, 3.02)	(1.05, 1.99, 3.34)	(4.05, 4.99, 6.07)	(4.35, 5.17, 6.28)	(4.45, 5.49, 6.92)	(4.39, 5.39, 6.61)	(4.44, 5.78, 7.75)
P. 7 Legal regulatory	(4.39, 5.37, 6.53)	(2.46, 3.13, 3.87)	(5.38, 6.19, 7.15)	(2.66, 3.42, 4.29)	(5.43, 6.78, 8.15)	(5.43, 6.98, 8.97)	(4.76, 6.99, 9.41)
P. 8 Political	(1.25, 2.08, 3.08)	(2.55, 3.47, 4.95)	(3.45, 4.20, 4.99)	(2.59, 3.39, 4.30)	(5.25, 6.81, 8.56)	(4.31, 5.20, 6.20)	(4.89, 6.82, 8.95)
P. 9 Procurement	(1.23, 2.09, 3.08)	(0.98, 1.56, 2.43)	(2.67, 3.29, 4.13)	(5.44, 6.59, 8.23)	(4.28, 5.22, 6.26)	(5.08, 6.18, 6.70)	(5.01, 6.41, 7.93)
P. 10 Public services	(0.89, 1.08, 1.40)	(0.88, 1.19, 1.65)	(2.59, 3.23, 3.94)	(2.53, 3.11, 4.01)	(3.75, 4.59, 5.73)	(2.21, 3.15, 4.11)	(1.23, 2.37, 3.77)
P. 11 Commercial	(2.19, 3.21, 4.49)	(2.52, 3.01, 3.85)	(4.57, 5.59, 6.89)	(4.35, 5.49, 6.85)	(4.33, 6.34, 8.39)	(5.07, 6.69, 8.63)	(4.96, 6.96, 9.06)
P. 12 Overseas agent	(0.92, 1.28, 1.78)	(0.87, 1.18, 1.62)	(0.89, 1.49, 2.55)	(3.77, 4.51, 5.33)	(1.57, 2.27, 3.12)	(0.89, 1.62, 2.45)	(0.73, 1.63, 2.73)

Table III Fuzzy performance score of innovation policies with respect to criteria (Cont'd)

Innovation policies	BNP values of Criteria						
	C31	C32	C33	C41	C42	C43	C44
P. 1 Public enterprise	(1.88, 3.13, 4.62)	(1.21, 2.02, 3.15)	(1.11, 2.32, 4.33)	(0.79, 1.49, 2.41)	(0.74, 1.38, 2.41)	(0.64, 1.21, 2.12)	(0.56, 1.38, 2.37)
P. 2 Scientific and technical development	(3.34, 4.14, 5.23)	(3.21, 3.94, 4.89)	(5.04, 6.42, 8.12)	(2.84, 3.52, 5.47)	(2.14, 2.86, 4.09)	(3.25, 4.09, 5.31)	(4.25, 5.91, 8.07)
P. 3 Education	(2.23, 3.18, 4.24)	(2.45, 3.15, 4.29)	(4.35, 5.17, 6.19)	(1.35, 2.06, 2.98)	(0.85, 1.55, 2.46)	(0.91, 1.15, 1.71)	(3.91, 4.53, 5.91)
P. 4 Information	(5.25, 6.18, 7.28)	(5.19, 6.14, 7.35)	(5.26, 6.33, 7.67)	(4.34, 5.58, 7.26)	(4.47, 5.89, 7.70)	(3.99, 4.89, 6.19)	(4.78, 5.39, 6.48)
P. 5 Financial	(2.34, 3.19, 4.28)	(1.34, 2.20, 3.46)	(2.46, 3.15, 4.28)	(1.46, 2.25, 3.23)	(1.47, 2.15, 3.16)	(1.23, 2.07, 3.17)	(4.29, 5.29, 6.53)
P. 6 Taxation	(5.26, 6.19, 7.23)	(2.36, 3.35, 4.63)	(1.65, 2.94, 4.42)	(1.78, 2.65, 3.75)	(1.12, 1.95, 2.99)	(1.43, 2.34, 3.50)	(1.69, 2.63, 3.94)
P. 7 Legal regulatory	(3.03, 4.24, 5.52)	(1.94, 3.24, 4.62)	(4.11, 5.19, 6.36)	(1.15, 2.12, 3.23)	(0.94, 1.92, 3.10)	(1.02, 2.51, 4.11)	(4.71, 6.67, 8.79)
P. 8 Political	(4.79, 6.49, 8.39)	(1.89, 3.58, 5.47)	(4.16, 6.43, 8.88)	(0.83, 1.93, 3.20)	(0.65, 1.44, 2.28)	(4.09, 5.84, 7.76)	(3.77, 5.83, 7.99)
P. 9 Procurement	(4.12, 5.74, 7.53)	(4.94, 6.21, 7.55)	(2.13, 3.21, 4.39)	(0.75, 1.54, 2.39)	(3.02, 4.32, 5.73)	(3.97, 5.19, 6.60)	(3.89, 5.08, 6.37)
P. 10 Public services	(1.78, 3.61, 5.61)	(1.99, 3.19, 4.45)	(1.99, 3.45, 4.96)	(0.61, 1.33, 2.13)	(0.69, 1.30, 1.99)	(0.51, 1.24, 2.05)	(1.89, 3.19, 4.62)
P. 11 Commercial	(4.01, 5.18, 6.45)	(5.64, 7.18, 8.81)	(5.78, 7.51, 9.61)	(5.89, 7.29, 8.79)	(6.36, 7.05, 8.08)	(4.15, 6.51, 8.97)	(4.12, 5.51, 6.98)
P. 12 Overseas agent	(0.72, 1.52, 2.38)	(0.68, 1.49, 2.40)	(0.66, 1.43, 2.28)	(0.74, 1.73, 2.80)	(0.89, 2.32, 3.85)	(0.59, 1.32, 2.16)	(4.05, 5.59, 7.30)

Table IV BNP values of fuzzy performance score with respect to criteria

Innovation policies	BNP values of Criteria													
	C11	C12	C13	C21	C22	C23	C24	C31	C32	C33	C41	C42	C43	C44
P. 1 Public enterprise	1.561	1.512	1.875	4.869	5.423	6.325	6.225	3.211	2.127	2.587	1.564	1.512	1.323	1.435
P. 2 Scientific and technical development	6.525	4.124	6.978	5.124	6.872	3.215	5.659	4.235	4.012	6.528	3.942	3.029	4.215	6.078
P. 3 Education	6.992	6.825	6.695	2.368	2.128	2.264	3.315	3.215	3.297	5.236	2.129	1.621	1.258	4.785
P. 4 Information	6.548	6.684	5.928	4.651	5.239	5.659	3.851	6.238	6.225	6.421	5.725	6.021	5.024	5.549
P. 5 Financial	1.625	1.535	4.236	5.213	6.032	3.215	6.355	3.269	2.332	3.215	2.313	2.261	2.157	5.369
P. 6 Taxation	2.126	2.032	5.036	5.266	5.621	5.462	5.991	6.227	3.445	3.002	2.725	2.023	2.423	2.754
P. 7 Legal regulatory	5.429	3.154	6.239	3.456	6.785	7.127	7.054	4.264	3.265	5.219	2.165	1.985	2.547	6.725
P. 8 Political	2.135	3.658.	4.213	3.428	6.874	5.236	6.885	6.558	3.645	6.489	1.986	1.455	5.896	5.864
P. 9 Procurement	2.132	1.655	3.364	6.754	5.254	6.225	6.451	5.795	6.232	3.242	1.562	4.356	5.254	5.112
P. 10 Public services	1.122	1.241	3.254	3.215	4.689	3.155	2.457	3.665	3.211	3.465	1.356	1.325	1.265	3.232
P. 11 Commercial	3.295	3.125	5.684	5.564	6.354	6.795	6.992	5.214	7.210	7.632	7.325	7.162	6.542	5.535
P. 12 Overseas agent	1.325	1.224	1.642	4.535	2.321	1.652	1.698	1.541	1.524	1.457	1.756	2.354	1.356	5.648

Table V Synthetic utilities with λ values

λ	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12
-1.0	3.257	5.442	4.227	4.325	5.098	5.115	4.892	5.795	3.924	2.743	3.511	2.947
0	3.594	5.654	4.512	4.764	5.165	5.351	5.065	6.231	4.154	3.326	3.787	3.234
1.0	10.269	13.872	12.421	12.759	13.167	13.654	12.859	14.156	12.114	8.957	11.524	9.425
SAW [a]	5.707	8.323	7.053	7.283	7.810	8.040	7.605	8.727	6.731	5.009	6.274	5.202

[a] The synthetic utilities by simple additive weight (SAW) method with respect to polices.

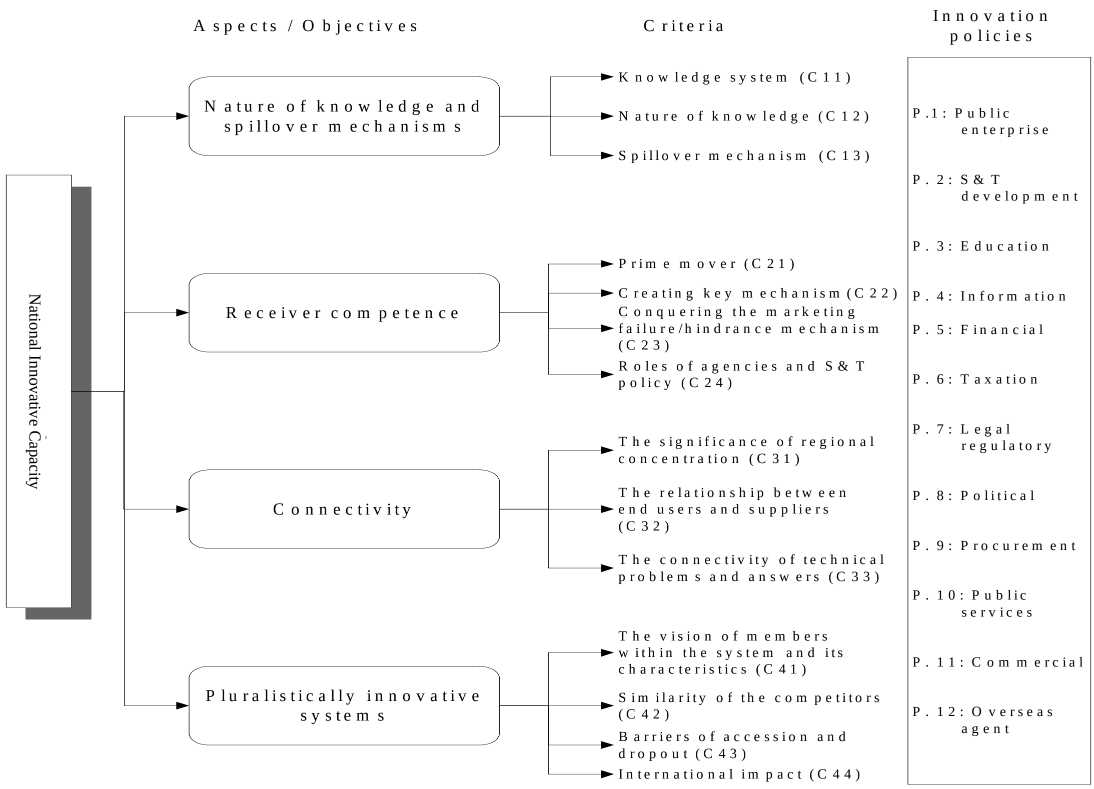

Figure 1. Hierarchical tree relevance systems for innovation policies

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PART 4

Conclusions: Innovation Policy for Developing Competitive Advantages of Taiwan IC Industry

Innovation Policy for Developing Competitive Advantages of Taiwan IC Industry

Abstract: Innovation is a prerequisite for every nation and business facing the emergence of a knowledge-based economy and globalization. For small and medium firms in developing countries with limited resources and relatively low national advantage innovation is much more difficult. Government innovation policy, stemming from three sides - supply, demand, and environment, has been shown to play a major role in assisting firms to conduct innovation activities, especially in developing countries. This paper first summarizes recent tends and issues relevant to Taiwan's innovation structure and policy. Then, considering the present situation of Taiwan, analyzes the effect of government policy and current problems. Recommendations are presented systematically, based upon innovation policy.

Keywords: Innovation Policy, Innovation Infrastructure, National Advantages

1.Introduction

Knowledge is becoming the main resource for economic development, and the application of technology and innovation are the fundamental means of creating knowledge. Indeed, science and technology are the very foundation for industry's competitiveness. Many countries around the world adopt innovation policy to improve people's livelihood and promote economic prosperity. All leading countries strive for technological innovation and new product development to ensure their competitiveness and continuous economic growth.

Theoretically, innovation is the engine for national technological development. However, innovation has excessively high risk and the return is uncertain, especially for large-scale integrated systems and high technology products. In this regard, government intervention is essential. Experiences of advanced countries show that the most favorable conditions for innovation include an open and democratic society, a superior national innovation system, and appropriate government intervention.

Taiwan's economy has prospered in the past four decades, but Taiwan is now faced with wage increases, appreciating value of currency value, the rising of international protectionism, and thus is losing its competitive advantages. Consequently, a number of industries are moving out of Taiwan, and industry growth and exports have slowed down. To break through these post-growth bottlenecks and open up new space for industry growth, Taiwan needs to adjust its industry structure, upgrade the technical level, and develop high technology industries to promote industrial competitiveness. The most effective approach to achieve this goal is to assist the private sector's innovation and utilize manpower to build up the business competency, and thereby create the industry profits.

The purpose of this paper is to evaluate the current innovation infrastructure and policy of Taiwan and is organized as follows. Section 1 describes the background of the concept of innovation and innovation policy. Section 2 evaluates innovation infrastructure and policy. Recommendations for Taiwan innovation policy are in Section 3. Section 4 is the conclusion.

2. Innovation and innovation policy background

Schumpeter (1934) defines innovation as the activity of developing an invented element into a commercially useful element that becomes accepted in a social system. Peter Drucker (1985) wrote: "Business has only two basic functions: Marketing and innovation. Marketing and innovation produce results. All the rest are costs." Innovation is the use of new knowledge to offer a new product or service that customers want (Afuah, 1998). It is invention + commercialization (Freeman, 1982). It is, according to Porter, “a new way of doing things (termed invention by some authors) that is commercialized. The process of innovation cannot be separated from a firm’s strategic and competitive context (Porter, 1990). Therefore, innovation includes a series of activities such as: science, technology, organization, finance and commerce.

Theories have been elaborated according to Schumpeterian vision of technological and economic change, stressing the role of increasing returns, learning processes and non-maximising behaviors. From this approach, a theory of the economic process characterized by disequilibrium, nonlinearity, cumulativity and path dependency has been elaborated. As a consequence, in the field of technological change, certain hypotheses have been increasingly regarded as crucial. That is, innovation is not the product of the atomistic behavior of maximizing agents, but is the result of particular dynamics determined either at the sectoral or global (national) level (Leoncini et al., 1996).

2.1 Policy perspectives on innovation

Innovation policy can be classified as demand-side oriented or supply-side oriented (Edquist, C. and Hommens, L.,1999). Similarly, theories on innovation process can be classified as linear or systems-oriented. Important parallels and logical connections can be drawn between these two classifications. On the other hand, linear views of the innovation process support a supply-side orientation in innovation polices. Conversely, systems perspectives on innovation yield a much more fruitful perspective from the demand side, in terms of both theoretical and policy relevance.

2.2 Innovation policy

Innovation policy, oriented at appropriate new product ideas, production processes and marketing concepts, can produce at minimum temporary competitive advantages (Jacob, D., 1998). Innovation policy includes science and technology (S&T) policy and industry policy. The aim of the S&T policy, basically supply-side oriented, is to enhance the basic and applied research capacities of nations. Additionally, the latter one enhances the industry competitiveness. The making of industry policy is based upon demand-side consideration. A list of possible kinds of innovation policies given by Rothwell and Zegveld (1981) is summarized in Table1. These policies can be grouped under three main headings.

(a) *Supply*: provision of financial, manpower and technical assistance, including the establishment of scientific and technological infrastructure.

(b) *Demand*: central and local government purchases and contracts, notably for innovative products, process and services.

(c) *Environment*: taxation policy, patent policy and regulations, i.e., those measures that establish the legal and fiscal framework in which industry operates.

3. Innovation policy of Taiwan

The current innovation policy of Taiwan includes:

(1) Alleviation of taxation

Companies can have exemption from import duties for instruments and equipment for experiments in R&D. Equipment for R&D with a life of longer than two years can adopt two-year accelerated depreciation. Expenditures in R&D of 15-20% can be business income tax deductible.

(2) Loan subsidy

The Ministry of Economic Affairs also took action in promoting traditional industries' technology capacity with "Rules of encouragement for the private sector's development of new products" and the "Law governing development for directive new products"

(3) Supply of information and technological assistance institutions

The government has set up some institutions, such as the Technological Information Center, the National Science Commission, the Standard & Patents Information Center of the Central Standard Bureau, the Institute of Industrial Technological Research, and the Industries Assistance Center of the Ministry of Economic Affairs for collecting and managing market and technology information. This information can assist companies to cope with a changeable environment.

(4) Government procurement

Some rules and regulations have been drawn up to encourage government units to purchase products made in the local area.

(5) Protection of research results

Regulations of the Patent Law concerning obtainment and protection of patents have been redrawn and carried out in earnest.

(5) Cultivation of manpower

More training courses have employed to cultivate the manpower needed in R&D activities by government agencies and institutions. To encourage companies to build up manpower, 15% - 20% of expenditures on cultivation of manpower can be deducted from a firm's income tax.

Facing the highly changeable environment, the industrial circle needs various and adaptive innovation policies. Small and medium businesses with limited resources are the major components in Taiwan economy, therefore the government must be in a position to assist and guide these industries' technology development and to initiate some national strategic industries. Policy tools such as subsidy, loans, and financing are incentives that promote innovation capacity. The major tools include:

1. Scientific and technological fund of the National Science Commission: government prepares an

annual budget to support academia for fundamental research.

2. Technological project of the Ministry of Economic Affairs: government initiates large-scale research plans and appoints research institutions or business entities to execute the plans.
3. Development fund: government sets up the budget to support strategic investment projects and establish major fundamental industries. Investment in TSMC (Taiwan Semiconductor Manufacturing Company) is a typical example.
4. Rules of new products development of the Industrial Bureau: government sets up annual budget as non-interest loans to support businesses to develop new products
5. Subsidy for R&D activities of high-tech companies located in the Science-based Industrial Park: government prepares an annual budget as relative expenses to support firms' research projects.

3.1 Critical Issues of Taiwan's innovation infrastructure

Under the government's guidance, Taiwan industries have built a solid foundation of industry development. However, their ability to innovate still falls behind advanced countries. Following are some major issues relevant to Taiwan's innovation infrastructure:

1. Insufficient laws and regulations regarding innovation

Taiwan has imposed too many restrictions that discourage the private sector's interests. Although there is a law called "Technologies basic law", it still falls far behind liberalism, and thus lacks the incentives to encourage the private sector's investment in R&D.

2. Limited budgets and manpower for innovation

The R&D expenditures of Taiwan in 1998 were 5,495 million USD, far less than the 227,934 million USD in the United States. Taiwan expenditures also fell behind Japan and Korea, based on the R&D expenditure in 1997 (1115,20 million USD for Japan, 7,186 million USD for Korea). In terms of R&D expenditures a percentage of GDP in the year of 1998, Taiwan was 1.98%, less than the 2.79% in the United States. Taiwan percentage is obviously much lower.

3. Some key technologies depend on other leading countries

According to statistics, 1,300 companies purchased technologies from foreign countries in 1994, for 0.5 billion USD. About 150 companies sold technologies to foreign countries, for 0.085 billion USD. Domestic industries with lower levels of technology are moving out. Taiwan must develop products with higher levels of technology. However, technology needed for high value-added products is also the key technology in advanced countries. They are reluctant to transfer these technologies to Taiwan for the welfare of their domestic industries. This is why the introduction of key technologies becomes increasingly difficult.

4. Recommendations for Taiwan innovation policy

In order to maintain Taiwan's economic growth, an innovation policy of increasing incentives, based on supply side, demand side, and environment side, is essential. Supply side policy enhances capabilities for building technologies, and demand side policy aims at improving the demands for indigenous technologies and products. Environment side policy fortifies the national innovation systems.

1. Supply side policy

Supply side policy includes assisting firms to perform R&D activities, strengthening the function of public research institutions or foundations, setting up the open-labs, promoting the cooperation between industries and academics, revising of relevant laws to speed up technology transfer, and promoting technology cooperation between both sides of the China Strait.

(1) Assisting firms' R&D activities:

Even though the government has a number of incentives to encourage innovation, the accompanying red tape is time consuming and sometimes disputes regarding the ownership of intellectual properties arises. Firms find it difficult to adjust. We believe that a more practical method is to encourage cooperation among firms, research institutes and universities. Promote the positive benefits of innovation, on the other hand, and on the other revise laws, thereby increasing the incentives for the private sector to carry out R&D.

(2) Enhancing the innovation capabilities of research institutions

Research institutions such as the Industrial Technologies Research Institute, and China Technologies Research Institute are the main force in industrial R&D. Restricted by laws and regulations, the results of their R&D function is not fully utilized. A channel for technology diffusion is still not available and, as a result, creates the waste of R&D resources.

(3) Upgrade of Industries through cooperation between industries and academics

As competition grows fiercer and global specialization becomes a trend, how to make Taiwan become a "Technological Island" is the focus of the Taiwan government. The Triple Helix thesis states that the university can play an enhanced role in innovation in increasingly knowledge-based societies. The Triple Helix denotes not only the relationship of university, industry and government, but also internal transformation within each of these spheres (Etzkowitz and Leydesdorff, 2000). In recent years, government budgets for education and public research have been reduced. Universities have adopted the strategy to work actively with industries, thus can get some funding from industries and the research results can be commercialized. Many incubator centers have also been set up in the university campus to bring a new mode of interaction between academia and industry. Basically, such cooperation mode is a supply side strategy.

Another type of cooperation between industries and academic institutions is the demand side strategy. Businesses set up independent research centers in and make use of technological experts and public facilities for R&D activities for commercialization. There are at least six advantages for demand side strategy of cooperation:

a. Businesses have lower risk in innovation.

b. Businesses guide the direction of innovation and cans integrate their marketing, finance, and manufacturing departments more effectively.

c. With businesses guiding the direction of innovation, timing and external opportunities can be more leveraged.

d. Disputes regarding intellectual properties are less likely.

e. Businesses have more choices on strategies, such as technology cooperation and strategic alliances.

f. University resources are fully utilized and trained, thus upgrade national capability in innovation

(4) Establishment of open-style research institute

Private firms are reluctant to conduct innovation activities due to the huge capital required to buy equipment and unknowing risks and returns. If the government can provide assistance to private firms for their R&D, such as setting up regional innovation service center, professional and open-style research institute, even opening up university labs to facilitate the private firms' research and allowing small and medium businesses to conduct projects pertinent to upgrading manufacturing techniques and cultivation of R&D personnel with minimum expenses, this action, in effect, will upgrade the industries' manufacturing techniques and R&D capability.

(5) Leverage mainland China's technology resources and market

The technological resources on mainland China are owned and controlled by the government. Traditionally, innovation activities are mission-oriented under a planned economic model and lack considering of market demand that is very common to a capitalist society. Although mainland China has adoopted an "openness" policy, yet it is still unable to utilize technology resources to upgrade its industrial innovation capability. In Taiwan, the economy mainly consists of small and medium businesses which have leveraged returned students and comparative advantages of labor and land to create a vigorous economy. However, due to limited resources, small and medium businesses have neglected innovation. Consequently, promotion of industry has become a main issue for Taiwan innovation policy. Companies that depend upon cost advantage but have failed to promote themselves have elected to use cheap labor force in countries such as mainland China, Vietnam, e.g., and have made them their production centers to continue leveraging the labor cost advantage. A cross-strait technological system and innovation infrastructure built by both countries is the most promising method for the future. The establishment of a "World Chinese Business Technological Research Center" can be a proper mechanism to coordinate and channel both sides' resources into innovation efforts.

2. Demand side policy

The purpose of demand side policy is to stimulate market potential and assure the purchase power of customers. The government plays the role of setting up a mechanism for firms to find proper markets with export incentives or deregulation in some specific markets.

(1) Procurement

Due to limited market side, most Taiwan companies adopt export as their major method to enlarge their market. However, government procurement strategy also plays a fundamental role in enlarging their market. Contracts assigned to local businesses can provide them with a suitable and stable market, which are very crucial for an emerging business.

(2) Deregulation

A free market and deregulation have brought economic prosperity to the United States. Deregulation of the transportation, telecommunication, and finance market are considered the fundamental reasons of the emergence of a new economy (Ohmae, K., 2000). Compared to other leading countries, Taiwan's economy is still very conservative. With the coming of a new economy and globalization, deregulation and free market should be considered in Taiwan policy formulation process.

3. Environment side policy

A complete and well-established national innovation system is the best safeguard for industrial innovation. Government policy should be focused on building up the innovation system. In the industry environment, cultivation of superior production factors, encouragement of suitable industrial competition and demand, as well as the creation of relevant industries are the key tasks. In addition, the completeness of the technological system, especially the fortification of environment side policy, will accelerate the speed of knowledge diffusion.

Environment side policy includes encouragement of the emerging of venture capital, establishment of Technomart, supply of favorable financing measures and fortification of the capability of industrial and information supply center.

(1) Development of venture capital

Taiwan government has implemented “Administration Rules on Venture Capital” since 1983 and provided a number of incentives for investments. However, the subjects of these capitals are concentrated on the matured industries. The capital invested into the emerging industries only represents 10% of total capital. That is against the requirement of investment in the hi-tech industries with high-risk and high-profits. The investment in information, semi-conductor, consumer electronics and communications represents 70% of total fund, showing a tendency of over-concentration. Therefore, the government needs to evaluate the current investment policy.

(2) Establishment of Technomart

The government should set up, or assist private sector to set up technologies trade center. This center will provide a marketplace where the firms with the intention to sell technologies and the buyers for technologies can exchange efficiently. This very kind of mechanism also will accrue to the diffusion of technology and knowledge.

(3) Provide preferential financing measures

The government has a number of incentives to encourage the businesses. However, these measures are not fully implemented thoroughly, so the effects are not satisfactory. Such as tax break designed to encourage the investment in R&D, the criteria for R&D expenses is too loose, some businesses would fill R&D expenses includes irrelevant expenses, thus this policy is not working satisfactorily. The government needs to re-examine the incentives and gradually abolish the necessity of incentives in order to resume the essence of free competition.

(4) Augment the capability of the industrial information center

There are as many as 1 million small and medium businesses in Taiwan, representing 98% of the total number of businesses. Their abilities to collect, summarize, and apply information are relatively weak. In this regard, the government should assist the establishment of an industrial information system to increase their competitiveness. In recent years, the government set up, either by itself or assisted the private sector to set up, a number of industrial information centers, such as the the China External Trade Development Council, the Industrial Technology Information Service center, and associations for all industries. However, all these centers are not integrated, and thus are unable to provide really useful information or intelligence to users. Meanwhile, the government should reinforce the performance of all existing centers, especially in assisting them to establish a complete industrial database and intelligence, which can become the reference in decision-making.

5. Conclusions

During the first quarter of 2001, Taiwan has witnessed massive layoffs and restructuring of major corporations. A global economic depression seems imminent and is causing concern for corporate and national leaders. It looks as if globalization and cyber-space based movements of goods and capital are the first to blame. While globalization and cyber-space based activities continue to take the stance, development of common international practices and legal infrastructure are still burgeoning. Interdependence in a global economy will continue to move ahead at full steam, and only those who learn quickly to embrace the new world will prevail. Those who fail to do so will be left behind and isolated from the prosperity of the world.

The recent slow down in the global economy and the plunge of global capital markets reflect a continuous restructuring of the global economy. By no means, these trends are a result of a burst or overheating of a “bubble economy”. Rather, this restructuring will lead to an outcome where those companies, or nations, that have the greatest efficiency and nichmanship, are the most deregulated and most flexible, and that have the most adaptable infrastructure will gain a greater advantage over the long run. Cost-cutting and restructuring will represent an important complementary weapon for staying healthy in bad times for firms operating in the new economy. Investment in public works and controlling cross-border capital flow (into the Mainland) cannot guarantee success. (Look what has happened to the Japanese!) Economic prosperity and better quality should be the prevailing goals for the government and corporate leaders. Knowledge-intensive industries should be the focus. In this arena, flexibility, and non-standardized, externalized operations with an emphasis on dynamic thinking and global manipulation are all prerequisites. Development of knowledge-intensive service industries with a deregulated infrastructure that allows Taiwanese businesses to fully take advantage of their flexibility, pragmatism, and dynamic thinking, should be encouraged. Moreover, construction of needed infrastructure and bylaws is also very urgent.

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附錄
出國差旅心得報告

參加波特蘭工程與科技管理 2003 年國際會議

一、前言

在 E-世代之科技生活環境裡，許多「知識」與「創新」的觀念創造許多特徵(features)之價值，改變了「生產」、「市場銷售」、「行銷通路」等方式與觀念，在「資訊（網際）服務提供者(Information / Internet Service Provider)」、「生產之供應者(Suppliers)」，以及「顧客(Customers)之需求者」已邁向全球化及多層面之思維方式，此科技之發展更改變人類的生活方式，手機、電腦、資訊等科技發展之產物已成為人類生活中重要的一部分，並將全球化資訊網路結合成一大系統，在此全球化分成亞洲、美洲、歐洲之三大行銷生活圈系統，在此三大系統間之交互作用之際，工程與科技發展未來之走向、如何利用管理之手段發展工程與科技，應是更有效率、為人類創造更多價值，以滿足人類的需求(Needs)與幸福。

在此會議中，本校張俊彥校長獲得二年一次且為唯一一名之國際科技發展推動之教育類獎，此為交通大學、更為全台灣之光榮。

二、參加會議經過

本人於 7 月 18 日搭乘長榮航空自桃園國際機場出發，19 日抵達波特蘭之希爾頓大飯店（亦為本次會議之舉辦地點），20 日-24 日為會議之會期活動、25 日轉至舊金山、矽谷訪問史丹佛大學，拜訪同事及老友，並查詢該校之網路系統，27 日清晨 1:30 由舊金山返回台灣，並於 28 日清晨 5:40 抵達桃園國際機場、10 點回至交通大學。會議之過程簡述如下：

<u>1. 20 日會議過程：</u>

(1)下午 1:30-5:00 為「資深教授」與「博士班學生」之生涯座談，首先由波特蘭州立大學 Anderson 教授主持，介紹以美國為中心之博士班學生訓練之一般過程，入學審查委員會審查學生入學，修課規定、資格考、計畫書口試、博士論文繕寫與博士論文口試，在此過程中是否參加國際會議、發表期刊論文亦加入考量，此依學校、不同教職員(Faculty)觀念之不同而異。

其次為分組討論，將參加者分成四組：(a)入學後之前階段；(b)入學後之後階段；(c)計畫於畢業後往學術界發展；(d)計畫於畢業後往非學術界發展，此四組分別進行討論，本人則參加第三組，過程中大部分學生均提到畢業後將如何找工作、找何種工作，即找哪一類或哪一所學校、任教科目、如何準備教學及如何做研究，大家都擔心教學工作有關升等之壓力，升等必須要有期刊論文之發表，此制度各國不同，有的國家博士畢業後僅由「助教」做起（日本等）、有的由「講師」做起（英國或偏歐洲式等）、

有的由「助理教授」做起（美國、台灣等)、有的由「副教授」做起（中國及一些較落後、受高等教育較少的國家)。論文之要求亦各國不同，美國為 tenure，由助理教授升等至副教授，一般需在五至六年內升等，否則將被解聘，此條件不僅要 SSCI / SCI 之國際論文約十五篇以上，亦要能得到研究經費補助，此制度與台灣之「教學（評點)」、「服務（國科會等研究計畫案之經費及參與行政職等)」與「研究（SSCI / SCI 期刊之投稿)」。分組討論結束後休息 30 分鐘，由各組負責人整理各組之討論結果。最後，各組對討論獲致之結論提出報告，並開放共同討論，由博士班研究生提出問題，並請數位資深教授為未來的研究菁英做回答或簡答，互動良好。

(2)19:00-22:00 於希爾頓 Pavilion 舉辦 Ice Breaker 之茶會。

2. 21 日會議過程

(1)上午 8:00-9:30 為於 PAVI:ION Room 之大會場舉辦開幕典禮，首先由美國國會議員 (Senator) Smity, G.致歡迎詞(Welcoming Statement)，接著由本次大會主席 Kocaoglu, D.F. 教授報告本會 PICMET 之過去、現在與未來，最後由 Zobel, R.A.教授做專題演講，主題為「邁向知識基礎之經濟：歐洲研究與政策目標 (Toward Knowledge-Based Economy: European Research and Policy Goal)」。

(2)10:00-11:30 為論文發表、Tutorial 與 Panel。其中，論文發表共有七場，每場約有 3-4 篇論文發表，主題分別為 ：R&D Management-1: Managing R&D in China, Management of Technical Workforce-1, Information Technology Management-1, Collaborations in Technology Management-1, Technology Defussion-1, Cultural Issues-1, Intellectual Property-1；Tutorial 共四場，主題分別為：Creating Business Value With Technology: Metrics and Outcomes, Closing the Strategic Plan/Implementation Gap: The Logitech Benchmark, Reshaping Technical Organizations and Their People for 21st Century, Planning and Implementing International Technology Transfer in Developing Countries；Panel 一場，主題為 A Credo for MOT。

(3)13:30-15:00 為論文發表、Tutorial 與 Panel。其中，論文發表共有六場，主題分別為 ：Bring Technology and Innovation into the Boardroom, Project/Program Management-1, R&D Management-2, Entrepreneurship/ Intrapreneurship-1, Technology Management Education-1, Supply Chain Management-1；Tutorial 共五場，主題分別為：Investigating the Effect of Knowledge Practices on IT Project Success, Challenges for Technology Management in Less Indutrialised Economies, Technology Roadmapping: Developing a

Needs-Driven Technology Strategy, Understanding Culture, Language, and Communication Styles: A Key to Business Success in Global Markets, Intellectual Property；Panel 一場，主題為 Engineering & Technology Management Journals。

(4)15:30-17:00 則有十一場論文發表，主題分別為：Innovation Management-1, Project/Program Management-2, New Product Development-1, Science and Technology Policy-1, Information Technology Management-2, Decision Making in Technology Management-1, Technology Management Education-2, Supply Chain Management-2, Technology Transfer-1, Technology Difssion-2, Technological Changes-1。

(5)19:00-22:00 為於 Park Blocks 配合地方之演奏享用頗具地方風味之之公園 Buffet 晚宴。

3. 22 日會議過程

(1)上午 8:00-9:30 之專題演講為由 Lipscomb, T.H.董事長(Chairman of the Center for the Digital Future, CEO and Chairman of Internet Commerce Corporation, Inc.)主講，主題為「智慧財產：寬頻成長之關鍵(Intellectual Property: The Key to The Growth of Broadband)」，說明智慧財產之價值產生於 Marketplace 對顧客(Customers)產生之「效用/價值」。。

(2)10:00-11:30 為論文發表與 Panel。其中，論文發表共有十場，主題分別為：Innovation Management-2, Project/Program Management-3, New Product Development-2, R&D Management-3, Information Technology Management-3, Decision Making in Technology Management-2, Productivity Management-1, Supply Chain Management-3, Technology Transfer-2, Environmental Issues in Technology Management-1；Panel 則有二場，主題分別為：Technology, Entrepreneurship & Regional Economic Development, Foresight – Providing the Strategic Knowledge for Technology Management。

(3)13:30-15:00 共有十一場論文發表，主題分別為：Innovation Management-3, Project/Program Management-4, New Product Development-3, R&D Management-4, Science and Technology Policy-2, Decision Making in Technology Management-3, Technology Assessment and Evaluation-1, Supply Chain Management-4: SCM and related concepts, Technology Transfer-3, XML-TR: Steps Towards Defining a Language for Technology Roadmaps-1, Telecommunications-1: Wireless。

(4)15:30-17:00 則為論文發表與 Tutorial。其中論文發表共有十場，主題分別為：Technology Management Perspectives on Terrorism, New Product Development-4, Science and Technology Policy-3, Information Technology Management-4, Decision Making in Technology Management-4, Technology Assessment and Evaluation-2, Manufacturing Management-1, Technology Transfer-4, XML-TR: Steps Towards Defining a Language for Technology Roadmaps-2, Telecommunications-2: Wired；Tutorial 則有二場, 主題分別為：Earned Value Management Method, MOT Knowledge Mining。

(5)19:00-22:00 為頒獎晚餐，本校張校長與夫人聯袂參加此為其代表教育類「科技管理 Leadership」舉辦之授獎典禮。。

4. 23 日會議過程

(1)上午 8:00-9:30 之專題演講主為由本年三位「科技管理 Leadership」之獲獎者報告其 Leadership 之過程：

(a)Jong-Yong Yun 副董事長(Vice-chairman)兼執行長(CEO)代表產業類，其任職於韓國 Samsung 電子公司，為該公司發展之最大貢獻者，該場次由其報告如何推動公司至今日之規模與對國際之貢獻。

(b)Dr. Joseph Bordogma 為美國國科會 (National Science Foundation, NSF) 之 Deputy Director，為代表政府單位之獲獎者，其報告近年來如何推動科技發展之研究。

(c)我交通大學張俊彥校長為代表教育類之獲獎者，其介紹交通大學科技研究之發展，在國際 SCI、IEEE 論文發展居世界領先，有許多先進之卓越研究，另在台灣地區，亦由交通大學帶動新竹科學園區高科技產業之發展，為帶領台灣之科技發展走向全球之先驅者。

(2)10:00-11:30 為論文發表、Tutorial 與 Panel。其中，論文發表共有八場，主題分別為：E-Business-1, Knowledge Management-1, Entrepreneurship/Intrapreneurship-2, Information Technology Management-5, Decision Making in Technology Management-5, International Issues in Technology Management-1, Semiconductor Industry-1, Technology Marketing-1；Tutorial 一場，主題為 Project Strategy: The Path to Achieving Competitive Advantage/Value；Panel 一場，主題為 New Directions in Technology Forecasting and Assessment。

(3)13:30-15:00 為論文發表與 Tutorial。其中, 論文發表共有十一場, 主題分別為：Innovation Management-4, Project/Program Management-5, Knowledge Management-2, Entrepreneurship/Intrapreneurship-3, Technology Management Framework-1, Collaborations in Technology Management-2, Technology Management Education-3, Competitiveness in Technology Management-1, Technology Commercialization-1, Technology Planning and Forecasting-1, Software Process Management-1；Tutorial 共二場，主題分別為：New Product Development Using Adaptive Product Management, Strategic Implementation of Six Sigma and Project Management。

(4)15:30-17:00 則有十三場論文發表，主題分別為：Innovation Management-5, Project/Program Management-6, New Product Development-5, Knowledge Management-3, Entrepreneurship/Intrapreneurship-4, Historical Perspectives-1, Collaborations in Technology Management-3, Technology Management Education-4, Competitiveness in Technology Management-2, Technology Commercialization-2, Technology Planning and Forecasting-2, Strategic Management of Technology-1, Software Process Management-2。

(5)19:00-22:00 參加由 Stevens Institute of Technology 之 Aaron J. Sheugar 教授進行之特別演講，主題為 "Strategic Project Leadership"。

5. 24 日會議過程

(1)10:00-11:30 為論文發表與 Tutorial。其中，論文發表共有九場，主題分別為：Innovation Management-6, Project/Program Management-7, New Product Development-6, Resources Management-1, Healthcare Industry-1, Technological Changes-2, Manufacturing Management-2, Technology Roadmaping-1, Strategic Management of Technology-2；Tutorial 一場，主題為：T-CAT – A Technology Commercialization Assessment Tool。

(2)13:30-15:00 亦為論文發表與 Tutorial。其中，論文發表共有八場，主題分別為：Innovation Management-7: Best Practices at HP, Project/Program Management-8, New Product Development-7, Business Intelligence for Agile Manufacturing, Management of Technical Workforce-2, Manufacturing Management-3, Technology Roadmaping-2, Strategic Management of Technology-3；Tutorial 一場，主題為：Techno-Economics。

三、與會心得

整個會議每天行程安排得非常緊湊，內容非常豐富，有學界、實務界與理論之學者，為典型「產學合一」之大型國際會議，共有 129 個 sessions，計約 400 餘篇論文發表，有來自 200 個大學以及 100 家公司、研究機構與政府機關，並超過 40 個國家之人員共聚一堂，交換研究與實務經驗，本人所獲之心得如下：

1. 最興奮的為我交通大學張俊彥校長今年獲得教育類最高榮譽之科技管理 leadership 國

際大獎、為台灣在國際爭光，其獲獎之心得更激勵國人要有自信、努力就有機會獲得成果。

2. 台灣在半導體、光電、通訊、奈米等之高科技產業之發展頗受國際重視，台灣科學園區能有今日之成就，顯示「產、研、學」三者關係之密切。會中發現，一般之所以會成功，主要在於穩固的根基，發展科技還是在基礎，因此「產業發展（如新竹科學園區）」必須要有「研究機構（如工研院）」之研究，亦要有「基礎卓越之教育與研究（如交通大學）」，由具卓越研究成果之師資奠定好的研究基礎，方能有未來的成就與發展。

3. 資訊科技(Information Technology)之發展走向全球之知識經濟，市場亦是全球性，透過人造衛星、網路 E 化等將全球分成「歐洲」、「美洲」、「亞洲」之三大區，此在 Dr. Zobel, B.A.之專題演講 “Toward a Knowledge-Based Economy: European Research and Policy Goals”中已有提及，全歐盟之各獨立國已成為和平之一共同體，有其「政策目標(Goal)」，而我們亞洲呢？在野蠻霸權之大中國下，如何走向各自獨立且和平共存之「亞盟」？要走的這一條路是很遙遠的，在困苦的環境下，我們要如何邁向和平共存的國際化之路呢？

4. PICMET 國際大會主席 Dundar F. Kocaoglu 教授非常熱愛台灣，在其研究室之台灣留學生亦表現良好，Kocaoglu 教授已允諾出席今年 12 月 11-13 日由本校科技管理研究所承辦之「中華民國科技管理年會暨論文發表大會」，為大會進行專題演講，我國如要走向國際化，就必須要多促進國際間之外交與交流。

5. 此會議中，本人吸收許多實務界之實務思考內容，此可配合本人在方法論之理論基礎，啟發許多問題之思考、發展更多的研究主題，未來預期在此方面將可有許多成果。