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Innovation System Assessment Model for Sustainability Planning in Taiwan

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Abstract: Research evidence has shown that innovation systems play crucial roles in the sustainability of a country. Taiwan as a natural resource-restricted society with a unique situation should pay great attention to related topics. Regarding this, scientific and strategic foresight planning is engaged in order to be competitive and sustainable. An advanced plan with evaluation and police research was revealed in this study, which utilized DEA (data envelope analysis) to reform qualitative principles and quantitively evaluate 22 counties of Taiwan, exploring potential opportunities among the counties. Moreover, based on the findings, a rational suggestion of smart healthcare development was investigated to help in decision making. In comparing the practical evidence with results, we conclude following viewpoints: First, sometimes policies have to be made with limited data and time because of the rapidly changing environment, though an effective solution to consistently bridge the conceptual principles with quantitative results is feasible. Second, we show quantitative results derived from qualitative principles that uncover missing phenomena from intuitive discussions. Third, by adapting the observation boundaries with variables, a new scenario can be exposed to meaningfully support decisions in new territories, including sustainability. Compared to intuitive decisions, scientific planning is fruitful according to social consensus in order to lay the foundation for sustainability.

Keywords: public evaluation; public sector management; innovation system; multiple criteria decision making; data envelopment analysis

1. Introduction

The concept of sustainable development (SD) deals with humanity's aspirations of a better life within the limitations imposed by nature, and it was defined as "the development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [1]. To balance economic, social, and environmental development, balancing stakeholder needs and operationalizing and measuring sustainability, the United Nations adopted the 17 Sustainable Development Goals (SDGs), in the 2015 United Nations General Assembly [2]. Researches with evidences indicate the innovation is the crucial key to achieve the goals [3–6].

How innovation system analyses contribute to sustainable transitions has been evidenced in practical evolution and academic studies [7]. The links between sustainability, innovation, and competitiveness at country level have been investigated, concluding that there is a high correlation (and a possible relationship) between social sustainability, innovation and competitiveness at country level [8]. For Europe to be more innovative and achieve overall progress and sustainability, the maturity and structural advancement of its innovation ecosystems and their determinants should be properly assessed. The Innovation Union Scoreboard [9] is one of the main tools applied to monitor and benchmark innovation across Europe, providing a regular update on the subject [10]. A friendlier

context and the stronger support from the government are relevant enablers for the successful implementation of sustainable business models [11]. Research has concluded that the country-specific tradition can influence their development of practices of transparency and accountability with respect to sustainability, and there is the need to improve transparency in that regard [12] this investigation aims to present an innovation system assessment system, particularly tailored to Taiwan [13].

In these, the early policy concepts of innovation can be dated to the mid-1980s. After that decade, the types of innovation systems that were developed included a national innovation system (NIS) [7,14], regional innovation systems (RISs) [15], sectoral innovation (SIS) [16,17], and technological innovation systems (TISs) [18–20]. These system approaches are highly interdependent across features, concepts, and boundaries. Various research works have analyzed the complex relationship between individual viewpoints and co-evolution mechanisms in regards to sustainable transitions [21,22]. This article claims to engage innovation system analyses to study the sustainability of transitions in equipping policy makers with a tool to identify system weakness that should be enhanced in order to influence policy directions in the promising growth of the system [7].

Among the types of innovation systems, NIS and RIS are highly emphasized not only in study but also in reports in international organizations and economics. There are well-established indicator systems to evaluate worldwide innovations for countries and economies. For example, The Global Innovation Index (GII) [23] and European Innovations Scoreboard (EIS) [9] aim to track global innovation and compare analyses of innovation performances in EU countries individually. These indictor systems guide the countries with scientific measurement rules to develop their national innovation system to achieve the common goal of worldwide sustainability. On the other hand, major economies and countries have focused on RIS to increase competition in the global economy. OECD (organization for economic co-operation and development), Europe, Japan, and China evaluate their RISs with their own constructs, principles, and relative indicators. These differences have been realized as impacts by the rapid evolution of international situations, and developing a scientific, innovative, and effective evaluation system is necessary in order for a country to be competitive and sustainable.

Taiwan, as a resource-limited society, is aware of the importance of innovation and sustainability. Projects supported by governments that create indictors to evaluate RIS are pushed urgently by policy makers. However, due to the uniqueness of the island environment and international situations, barriers to constructing a reliable indicator system should be considered carefully. Innovative policy making is important in gathering the consensus of people, which will solidify the foundation of promising growth in society. Under the circumstances, effective methodologies are an alternative solution. On the other end, the achievements from other methodologies are also considered as pre-study results to the indicator studies that help to conquer identified barriers in the early stages. This work attempts to achieve the following criteria: (1) Align the same concepts and bases under development in NIS and RIS projects. (2) Analyze quantitative results relative to qualitive principles and requirements identified by the relevant governmental department. (3) Evaluate cross-evidence with practical phenomena and under consensus of research. (4) Extend the methodology so it can be applied in different territories and topics, thereby leveraging the future of policy making.

"Six Special Municipalities" as well as the "5 + 2 Industrial Transformation Plan" are the most important policies and plans according to economic development in Taiwan nowadays. The local government in Taiwan, the highest administrative division units are classified as the province and special municipality since 1998. Taipei, New Taipei, Taoyuan, Taichung, Tainan and Kaohsiung are current special municipalities are also known as "Six Special Municipalities" in Taiwan [24]. The 5 + 2 Major Innovative Industries policy aims to upgrade Taiwan's industrial from traditional manufacturing to high-value-added business, service and solution [25–27]. The 5 + 2 industrial sectors focus on the internet of things, biomedical, green energy, smart machinery and defense then expended into new agriculture and circular economy. A strategical policy, named "Special Act for Forward-Looking Infrastructure", was constructed to align local industrial development with central government vision.

Which strategically empowered "Six Special Municipalities" and "5 + 2 industrial Transformation Plan" with the significant importance of Taiwan [28].

Developing adequate innovation systems will contribute to evaluating scientific exploration of the environmental status. Many projects with various methodologies have been discussed in parallel and tested in academic and practical ways. This study utilized data envelop analysis (DEA) methodology to explore the fitness between the current status and indicators by using data, and it makes a scientific suggestion of smart-health development. This study demonstrates an efficient, practical, and quantified method to resolve the complexity and gap between social phenomena and intuitive arguments in an efficient, comprehensive, and flexible manner. Policy makers can quickly obtain support for feasible and scientific decisions, for instance, if there is a shortage of evidence and data before a completed survey, if there are sudden changes in the situation, or if policy needs to be fine-tuned after environmental scans.

2. Methodology and Data

2.1. DEA Models

The data envelopment analysis (DEA) method was developed by Charnes et al. in 1978 [29]. It can be realized as leveraging the linear programing model in mathematics to approach an optimal efficiency in economic theory. A similar concept can be tracked to the paper by Farrell (1957) [30]. Differences between the concepts were discussed in a recent article [31]. DEA establishes an envelopment surface that is composed of an efficiency frontier among all decision-making units (DMUs), which are measured with user-defined multiple inputs and outputs. Then, the relative efficiency is calculated in numerical values. Manipulating the values and analyzing the trend of relationships help decision makers develop optimal strategies with relative efficiency. In order to approach individual scenarios more properly, various models have been developed with relative assumptions to support more precise decision making.

The early DEA model by Charnes et al. (1978) is known as CCR [29]. It was limited by certain assumptions, for example, its returns to scale (RTS) is constrained by constant returns to scale (CRS) only. However, the returns to scale issues are concerning in academic and practical matters. An extended model to deal with variable returns to scale (VRS) issues, named the BCC model, was invented by Banker et al. (1984). In addition to the BCC model, Tone (2001) proposed a slacks-based measure (SBM) model of DEA (SBM-DEA) to also deal with the issues. In his article, the SBM-DEA has close connections with the CCR and BCC models, evidenced by its validity and compatibility with numerical experiments [32]. Outperforming CCR and BCC models, the SBM model can interpret profit maximization from "dual sides". The model handles excesses inputs and output shortfalls of DMUs by directly providing an outstanding way to evaluate comprehensive viewpoints while making decisions. Its flexibility contributes to studies that are based on SBM-DEA, for example, super-efficiency DEA [33], network DEA [34], and estimation of RTS [35] studies of DEA.

2.1.1. Relations among Input-Oriented, Output-Oriented, and Non-Oriented SBM-DEA

Referring to the definition and computational scheme by Tone (2001, 2002) [32,33], the SBM model was reorganized according to the following statements.

- Definitions:

When dealing with n DMUs with input matrices $X = \left(x_{ij}\right) \in \mathbb{R}^{m \times n}$ and input matrices $Y = \left(y_{ij}\right) \in \mathbb{R}^{s \times n}$, assume $X > 0$ and $Y > 0$.

Define the production possibility set as P:

$$P = \{(x, y) \mid x \geq X\boldsymbol{\lambda},\ y \leq Y\boldsymbol{\lambda},\ \boldsymbol{\lambda} \geq 0\}, \tag{1}$$

where $\boldsymbol{\lambda}$ is a non-negative vector in $\mathbb{R}^n$.

A certain DMU $(\boldsymbol{x_o}, \boldsymbol{y_o})$ is denoted as:

$$\boldsymbol{x_o} = X\boldsymbol{\lambda} + \boldsymbol{s}^-, \tag{2}$$

$$\boldsymbol{y_o} = Y\boldsymbol{\lambda} - \boldsymbol{s}^+, \tag{3}$$

in which $\lambda \geq 0$, $s^- \geq 0$, and $s^+ \geq 0$. The vectors $s^- \in \mathbb{R}^m$ indicate input excess and $s^+ \in \mathbb{R}^s$ means output shortfall, which are called slacks. An index ρ was defined as:

$$\rho = \frac{1 - \frac{1}{m}\sum_{i=1}^{m} \frac{s_i^-}{x_{i0}}}{1 + \frac{1}{s}\sum_{r=1}^{s} \frac{s_r^+}{y_{ro}}} \tag{4}$$

Because $X > 0$ and $\lambda \geq 0$, $\frac{s_i^-}{x_{i0}} \leq 1$ can be obtained from Equation (2), and it holds that $0 < \rho \leq 1$.

- Computational scheme:

From the definition, the SBM is formulated as the fractional program:

$$\begin{array}{ll} \text{minimize} & \rho = \frac{1-\frac{1}{m}\sum_{i=1}^{m} \frac{s_i^-}{x_{i0}}}{1+\frac{1}{s}\sum_{r=1}^{s} \frac{s_r^+}{y_{ro}}} \\ \text{Subject to} & \boldsymbol{x_o} = X\boldsymbol{\lambda} + \boldsymbol{s}^-, \\ & \boldsymbol{y_o} = Y\boldsymbol{\lambda} - \boldsymbol{s}^+, \\ & \boldsymbol{\lambda} \geq 0,\ \boldsymbol{s}^- \geq 0,\ \boldsymbol{s}^+ \geq 0 \end{array} \tag{5}$$

In the context of the paper, Equation (5) was transferred to the CCR model, and mathematical equivalents were proven.

If analyzing the fractional equation to index ρ in program (5), input excess s^+ and output shortfall s^- were calculated at the same time. The model was also named as a non-oriented SBM model. In relation, this is in dealing with input excess s^+ and output shortfall s^- individually, as in programs (6) and (7). The model names are known as input-oriented SBM (SBM-I) and output-oriented SBM (SBM-O), respectively.

- Input-oriented SBM program:

$$\begin{array}{ll} \text{minimize} & \eta_o = 1 - \frac{1}{m}\sum_{i=1}^{m} \frac{s_i^-}{x_{i0}} \\ \text{Subject to} & \boldsymbol{x}_o = X\boldsymbol{\lambda} + \boldsymbol{s}^-, \\ & \boldsymbol{y}_o = Y\boldsymbol{\lambda} - \boldsymbol{s}^+, \\ & \boldsymbol{\lambda} \geq 0,\ \boldsymbol{s}^- \geq 0,\ \boldsymbol{s}^+ \geq 0 \end{array} \tag{6}$$

- Output-oriented SBM program:

$$\begin{array}{ll} \text{minimize} & \eta_o = 1 - \frac{1}{m}\sum_{i=1}^{m} \frac{s_i^-}{x_{i0}} \\ \text{Subject to} & \boldsymbol{x}_o = X\boldsymbol{\lambda} + \boldsymbol{s}^-, \\ & \boldsymbol{y}_o = Y\boldsymbol{\lambda} - \boldsymbol{s}^+, \\ & \boldsymbol{\lambda} \geq 0,\ \boldsymbol{s}^- \geq 0,\ \boldsymbol{s}^+ \geq 0 \end{array} \tag{7}$$

The concepts of input- and output-oriented models are similar to CCR models and compared in related studies [36–38].

2.1.2. Super-Efficiency SBM-DEA and Returns to Scale

The super-efficiency SBM was developed by Tone (2002), which was intended to rank the efficiency of DMUs among efficient frontiers evaluated by SBM. In brief, the model measures the distances

between DMUs in one frontier to a new frontier, and subsets excluded DMUs in the original frontier. This makes it possible to rank the DMUs in the frontier with a new efficiency $\delta^* > 1$ to identify their "super-efficiency" priority. The article also discusses the Super SBM-I (input-oriented super-efficiency SBM) and super SBM-O (output-oriented super-efficiency SBM) in mathematical terms. Program (8) lists the equations in which λ is noted as the algebraic expression of vector $\boldsymbol{\lambda}$.

Banker et al. (1984) relaxed the radial constraint measure from the origin in CCR, which extended the measurement of scale influences from CRS to VRS [39]. Tone (2002) deals with the scales' influence of SBM by adding the constraint vector $\boldsymbol{\lambda}$. Wu and An (2013) estimated the SBM return to scale among NDRS (non-decreasing returns to scale), NIRS (non-increasing returns to scale), and VRS under similar concepts with corresponding constraint to λ. Programs (8) and (9) are the SBM and super SBM in VRS with $\boldsymbol{\lambda}$ in algebraic formation, which is consistent with all definition in Tone (2002).

- SBM VRS

Definition 1. *Refers to Equations (1)–(4)*

[Program equations]

$$\begin{array}{ll} \text{mini} & \rho = \frac{1-\frac{1}{m}\sum_{i=1}^{m}\frac{s_i^-}{x_{i0}}}{1+\frac{1}{s}\sum_{r=1}^{s}\frac{s_r^+}{y_{ro}}} \\ \text{Subject to} & \boldsymbol{x}_o = X\boldsymbol{\lambda} + \boldsymbol{s}^-, \\ & \boldsymbol{y}_o = Y\boldsymbol{\lambda} - \boldsymbol{s}^+, \\ & \boldsymbol{\lambda} \geq 0,\ \boldsymbol{s}^- \geq 0,\ \boldsymbol{s}^+ \geq 0 \\ & \sum_{j=1,\neq 0}^{n} \lambda_j = 1 \end{array} \tag{8}$$

- Super-SBM VRS

Definition 2. *Define the production possibility set as P\:*

$$\mathrm{P}\backslash\left(\boldsymbol{x_o}, \boldsymbol{y_o}\right) = \left\{ (\overline{\boldsymbol{x}}, \overline{\boldsymbol{y}}) | \overline{\boldsymbol{x}} \geq \sum_{j=1,\neq 0}^{n} \lambda_j x_j, \qquad \overline{\boldsymbol{y}} \leq \sum_{j=1,\neq 0}^{n} \lambda_j \boldsymbol{y}_j,\ \overline{\boldsymbol{y}} \geq 0,\ \boldsymbol{\lambda} \geq 0 \right\} \tag{9}$$

Further, define a subset $\overline{P}\backslash(\boldsymbol{x_o},\ \boldsymbol{y_o})$ *of* $P\backslash(\boldsymbol{x_o},\ \boldsymbol{y_o})$ *as*

$$\overline{P}\backslash\left(\boldsymbol{x_o},\ \boldsymbol{y_o}\right) = \mathrm{P}\backslash\left(\boldsymbol{x_o}, \boldsymbol{y_o}\right) \cap \left\{ \overline{\boldsymbol{x}} \geq \boldsymbol{x}_o \text{ and } \overline{\boldsymbol{y}} \leq \boldsymbol{y}_o \right\} \tag{10}$$

Index δ *defines a weighted distance from* $\left(\boldsymbol{x_o},\ \boldsymbol{y_o}\right)$ *to* $(\overline{\boldsymbol{x}}, \overline{\boldsymbol{y}}) \in \overline{P}\backslash\left(\boldsymbol{x_o},\ \boldsymbol{y_o}\right)$ *as*:

$$\delta = \frac{\frac{1}{m}\sum_{i=1}^{m}\frac{\overline{x}_i}{x_{i0}}}{\frac{1}{s}\sum_{r=1}^{s}\frac{\overline{y}_i}{y_{ro}}} \tag{11}$$

[Program equations]

$$\begin{array}{ll} & \delta^* = \min\delta = \frac{\frac{1}{m}\sum_{i=1}^{m}\frac{\overline{x}_i}{x_{i0}}}{\frac{1}{s}\sum_{r=1}^{s}\frac{\overline{y}_i}{y_{ro}}} \\ \text{Subject to} & \overline{\boldsymbol{x}} \geq \sum_{j=1,\neq 0}^{n} \lambda_j x_j, \\ & \overline{\boldsymbol{y}} \leq \sum_{j=1,\neq 0}^{n} \lambda_j y_j, \\ & \overline{\boldsymbol{x}} \geq \boldsymbol{x_o} \text{ and } \overline{\boldsymbol{y}} \leq \boldsymbol{y_o} \\ & \overline{\boldsymbol{y}} \geq 0,\ \boldsymbol{\lambda} \geq 0. \end{array} \tag{12}$$

The program is transformed to CCR-I, CCR-O, and discuss the case of zero values to evidence the compatibility of DEA models [33].

2.2. Data

The foundations of the study are based on pioneering surveys of worldwide mainstream innovation indicator systems. One of the purposes is to leverage the concepts and principles from international economy systems with their outstanding viewpoints and investigations as well as to construct an adequate indicator for Taiwan. With a small but unique existence in the regional economics in East Asia, the government pays great attention to the system in order to indicate the right direction to a sustainable society. The consensus between society and the government agrees, that accelerating innovation with increasing efficiency is the key to overcoming the weakness of lacking natural resources compared to neighbor countries.

Regarding this, Taiwan innovation indicator systems were taken into serious consideration. Grupp and Mogee [40] surveyed various indicators systems including OECD in national science indicator report, National S&T (science and technology) indicators reports in Europe and S&T indicators in Japan. The article compared the background and relationship of those indicator systems in early ears. However, the recent reports on individual indicator systems were unified with the guideline of the Oslo Manual [41,42]. The individual systems survey specific topics with their aspects and principles with individual interests and considerations. As this view point, a government support project reviewed individually for their aspects, principles, and indicators among OECD Science, Technology, and Industrial Scoreboard 2015 [43], European Innovation Scoreboard 2017 [44] and Japanese Science and Technology Indicators 2016 [45]. Table 1 is a summary of innovation indicators with relative aspects listed. The framework of a Taiwan innovation system is developed by referring to structures. In this case, three aspects with 20 principles are proposed to be the preliminary framework, and its architecture is shown in Figure 1. In the studies, as the pioneer evaluation project, 12 out of 96 indicators were selected by experts with the viewpoints of representativity, availability, integrity, and operability. The criteria are comparing with aspects of world-wide indicator system in Table 1 as well as the situation in Taiwan. Besides, various variable combinations of same DEA models have been pre-tested and results to agree with the indicators selected by experts. The indicators are coded from (I-1) to (I-12) in this article, and the relative investigated item, description, and source are listed in Table 2. The preliminary framework is showed in Figure 1, and the marked attributes are input and output. The data collected in 2017 are reorganized in Tables 2 and 3 by type of input and output. Table 4 lists the relative data collected in 2017.

Table 1. Analysis of major, worldwide innovation indicator systems.

Indicator System	Architecture	Contents of Aspects
The OECD Science, Technology, and Industrial Scoreboard 2015	5 aspects 10 principles 150 indicators	1. Investing in knowledge, talent, and skills 2. Connecting to knowledge 3. Unlocking innovation in firms 4. Competing in the global economy 5. Empowering society with science and technology
European Innovation Scoreboard 2017	4 aspects 10 principles 27 indicators	1. Framework conditions 2. Investment 3. Innovation activates 4. Impacts
Japanese Regional Science and Technology Indicators 2016	4 aspects 11 principles 28 indicators	1. R&D (research and development) expenditure 2. R&D personnel 3. Industry–university collaboration 4. Patents and articles

Table 2. Input indicators with descriptions and sources.

Code	Investigated Items (Indicators)	Description and Source
(I-1)	Number of Full-time Teachers in Tertiary Institutions	Number of full-time teachers in public and private colleges and universities https://stats.moe.gov.tw/qframe.aspx?qno=MgAxADQA0
(I-2)	Number of Tertiary Institutions	Number of colleges and universities in the county and municipal jurisdictions announced by the Ministry of Education https://ulist.moe.gov.tw/
(I-3)	The Educational Level Structure of the Employed	Number of full-time teachers in public and private colleges and universities https://stats.moe.gov.tw/qframe.aspx?qno=MgAxADQA0
(I-4)	Number of Purchased Plans Received by Tertiary Institutions	Total number of projects published by colleges and universities in the county and city jurisdictions on the Taiwan Procurement Bulletin https://goo.gl/ws3WSx
(I-5)	Budget or Sum of Purchased Plans Received by Tertiary Institutions	Total number of items published on the Website of the Taiwan Procurement Bulletin by colleges and universities https://goo.gl/ws3WSx
(I-6)	Indictors of youth	Population ratio (0–14 years old/15–64 years old) in percent https://goo.gl/1yHDKG

Table 3. Output indicators with descriptions and sources.

Code	Investigated Items (Indicators)	Description and Source
(O-1)	Number of technology transfer patents	Statistical table on the number of applications for natural persons https://goo.gl/HghC6f
(O-2)	Number of New Registered Companies	Number of existing households registered by the company and the amount of paid-in capital https://data.gov.tw/dataset/8296
(O-3)	Number of Foreign Registered Companies	Number of companies recognized by foreign companies in the county and city https://goo.gl/cX35Dq
(O-4)	Level of Industry–academia Cooperation	Level of Industry–academia cooperation, excluding Construction and Education Cooperation https://goo.gl/wohB1X
(O-5)	Amount of Investment in R&D	Investment amount of R&D of factories in operation https://goo.gl/iekQzC
(O-6)	Number of Companies Investing in R&D	Overview of the R&D of factories in operation https://goo.gl/iekQzC

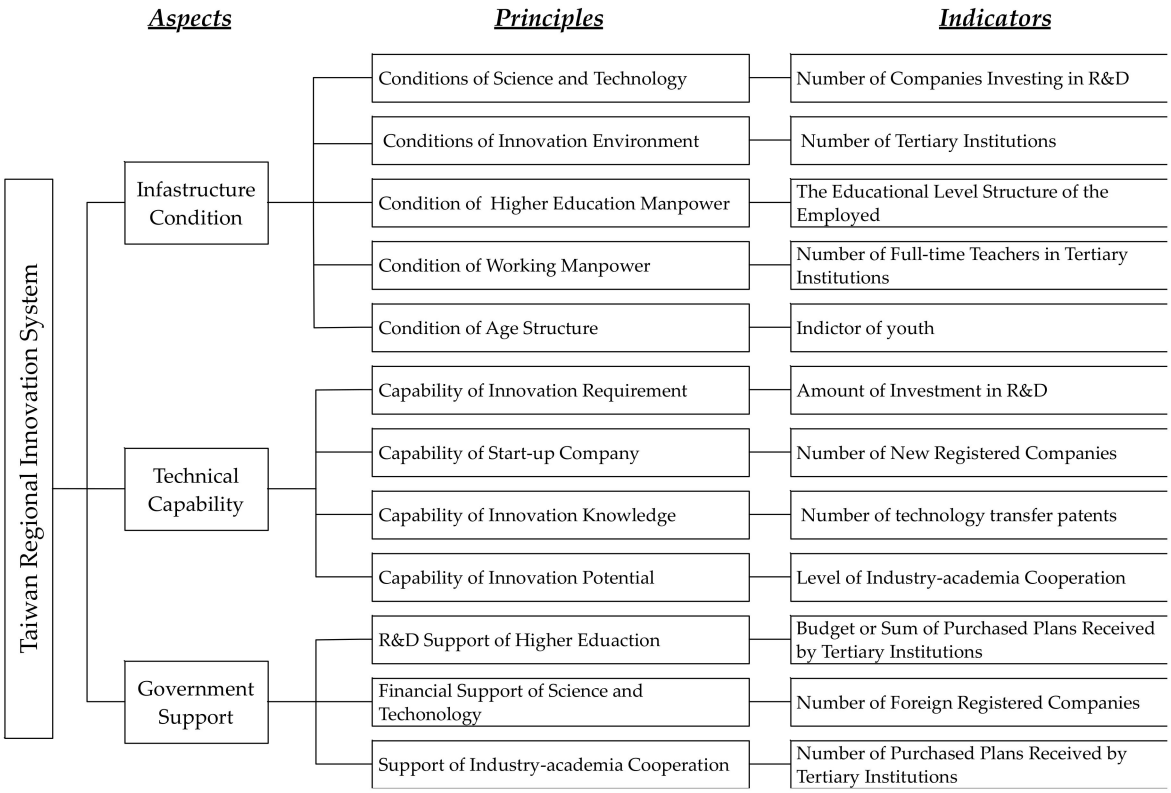

Figure 1. The preliminary framework and architecture.

Table 4. Data of input and output indicators of Taiwan in 22 counties and cities in 2017.

No.	County/City	(I-1)	(I-2)	(I-3)	(I-4)	(I-5)	(I-6)	(O-1)	(O-2)	(O-3)	(O-4)	(O-5)	(O-6)
1	Keelung City	654	3	50.47	198	295,172,049	85.19	111	107	4	1	1,392,389	31
2	Taipei City	10,654	29	81.05	7441	21,243,701,232	83.63	1880	3194	3798	47	5,601,146	145
3	New Taipei City	4844	22	51.39	1245	1,541,788,480	87.4	2045	3242	579	12	61,404,633	1312
4	Taoyuan City	3891	15	47.51	1045	1,944,103,673	89.22	781	2298	189	13	106,489,582	1306
5	Hsinchu City	2164	5	59.9	833	1,166,351,017	88.5	179	430	77	0	90,815,599	280
6	Hsinchu County	482	2	48.75	54	94,784,482	88.01	176	616	134	6	72,542,478	475
7	Miaoli County	677	4	38.71	207	166,294,688	84.59	104	191	9	2	14,408,157	216
8	Taichung City	6286	17	50.65	1364	2,235,408,502	88.5	2357	4105	401	43	36,290,851	896
9	Changhua County	1225	5	36.55	294	398,239,070	85.22	821	853	38	5	6,544,445	336
10	Nantou County	463	3	37.98	379	308,809,740	83.48	140	152	4	0	2,412,860	98
11	Yunlin County	875	3	33.27	758	1,026,720,156	82.45	134	288	10	2	4,146,513	138
12	Chiayi City	711	2	64.06	166	203,114,070	85.84	92	167	6	2	205,141	18
13	Chiayi County	982	5	29.41	326	317,999,087	81.54	184	150	9	1	1,487,100	103
14	Tainan City	4752	15	44.68	2505	5,423,260,853	85.62	913	1349	77	16	55,439,738	667
15	Kaohsiung City	5233	25	50.28	1803	2,402,612,623	85.78	873	2367	185	11	25,179,030	679
16	Pingtung County	1388	5	35.63	616	1,051,745,515	84.18	157	386	7	2	993,658	126
17	Yilan County	604	4	41.1	786	1,414,129,567	84.66	107	219	13	0	1,489,749	96
18	Hualien County	999	5	42.42	149	263,842,463	84.67	50	57	6	0	92,290	13
19	Taitung County	256	2	29.12	260	291,907,751	84.44	31	92	1	0	1950	5
20	Lienchiang County	-	0	44.12	0	0	89.43	0	13	0	0	0	0
21	Kinmen County	149	1	38.35	52	75,489,845	87.76	18	85	1	0	49,351	4
22	Penghu County	123	1	47.01	76	53,003,446	84.46	10	59	0	0	0	0

3. Results

The data were tested by the DEA model in CCR and BCC to clarify if there were any concerning differences. After the analysis results, the SBM was utilized for integrity in the study. The first part was an empirical analysis to examine the effectiveness of SBM-C and SBM-V as well as the relevance among indicators as valid and reliable markers. In the second part, the suggestions of innovation policies, were promoted by validation and sensitivity tests between data and models. In the last part we added a new medical indicator and extended it to super-DEA models to evaluate promising places to invest in the smart-health industry across 22 counties and cities of Taiwan.

3.1. Empirical Analysis of SBM-DEA

3.1.1. SBM-C and SBM-V Model Analyses

Table 5 is the summary of SBM, including constant RTS (SBM-C) and variable RTS (SBM-V), and makes a remark on the efficiency of counties and cities. Compared to the (efficiency) score between SBM-C and SBM-V, we categorized efficiency into three groups (Lienchiang County and Penghu County were excluded due to insufficient data). The first type is "efficient", which means DMUs that belong to the group are efficient no matter if they have constant or variable RTSs. The other DMU types were marked as "efficient in VRS", which means they also reached an efficient frontier by releasing the constant RTS to variable RTS, and the remaining DMUs were the "insufficient" type.

Table 5. Summary of slacks-based measure (SBM) in constant and variable returns to scale (RTS).

No.	DMU	SBM-C		SBM-V			Remark
		Score	Rank	Score	Rank	RTS	
1	Keelung City	0.03498	17	0.08252	20	Increasing	inefficient
2 [1,*]	Taipei City	1	1	1	1	Constant	efficient
3 *	New Taipei City	1	1	1	1	Constant	efficient
4 *	Taoyuan City	1	1	1	1	Constant	efficient
5	Hsinchu City	1	1	1	1	Constant	efficient
6	Hsinchu County	1	1	1	1	Constant	efficient
7	Miaoli County	0.14456	12	1	1	Increasing	efficient in VRS
8 *	Taichung City	1	1	1	1	Constant	efficient
9	Changhua County	1	1	1	1	Constant	efficient
10	Nantou County	0.06033	15	1	1	Increasing	efficient in VRS
11	Yunlin County	0.09795	13	1	1	Increasing	efficient in VRS
12	Chiayi City	0.01036	19	0.02145	21	Increasing	inefficient
13	Chiayi County	0.06171	14	1	1	Increasing	efficient in VRS
14 *	Tainan City	0.30963	10	1	1	Increasing	efficient in VRS
15 *	Kaohsiung City	0.42092	9	0.48468	17	Increasing	inefficient
16	Pingtung County	0.03444	18	0.10795	19	Increasing	inefficient
17	Yilan County	0.05224	16	0.1382	18	Increasing	inefficient
18	Hualien County	0.0044	21	0.01591	22	Increasing	inefficient
19	Taitung County	0.00016	22	1	1	Increasing	efficient in VRS
20	Lienchiang County	1	1	1	1	Constant	Insufficient Data
21	Kinmen County	0.00561	20	1	1	Increasing	efficient in VRS
22	Penghu County	0.15037	11	1	1	Increasing	Insufficient Data

Note: [1] The cities marked with * indicate the city is one of "Six Special Municipalities" in Taiwan.

3.1.2. Correlation and Weight among Indicators

Table 6 is the Pearson correlation matrix for indicators. It identified there were highly related indicators which correlation coefficient larger than 0.8 including (I-1) to (I-2), (I-1) to (I-3), (I-1) to (I-4), (I-1) to (O-1), (I-1) to (O-2), (I-1) to(O-4), (I-2) to (O-1), (I-2) to (O-2), (I-4) to (I-5), (I-5) to (O-3), (O-1) to (O-2), (O-1) to (O-4) and (O-2) to (O-4). The reasons can be obtained from the definition and description

in Tables 2 and 3. In addition, the similarity of indicators trims the dimensions of model that satisfies the constraint [46].

However, there is no indicator that can be taken out the model to keep the weight of the indicator consistent with its viewpoints.

Table 6. Correlation table among indicators.

	(I-1)	**(I-2)**	**(I-3)**	**(I-4)**	**(I-5)**	**(I-6)**	**(O-1)**	**(O-2)**	**(O-3)**	**(O-4)**	**(O-5)**	**(O-6)**
(I-1)	1.000											
(I-2)	0.949 *	1.000										
(I-3)	0.659	0.550	1.000									
(I-4)	0.893 *	0.785	0.671	1.000								
(I-5)	0.829 *	0.693	0.675	0.987 *	1.000							
(I-6)	0.105	0.101	0.298	−0.136	−0.159	1.000						
(O-1)	0.867 *	0.850 *	0.472	0.625	0.547	0.237	1.000					
(O-2)	0.889 *	0.898 *	0.498	0.618	0.530	0.322	0.966 *	1.000				
(O-3))	0.795	0.664	0.705	0.937	0.964 *	−0.121	0.573	0.549	1.000			
(O-4)	0.915 *	0.791	0.597	07998	0.766	0.150	0.876 *	0.874 *	0.758	1.000		
(O-5)	0.321	0.352	0.276	0.090	0.020	0.627	0.337	0.443	−0.009	0.220	1.000	
(O-6)	0.533	0.652	0.177	0.180	0.070	0.499	0.701	0.777	0.065	0.448	0.772	1.000

Note: The number marked with * indicate the correlation coefficient >0.8.

3.2. Sensitivity Test

A sensitivity test was utilized to identify the effectiveness of individual indicators. This method compares the differences of efficiency scores, excluding the indicator and itself. In Tables 7 and 8, we defined the $\left(\overline{IND}\right)$ as a subset, removed the data belonging to the indicator (IND), then recalculated its efficiency score and rank in the SBM-C model. For example, the score and rank under $\left(\overline{I-1}\right)$ indicates a rebuilt SBM-C model, excluding the measurement of "number of full-time teachers in tertiary institutions "(I-1). The difference value represents the strength or weakness of the indicator to DMU. In addition, the re-ranking order of the DMU in SBM-C after elimination guides decision makers in discovering the relative contribution from each indicator by comparing original rankings.

Table 7. Sensitivity test results of input indicators.

No. (DMU)	Original		$(\overline{I-1})$		$(\overline{I-2})$		$(\overline{I-3})$		$(\overline{I-4})$		$(\overline{I-5})$		$(\overline{I-6})$	
	Score	**Rank**	**Score**	**Rank**	**Score**	**Rank**	**Score**	**Rank**	**Score**	**Rank**	**Score**	**Rank**	**Score**	**Rank**
1	0.03498	17	0.03423	18	0.03497	18	0.03183	17	0.03911	18	0.0386	18	0.03112	17
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3	1	1	1	1	1	1	1	1	1	1	1	1	1	1
4	1	1	1	1	1	1	1	1	1	1	1	1	1	1
5	1	1	1	1	1	1	1	1	1	1	1	1	0.28069	10
6	1	1	1	1	1	1	1	1	1	1	1	1	1	1
7	0.14456	12	0.14503	11	0.1535	11	0.12316	12	0.16305	12	0.1507	11	0.13191	12
8	1	1	1	1	1	1	1	1	1	1	1	1	1	1
9	1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	0.06033	15	0.05551	15	0.06156	15	0.0514	14	0.07003	14	0.0669	14	0.05557	15
11	0.09795	13	0.09983	13	0.09621	13	0.07203	13	0.11487	13	0.1017	13	0.08666	13
12	0.01036	19	0.01045	19	0.00951	19	0.01021	19	0.01148	19	0.01107	19	0.00943	19
13	0.06171	14	0.06278	14	0.06449	14	0.03929	16	0.06814	15	0.06509	15	0.05885	14
14	0.30963	10	0.3096	10	0.3032	10	0.28163	10	0.31463	10	0.2968	10	0.31769	9
15	0.42092	9	0.39838	9	0.41927	9	0.38116	9	0.43775	9	0.42174	9	0.37295	8
16	0.03444	18	0.03653	17	0.03571	17	0.02327	18	0.03984	17	0.03995	17	0.02919	18
17	0.05224	16	0.04902	16	0.05412	16	0.04237	15	0.06151	16	0.06154	16	0.04488	16
18	0.0044	21	0.0046	20	0.00472	21	0.00368	21	0.00477	21	0.00478	21	0.00383	21
19	0.00016	22	0.00014	22	0.00016	22	0.00014	22	0.00019	22	0.00019	22	0.00016	22
20	1	1	1	1	1	1	1	1	1	1	1	1	1	1
21	0.00561	20	0.00451	21	0.00536	20	0.00586	20	0.00602	20	0.00587	20	0.00604	20
22	0.15037	11	0.11308	12	0.14607	12	0.16262	11	0.16823	11	0.14971	12	0.16253	11

Table 8. Sensitivity test results of output indicators.

No. (DMU)	Original		$\overline{(O-1)}$		$\overline{(O-2)}$		$\overline{(O-3)}$		$\overline{(O-4)}$		$\overline{(O-5)}$		$\overline{(O-6)}$	
	Score	**Rank**	**Score**	**Rank**	**Score**	**Rank**	**Score**	**Rank**	**Score**	**Rank**	**Score**	**Rank**	**Score**	**Rank**
1	0.03498	17	0.02956	17	0.03069	17	0.04124	17	0.03076	17	0.05357	19	0.03366	17
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3	1	1	1	1	1	1	1	1	1	1	1	1	1	1
4	1	1	1	1	1	1	1	1	1	1	1	1	1	1
5	1	1	1	1	1	1	1	1	1	1	0.26264	9	1	1
6	1	1	1	1	1	1	1	1	1	1	1	1	1	1
7	0.14456	12	0.12766	12	0.13496	11	0.23885	11	0.13383	12	0.14472	12	0.12998	12
8	1	1	1	1	1	1	1	1	1	1	1	1	1	1
9	1	1	0.25915	10	1	1	1	1	1	1	1	1	1	1
10	0.06033	15	0.04895	14	0.05316	15	0.09093	14	0.05115	15	0.08368	16	0.05375	15
11	0.09795	13	0.08262	13	0.08627	12	0.12178	13	0.08805	13	0.11593	15	0.08912	13
12	0.01036	19	0.00867	19	0.00871	19	0.00913	19	0.00869	19	0.06187	18	0.00922	19
13	0.06171	14	0.0435	16	0.05486	14	0.06496	15	0.05562	14	0.11865	14	0.05475	14
14	0.30963	10	0.27189	9	0.28084	10	0.47768	9	0.27416	10	0.25437	10	0.27461	10
15	0.42092	9	0.41829	8	0.38504	9	0.41691	10	0.38489	9	0.39497	8	0.39095	9
16	0.03444	18	0.02768	18	0.02919	18	0.03572	18	0.02958	18	0.07662	17	0.02983	18
17	0.05224	16	0.04383	15	0.04535	16	0.05104	16	0.04458	16	0.13068	13	0.04684	16
18	0.0044	21	0.00365	21	0.00371	21	0.00376	21	0.00368	21	0.0412	20	0.00383	21
19	0.00016	22	0.00014	22	0.00014	22	0.00014	22	0.00014	22	0.02068	22	0.00014	22
20	1	1	1	1	0.66668	8	1	1	1	1	1	1	1	1
21	0.00561	20	0.0047	20	0.00469	20	0.00506	20	0.0047	20	0.02949	21	0.00502	20
22	0.15037	11	0.16756	11	0.0571	13	0.14735	12	0.14735	11	0.14735	11	0.14735	11

3.3. Apply Super SBM to Forecast the Smart-Health Industry

It's always full of challenges to justify the decisions on public investments are made in fair, scientific way. Satisfying social consensus is uneasy about Taiwan, some policy plans were serious debated as intuitive decisions then fall back that really harmful to social sustainability. Regarding this, the experimental mission endeavored a methodology with limit time and data resource has to be accomplished with scientific results. This project plans to extend the method to forecast the smart-health industry in 5 + 2 industrial policy transformation. The scenario is to choose the most potential county to invest in to increase opportunity for success in international competition. A base assumption was made, that a "highly efficient and innovative environment with a mature medical industry" would be a concrete foundation to invest in smart health. Data from the Medical Institute Assessment by Joint Commission Taiwan were reorganized as indicators [47]. Table 9 lists the statistics of the number of assessed institutes as the input indicator (I-m) and grade A institute as the output indicator (O-m). The institutes include children's and mental hospitals because of their unique assessments.

Table 9. Statics of assessed institutes of counties and cities in Taiwan.

No.	DMU	Number of Assessed Institutes (I-m)	Number of Grade A Institutes (O-m)
1	Keelung City	6	2
2	Taipei City	30	14
3	New Taipei City	40	10
4	Taoyuan City	31	11
5	Hsinchu City	7	3
6	Hsinchu County	8	4
7	Miaoli County	14	4
8	Taichung City	53	16
9	Changhua County	24	6
10	Nantou County	10	5
11	Yunlin County	14	5
12	Chiayi City	9	4
13	Chiayi County	4	3
14	Tainan City	33	12
15	Kaohsiung City	75	16
16	Pingtung County	20	8
17	Yilan County	7	4
18	Hualien County	9	3
19	Taitung County	7	2
20	Lienchiang County	1	0.0001
21	Kinmen County	1	0.0001
22	Penghu County	3	0.0001

3.3.1. Environment Scanning by DEA in CRS Models

RTS is a constraint to CRS because the assumption of this trial was to select the most efficient DMU from 22 counties and cities, which is shown in Table 10. The various models in CRS, including CCR-I, CCR-O, and SBM-C, were investigated and obtained the same results. Chiayi County, Yilan County, and Hsinchu County are the three top-ranked counties.

Table 10. Summary of data envelope analysis (DEA) models in constant returns to scale (CRS) of medical institutions.

Rank	DMU	CCR-I		CCR-O		SBM-C	
		No.	Score	No.	Score	No.	Score
1	Chiayi County	13	1	13	1	13	1
2	Yilan County	17	0.762	17	0.762	17	0.762
3	Hsinchu County	6	0.667	6	0.667	6	0.667
3	Nantou County	10	0.667	10	0.667	10	0.667
5	Taipei City	2	0.622	2	0.622	2	0.622
6	Chiayi City	12	0.593	12	0.593	12	0.593
7	Hsinchu City	5	0.571	5	0.571	5	0.571
8	Pingtung County	16	0.533	16	0.533	16	0.533
9	Tainan City	14	0.485	14	0.485	14	0.485
10	Yunlin County	11	0.476	11	0.476	11	0.476
11	Taoyuan City	4	0.473	4	0.473	4	0.473
12	Keelung City	1	0.444	1	0.444	1	0.444
12	Hualien County	18	0.444	18	0.444	18	0.444
14	Taichung City	8	0.403	8	0.403	8	0.403
15	Miaoli County	7	0.381	7	0.381	7	0.381
15	Taitung County	19	0.381	19	0.381	19	0.381
17	New Taipei City	3	0.333	3	0.333	3	0.333
17	Changhua County	9	0.333	9	0.333	9	0.333
19	Kaohsiung City	15	0.284	15	0.284	15	0.284
20	Lienchiang County	20	0	20	0	20	0
20	Kinmen County	21	0	21	0	21	0
22	Penghu County	22	0	22	0	22	0

3.3.2. Integrating Innovation and Medical Indicators

Table 11 lists the data with innovation input indictors from (I-1) to (I-6), and the added medical input indicator (I-m) and output indicators are treated in the same way. The purpose of Table 11 was to extend the conceptual assessment from innovative to only medically innovative indicators that are supposed to leverage smart-health development. Table 12a shows the data investigated in SBM-C, and it found 12 DMUs in the efficiency frontier that were not helpful in making decisions. The super SBM relaxed the efficiency score, which was limited in Table 1, then the new rank was obtained as Table 12b. Regarding the unbalanced indicator count between innovation and medical innovation, Table 12c weighs the medical indicators three times to get another rank. The first choice is still Hsinchu County; however, the rest are different.

Table 11. Summary of SBM-C by integrating innovation and medical indicators.

No.	(I-1)	(I-2)	(I-3)	(I-4)	(I-5)	(I-6)	(I-m)	(O-1)	(O-2)	(O-3)	(O-4)	(O-5)	(O-6)	(O-m)
1	654	3	50.47	198	295,172,049	85.19	6	111	107	4	1	1,392,389	31	2
2	10,654	29	81.05	7441	21,243,701,232	83.63	30	1880	3194	3798	47	5,601,146	145	14
3	4844	22	51.39	1245	1,541,788,480	87.4	40	2045	3242	579	12	61,404,633	1312	10
4	3891	15	47.51	1045	1,944,103,673	89.22	31	781	2298	189	13	106,489,582	1306	11
5	2164	5	59.9	833	1,166,351,017	88.5	7	179	430	77	0.0001	90,815,599	280	3
6	482	2	48.75	54	94,784,482	88.01	8	176	616	134	6	72,542,478	475	4
7	677	4	38.71	207	166,294,688	84.59	14	104	191	9	2	14,408,157	216	4
8	6286	17	50.65	1364	2,235,408,502	88.5	53	2357	4105	401	43	36,290,851	896	16
9	1225	5	36.55	294	398,239,070	85.22	24	821	853	38	5	6,544,445	336	6
10	463	3	37.98	379	308,809,740	83.48	10	140	152	4	0.0001	2,412,860	98	5
11	875	3	33.27	758	1,026,720,156	82.45	14	134	288	10	2	4,146,513	138	5
12	711	2	64.06	166	203,114,070	85.84	9	92	167	6	2	205,141	18	4
13	982	5	29.41	326	317,999,087	81.54	4	184	150	9	1	1,487,100	103	3
14	4752	15	44.68	2505	5,423,260,853	85.62	33	913	1349	77	16	55,439,738	667	12
15	5233	25	50.28	1803	2,402,612,623	85.78	75	873	2367	185	11	25,179,030	679	16
16	1388	5	35.63	616	1,051,745,515	84.18	20	157	386	7	2	993,658	126	8
17	604	4	41.1	786	1,414,129,567	84.66	7	107	219	13	0.0001	1,489,749	96	4
18	999	5	42.42	149	263,842,463	84.67	9	50	57	6	0.0001	92,290	13	3
19	256	2	29.12	260	291,907,751	84.44	7	31	92	1	0.0001	1950	5	2
20	0.0001	0.0001	44.12	0.0001	0.0001	89.43	1	0.0001	13	0.0001	0.0001	0.0001	0.0001	0.0001
21	149	1	38.35	52	75,489,845	87.76	1	18	85	1	0.0001	49,351	4	0.0001
22	123	1	47.01	76	53,003,446	84.46	3	10	59	0.0001	0.0001	0.0001	0.0001	0.0001

Table 12. Ranked DEA model results: (**a**) ranks in SBM-C, (**b**) ranks in super SBM-C, and (**c**) ranks in super SBM-C with adjusted weight.

(a)			(b)			(c)		
No.	**Score**	**Rank**	**No.**	**Score**	**Rank**	**No.**	**Score**	**Rank**
2	1	1	6	3.010	1	6	2.238	1
3	1	1	8	1.311	2	2	1.384	2
4	1	1	2	1.280	3	13	1.246	3
5	1	1	3	1.203	4	8	1.244	4
6	1	1	4	1.148	5	4	1.119	5
8	1	1	9	1.101	6	3	1.112	6
9	1	1	13	1.090	7	10	1.087	7
10	1	1	5	1.052	8	9	1.083	8
12	1	1	10	1.043	9	16	1.076	9
13	1	1	16	1.032	10	5	1.031	10
14	1	1	15	1.017	11	14	1.021	11
15	1	1	14	1.008	12	15	1.020	12
16	1	1	17	1.006	13	17	1.019	13
17	1	1	21	1.004	14	21	1.003	14
20	1	1	12	1.001	15	12	1.001	15
21	1	1	20	1.000	16	20	1.000	16
11	0.291	17	11	0.291	17	11	0.408	17
7	0.236	18	7	0.236	18	7	0.332	18
22	0.164	19	22	0.164	19	22	0.200	19
1	0.046	20	1	0.046	20	1	0.095	20
18	0.005	21	18	0.005	21	18	0.011	21
19	0	22	19	0.000	22	19	0.000	22

4. Discussion

The data collected in this study were quantitatively analyzed by DEA models. The indicators selected by exports matched well in practical observations. The discussion will correspond to results and procedures made in the previous section for a better understanding.

4.1. Suggestions from SBM-DEA Results

Figure 2 is a geographic map of Taiwan with the results of Table 5. It contributes to observing the relations of innovation efficiencies among national and regional viewpoints in the discussion.

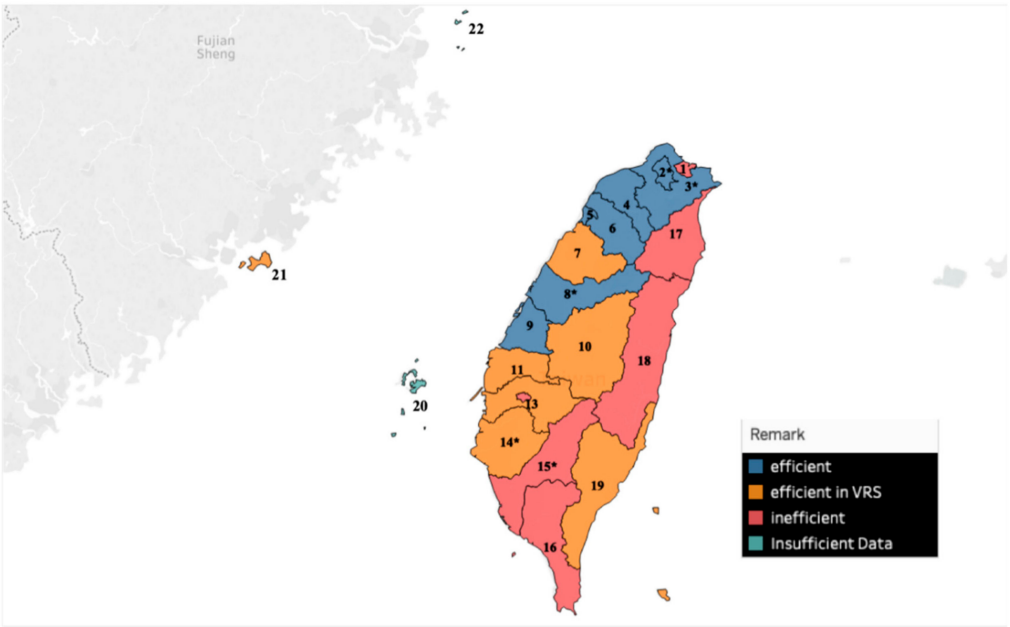

Figure 2. Results of efficient types in a geographic map of Taiwan.

4.1.1. Strategies Proposed by SBM with RTS

Section 3.1.1 classifies the innovation types of DMUs into inefficient, efficient in VRS, and efficient (in CRS and VRS). From a strategic viewpoint, inefficient DMUs have to eliminate input and increase output, whereas efficient DMUs only in VRS focus on increasing the output and analyzing those efficient DMUs to find out the key success factors to increase development. The data generated from DEA models can construct the guidelines to the counties/cities, respectively:

1. Guidelines for inefficient DMUs: Chiayi City, Kaohsiung City, Pingtung County, Yilan County, and Hualien County are listed in the inefficient group. Suggestions are made by the results of SBM-C for the group. Table 13 points out the target county that each inefficient county should refer to. The ratio of the reference set shows the gap between the inefficient city and target city. For example, the efficiency of Pingtung County is closer to Hsinchu County than New Taipei City, which means Hsinchu County is easier to reach within the two reference counties. The uniqueness of DMUs in the reference set can be resolved by the sensitivity test in Section 4.2. Table 14 shows the inputs to be decreased and Table 15 shows the outputs to be increased in order to raise the efficiency of the county/city.

Table 13. Guidelines for inefficient decision-making units (DMUs).

No.	DMU	Score	Rank	Reference Set	
1	Keelung City	0.035	17	Hsinchu County	0.968
12	Chiayi City	0.01	19	Hsinchu County	0.975
15	Kaohsiung City	0.421	9	New Taipei City	0.917
16	Pingtung County	0.034	18	New Taipei City Hsinchu County	0.015 0.715
17	Yilan County	0.052	16	Hsinchu County	0.608
18	Hualien County	0.004	21	Hsinchu County	0.284

Table 14. Suggestions for decreasing inputs of inefficient DMUs.

No.	(I-1)		(I-2)		(I-3)		(I-4)		(I-5)		(I-6)	
	Data	Diff. (%)	Data	Diff. (%)	Data	Diff. (%)	Data	Diff. (%)	Data	Diff. (%)	Data	Diff. (%)
1	654	−28.6	3	−35.5	50.47	−6.5	198	−73.6	295,172,049	−68.9	85.19	0
12	711	−33.8	2	−2.5	64.06	−25.8	166	−68.2	203,114,070	−54.4	85.84	0
15	5233	−9.4	25	−13.9	50.28	0	1,803	−32.4	2,402,612,623	−37.2	85.78	−0.3
16	1388	−69.8	5	−64.6	35.63	0	616	−90.6	1,051,745,515	−91.3	84.18	−23.6
17	604	−51.4	4	−69.6	41.1	−27.9	786	−95.8	1,414,129,567	−95.9	84.66	−36.7
18	999	−86.2	5	−88.6	42.42	−67.4	149	−89.7	263,842,463	−89.7	84.67	−70.4

Table 15. Suggestions for increasing outputs of inefficient DMUs.

No.	(O-1)		(O-2)		(O-3)		(O-4)		(O-5)		(O-6)	
	Data	Diff. (%)	Data	Diff. (%)	Data	Diff. (%)	Data	Diff. (%)	Data	Diff. (%)	Data	Diff. (%)
1	111	53.4	107	457.2	4	3142.6	1	48,077.5	1,392,389	4942.9	31	1383.1
12	92	86.5	167	259.7	6	2078.2	2	19,260.3	205,141	34,390.3	18	2473.8
15	873	129.1	2367	34.0	185	206.2	11	673.5	25,179,030	138.6	679	89.0
16	157	0	386	26.8	7	1394.4	2	12,359.0	993,658	5212.6	126	185.3
17	107	0	219	71.0	13	526.6	0.0001	-	1,489,749	2860.4	96	200.8
18	50	0	57	207.0	6	534.4	0.0001	-	92,290	22,230.3	13	938.0

2. Guidelines for efficient in SBM-V: Similar strategies to reach efficient DMUs on the front end in constant RTS are listed in Table 16. In addition, those DMUs can focus on the scale's influence, i.e., increase their output to perform efficiently in variable RTS. In this case, the reference sets are listed in Table 16, and output shortages are listed in Table 17.

Table 16. Guidelines for DMUs efficient in SBM-V.

No.	DMU	Score	Rank	Reference Set	
7	Miaoli County	0.145	12	Hsinchu County	0.794
10	Nantou County	0.06	15	New Taipei City	0.002
				Hsinchu County	0.777
11	Yunlin County	0.098	13	New Taipei City	0.007
				Hsinchu County	0.675
13	Chiayi County	0.062	14	New Taipei City	0.042
				Hsinchu County	0.559
14	Tainan City	0.31	10	Taipei City	0.211
				New Taipei City	0.09
				Taoyuan City	0.408
				Hsinchu County	0.073
19	Taitung County	0	22	Hsinchu County	0.176
21	Kinmen County	0.006	20	Hsinchu County	0.138

Table 17. Suggestions for increasing the outputs of efficient SBM-V DMUs.

No.	(O-1)		(O-2)		(O-3)		(O-4)		(O-5)		(O-6)	
	Data	Diff. (%)	Data	Diff. (%)	Data	Diff. (%)	Data	Diff. (%)	Data	Diff. (%)	Data	Diff. (%)
7	104	34.3	191	156.0	9	1082.2	2	138.215	14,408,157	299.7	216	74.6
10	140	0	152	218.3	4	2526.8	0.0001	4,682,788.7	2,412,860	2241.3	98	278.8
11	134	0	288	52.6	10	847.1	2	106.858	4,146,513	1091.2	138	139.2
13	184	0	150	220.1	9	1001.7	1	285.721	1,487,100	2800.4	103	211.1
14	913	0	1349	44.4	77	1121.9	16	4.649	55,439,738	0	667	7.39
19	31	0	92	17.9	1	2260.2	0.0001	1,056,348.1	1950	655,149.6	5	1573.2
21	18	34.9	85	0	1	1749.0	0.0001	827,452.1	49,351	20,183.1	4	1538.5

3. Discovery of efficient DMUs: High DMU efficiencies imply success factors that need to be explored. The following points aim to identify reasons with scientific explanations that can be suggested to policy makers, and they also review the current state of policy in Taiwan.

    - Urbanization: In 2010, five Special municipalities—Taipei, New Taipei, Taichung, Tainan, and Kaohsiung—were formally established in Taiwan. In 2014, the sixth special municipality was announced as Taoyuan. The results of these polices were highly represented as related to the innovation efficiency in Figure 2. Tainan and Kaohsiung are the only exceptions. Tainan is efficient in VRS, and the trend is growing upwards. Kaohsiung seems to suffer from ongoing inefficiency issues. All the results of DEA highly match with current observations in Taiwan.
    - "Technology diffusion" vs. "hidden champions": Research and practical observations all agree that "Hsinchu Science Park" has dominated economic development in Taiwan [48–50]. The high efficiency of Hsinchu county was considered to be due to the effect of "Technology Diffusion". Miaoli has developed in a similar way and set up "Tongluo Science Park" in 2010. However, a special relationship between Taichung City and Changhua County was noted. It is hard to explain technology diffusion as the leading cause of Miaoli's development. The relationships of industry are not upstream and downstream, but they are competitive and sometimes independent. For this reason, the concept of "hidden champion" was prompted as one of the explanations. Indeed, unique companies and businesses have been revealed in some reports in Changhua County, but in very low profile, which characterizes the "hidden champion". As the challenge of capitalization exists in high-tech industry, the Taiwan government is highly attentive towards developing another potential model beyond a science park. A survey of hidden champions is proposed based on these results. An industrial strategy that incorporates less capitalization will likely be sustainable compared to the high consumption of resources for some high technology industries, and it will increase the chances of success.

4.1.2. Effectivity of Indicators

Qualitive principles have to support and consist of the quantitative indicators in a well-established indicator system. Effectiveness is constrained by the related model, which was DEA in this paper. The suitable number of input and output indicators should be no more than half of the DMUs. In this case, there were 22 DMUs, so the number of input and output indicators should be less than 11. The correlation results show highly related indictors that satisfy the assumptions and keep the weighting. However, that also implies that DEA may not be an innovative assessment system because 20 indicators were proposed in the Taiwan Innovation System. A more detailed search will be made on the issues once the system is defined.

4.2. Sensitivity Test

When the number of DMUs under review changes, when different inputs and outputs are selected, or when there are numerical changes in the inputs and outputs, the shape or position of the leading efficiency boundary of the DEA may be affected. In order to make the efficiency measurement more convincing, a sensitivity analysis ensures the credibility of the efficiency measurement results. Figures 3–5 are the radar charts describing the variation in efficiencies of individual indicators after a sensitivity test, which are grouped by efficiency types for comparison. The higher positive value means the indicator contributes more efficiency to the DMU, and negative values are the converse way.

DMUs in the efficient group show import evidence. Hsinchu City is outstanding in indicator (I-6) "indictor of youth" and indicator (O-5) "amount of companies investing in R&D". Changhua County leads in indicator (O-1) "number of technology transfer patents". The findings highly support our inference to characteristics of "technology diffusion" and "hidden champions". The remaining DMUs had balanced growths.

DMUs that performed efficiently only in VRS varied in indicators (O-3) "number of foreign registered companies" and (O-5) "number of companies investing in R&D". They are attributed to internationalization and investment. Inefficient DMU statuses are diversified. Chiayi City, Yilan County, and Hualien seemed to suffer from less investment. Kaohsiung City and Pingtung County were inefficient overall. This analysis was highly consistent with the current status in Taiwan.

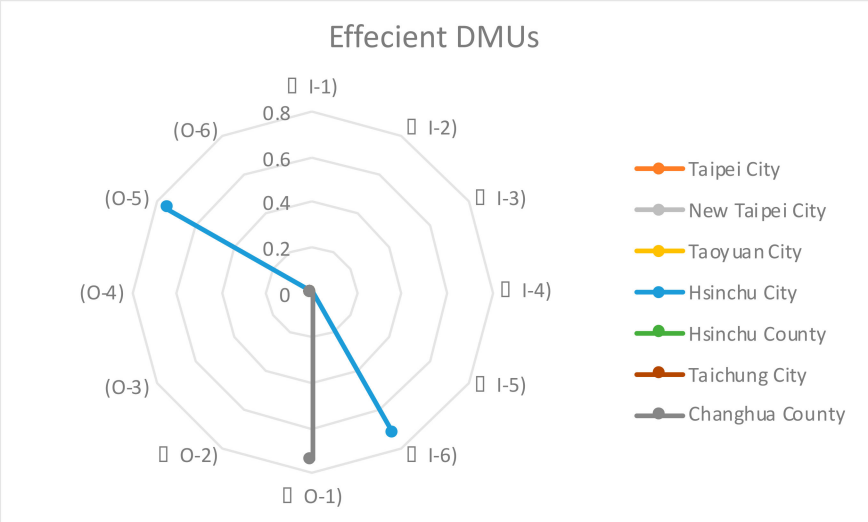

Figure 3. Comparison of efficient DMU indicators by sensitivity test.

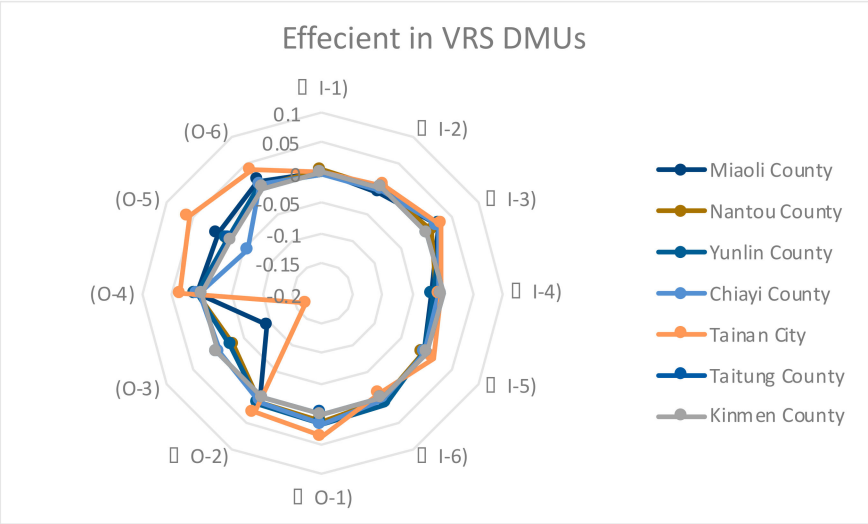

Figure 4. Comparison of efficient variable returns to scale (VRS) DMU indicators by sensitivity test.

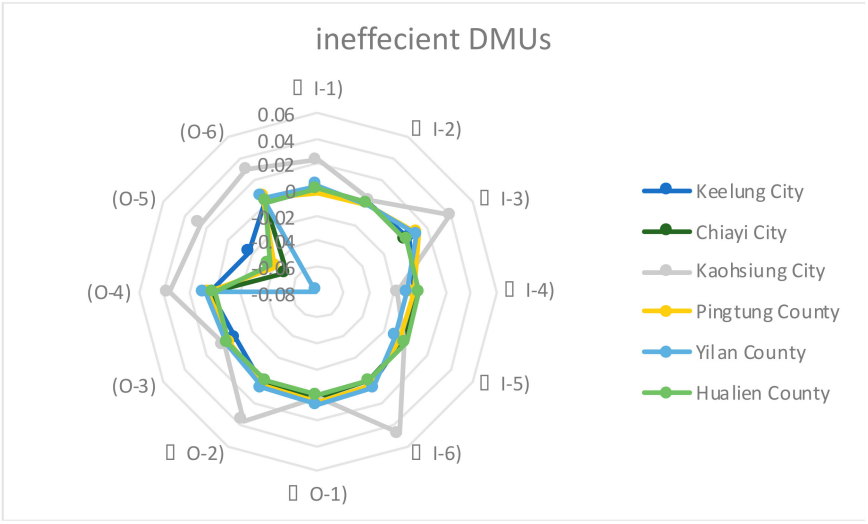

Figure 5. Comparison of inefficient DMU indicators by sensitivity test.

4.3. Strategic Foresight Innovation System

The plan in 3.3 forecasts the possibility to assess a new industrial investment strategy based on an innovative system. The focus aims to construct a bidirectional methodology between indicator system and strategic policy. "Foresight" has been highly emphasized in the Taiwan government in recent years. It should be possible to apply the methodology in other territories.

4.4. Limitations and Future Studies

As this study is a pioneering project of the Taiwan Innovations System, there are an increasing number of indicators under survey. Not only the 12 out of 97 indicators voted by experts, but also various combinations have been tested and concluded consistency with 12 indicators. Missing data in counties are requested to be filled in the upcoming year. The title of 97 indicators collected form government reports still accumulates yearly, and the panel data are possible to apply in testing other DEA models like 2-stage or network models. The indicators of worldwide innovation systems lean towards economic growth; however, more environmental indicators are necessary in regard to sustainability.

5. Conclusions

Innovation plays a crucial role for a society to develop sustainably. An innovation indicator system is established as a foresight plan to rationalize strategic decisions made by the government. However, as individual countries are unique, it is difficult to directly transfer the system between economies without proper evaluation. This study proposes a DEA assessment processes to align indicators with practical phenomena. The proposed procedures not only evidence its effectivity but also aid in discovering potential opportunities in Taiwan. The contributions include its efficiency, consistency, and extendibility, by cross-referencing DEA models, in making decisions from the early survey stage to forecasts in future policy making.

The article contributes to knowledge advancements in several ways. First, it applied a single methodology DEA but in various models corresponded to individual development stages including construct concepts, data validation, empirical evidence and propose a new plain. Comparing to composite indicator systems of RIS, it takes advantages in simplicity, consistency, robustness and efficiency. Second, it not only assessed the regional innovation among 22 counties in Taiwan but also discovered a promising "hidden champion" model to compensate the over-reliance of high-tech development. In other words, it demonstrates a possible thinking for social sustainability from competing to cooperate development across regions. At last, as foresight innovations with forward-looking plans dominate the future Taiwan. This study proposes operational procedures to extend the established results to foresee the changes in scientific way. That is a guideline on data collection and manipulation bridging from the academical study to practical application.

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