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EVALUATION OF REGIONAL INNOVATION CAPABILITY: AN EMPIRICAL STUDY ON MAJOR METROPOLITAN AREAS IN TAIWAN

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Abstract. Establishing an analytical structure to classify proper criteria and identify the relative importance among them in different cities or municipalities for selection and resource allocations of government-sponsored regional innovation is crucial. In this paper, we construct an index system through the subject views of experts to evaluate regional scientific and technological innovation capabilities and collect empirical data to compare the six special municipalities in Taiwan by employing a hybrid CFPR-VIKOR approach. The research results show that a structural evaluation system is a basis for regional innovation policy. The need for fundamental data and regional resources assessments is apparent, and the role of the central government needs to be adapted to rapid changes. Through the design and adjustment of the regulatory system, decision-makers can decide how to allocate resources and further contribute to the development of regional innovation. We demonstrate that our approach can be extended to the regional innovation policies in the public sector.

Keywords: regional innovation system, innovation capability, science and technology, multi-criteria decision-making, CFPR-VIKOR, Taiwan.

JEL Classification: C44, O11, O38, P25, R58.

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Introduction

Innovation is a multi-level phenomenon that nests and evolves in various societies (Abbasi et al., 2019). Through an evolutionary process of collective learning, companies, research institutions, customers, governments, financial institutions, and other stakeholders can work together for innovation and develop cooperative projects (Tödtling & Trippl, 2005; van Mierlo et al., 2010). Since Cook (1992) first published his research on Regional Innovation Systems (RIS), the concept of RIS has received significant attention in both academic and policymaking contexts mainly because of the growing importance of evolution and development in a globalized economy in terms of national or non-State economic entities (Freeman, 2002). For example, Nelson (1993) defined RIS as a system formed by regional systems, regulations, innovation practices, etc., to promote regional innovation activities; Cooke et al. (1997) focused on the institutional and organizational dimensions of RIS; Braczyk et al. (1998) analyzed the role of government governance under globalization; Asheim and Coenen (2005) discussed different types of RIS. Some researchers emphasized the importance of multi-actor innovation networks (Todtlin & Trippl, 2005; Pekkarinen & Harmaakorpi, 2006), innovative resources, institutional and framework conditions, and innovation outputs and commercialization (Buesa et al., 2010; Chen & Guan, 2011). Others studied the determinants of the efficiency of RIS (Fritsch & Slavtchev, 2011; Abbasi et al., 2011; Dobrzanski & Bobowski, 2020). Most recently, Fernandes et al. (2021) and López-Rubio et al. (2020), aiding in the definition of new territorial innovation policies, applied bibliometric analysis to evaluate existing research results in detail and identified the main trends in research.

Besides academic research, many countries have promoted various RIS policies to foster knowledge creation and innovation at national, regional, and local levels. For instance, the Japanese government started cluster policies in 2001 (Kitagawa, 2005; Okamuro & Nishimura, 2015; Haberla, 2018). The German government adopted a new German high-tech strategy entitled "Innovation for Germany" to ensure coherence within Germany's innovation policy and enhance economic growth (European Commission, 2018). The United States passed the U.S. Innovation and Competition Act of 2021 to generate investments in research and development and advanced manufacturing, including creating regional technology hubs and supply chain resiliency programs (Congress.gov, 2021). Not only national public administrations but also supranational organizations such as the European Union (EU), the Organisation for Economic Cooperation and Development (OECD), and the World Bank have adopted the innovation system approach to develop innovation policies (Lundvall et al., 2002; Sharif, 2006; López-Rubio et al., 2020). For example, The European Commission proposed Research and Innovation Strategies for Smart Specialisation (RIS3) in 2011 to link innovation policy on selected priority areas (European Commission, 2014a), contributing to growth and prosperity by helping and enabling regions to focus on their strengths (European Commission, 2017). OECD Reviews of Innovation Policy assess the innovation system of the individual OECD member, focusing on the role of government and partner countries and providing concrete recommendations on how to improve policies (OECD, 2018; Fagerberg & Hutschenreiter, 2020). The World Bank also played an important role in supporting innovation systems projects (Goel et al., 2004), including lending and investment portfolio for innovation and entrepreneurship (World Bank, 2014).

As governments in the world attempt to be more innovative and competitive but remain effective and efficient, the decision of government-sponsored RIS projects has become more important. Due to the funding scale and complexity of technology, RIS development's selection and resource allocations can be viewed as a multiple-attribute decision that a review committee typically makes with experts from academia and the government in Taiwan. However, these experts, who have diverse knowledge, enter the group with different assumptions, viewpoints, and interpretations of the issues involved and often make decisions based on evaluation criteria that are not clearly defined. It is critical to develop an analytical structure to classify proper criteria and identify their relative importance since the purpose of weighting is to identify the most appropriate criteria and to help the optimal resource allocations (Henriksen & Traynor, 1999). Thus, an effective mechanism to resolve this issue is critical.

Many published studies on RIS evaluation have developed a wide variety of multi-criteria decision-making (MCDM) models related to experts' judgments (Baker, 1974; Liberatore, 1987; Schmidt & Freeland, 1992). For example, Paredes-Frigolett et al. (2014) adopted MCDM to rank the performance of national innovation systems of Argentina, Brazil, Chile, Mexico, Portugal, and Spain. Various researchers formulated their theoretical frameworks based on the analytic hierarchy process method (AHP) to evaluate the innovation performance of the Czech NUTS2 or NUTS3 regions (Poledníková & Kashi, 2014; Minarčíková, 2015). Hwangbo and Park (2021) also adopted AHP to study the policy instruments related to the development of a regional innovation system in the Mekong Delta. Ture et al. (2019) used TOPSIS to evaluate the performance of 27 EU member countries in terms of each EU 2020 Strategy. Stanković et al. (2021) used VIKOR to rank the European cities according to their urban development indicators. However, research results show that many approaches become complex and challenging to maintain consistency within and among evaluators when there are many criteria. In this study, we compare previous research approaches and develop an analytical structure based on Consistent Fuzzy Preference Relation (CFPR) (Herrera-Viedma et al., 2004) and VIKOR (Opricovic & Tzeng, 2004) to help government RIS decisions.

There are various units of analysis for RIS, including cities, metropolitan regions, districts within cities regions, and areas on the supra-regional/sub-national scale (Klein & Sauer, 2016). Unlike RIS evaluation among countries, nationwide evaluation (Fattahi et al., 2013; Imani et al., 2017) is less discussed. It is critical to develop an analytical structure to classify proper criteria and identify the relative importance among them for allocating government resources in different cities or municipalities. In the following sections, we first describe the current regional development trend, related policies, and challenges to government-sponsored RIS decisions in Taiwan. We employ a hybrid CFPR and VIKOR approach to develop a hierarchical structure for RIS capability evaluation, and interview 36 RIS experts to obtain proper evaluating measurements. We then discuss the VIKOR findings of the theoretical and managerial perceptions by simulating the ranking of regional innovation conditions. We further discuss our research findings and then deliberate the policy implications and conclusions.

1. RIS in Taiwan: a background

Since Taiwan conducted the merger and upgrade of city-county in 2010, the two special municipalities, eighteen counties, and five cities have been merged and upgraded to six special municipalities, thirteen counties, and three cities. According to government statistics, the total population of the six special municipalities account for 69.45% of the national population in 2020 (Ministry of the Interior, 2021). Thus, industrial and commercial activities are more concentrated. For example, the number of registered profit-seeking enterprises in the six special municipalities accounted for 66% nationwide, the sum of sales amounts for 78%, and the total company capital is even above 87% (Ministry of Economic Affairs, 2020). Based on a survey in April 2021, the total number of startup hubs and innovation parks is sixty-four in Taiwan, and forty-six of them are located in the six special municipalities, with 70% above (Huang, 2021). The issue of a balanced development among the six special municipals becomes crucial.

Seeking to accelerate Taiwan's industrial transformation and upgrading and a coordinated and balanced development among regions, the government has promoted the 5 + 2 industrial innovation plan since 2016. The seven pillar industries are Internet of Things (also referred to as Asia Silicon Valley), biomedicine, green energy, smart machinery, national defense, high-value agriculture, and circular economy. In 2018, the Executive Yuan, Taiwan launched the National Strategic Plan for Regional Revitalization and designated 2019 as Taiwan's Regional Revitalization Year. The central government's policy aims to provide resources to support local governments to promote science and technology industries, accelerate local, form a regional industrial chain, and facilitate the development of different industries in various municipals in Taiwan.

Moreover, affected by the US-China trade war and the government's implementation of the "Three Major Programs for Investing in Taiwan" in 2019, many Taiwanese businessmen are attracted to return to invest in Taiwan. The programs also attract international companies to set up factories or increase investment in Taiwan. These enterprises need to evaluate and select appropriate investment locations. If a region has more resources and budget support from the central government and develops a strong innovation system, it would attract more enterprises to build factories or increase investment. The competition among the six special municipalities for more funding is getting more fierce. Thus, evaluating their innovation environment and performance is crucial for policymakers to design proper regional policies. In this context, the Board of Science and Technology of Executive Yuan, the highest policymaking body in science and technology in Taiwan, set up the Board of Science and Technology Regional Innovation Ecology Office (BOST RIEO) and conducted the "Regional Innovation and Technology Policy Development Plan". The primary mission of BOST RIEO is to promote regional innovation and balance the regional ecosystems. Under the plan, our research project "Research of Intelligence Survey for Regional Innovation Technology" aims to construct an index system to evaluate regional scientific and technological innovation capabilities and collect empirical data to compare different regions, especially the six special municipalities. This study details the development process of the evaluation system and MCDM mathematical methods employed to analyze the empirical data.

2. Capabilities evaluation of region innovation systems

2.1. Approaches to RIS evaluation

The literature of RIS is rich in theoretical and empirical studies. Pino and Ortega (2018) reviewed 78 articles from nine top journals and categorized RIS research into organizational, institutional, capabilities, national, and assessment five approaches[1]. López-Rubio et al. (2020) employed bibliometric techniques to analyze RIS studies from 1992 to 2017 and reveals three trends of RIS: (1) *The innovation system research* explores the approach of different perspectives such as institutions, organizations, networks, policies, regulations, or the evolutionary; (2) *The knowledge management research* focuses on knowledge creation, spillover, diffusion, flows, R&D, and patents; and (3) The research on *entrepreneurial ecosystems* has been an increasing concern in recent years[2]. Fernandes et al. (2021) further identified four distinct clusters of RIS, and essential research factors within each cluster: (1) *The regional knowledge systems* focus on the role of knowledge externalities and the new and economically sound knowledge; (2) *The regional institutional systems* emphasize that the spillovers from the private sector, universities and other public research institutions, as well as the intensity of the public-private interactions, could generate positive effects on the efficiency of the R&D; (3) *The regional R&D systems* verify the importance of the geographical co-locations of university research centers and industrial R&D facilities, the existence of a pool of well-trained and educated workers contribute to support of innovation as well as regional growth; and (4) *The regional network systems* focus on the interconnection between the environment of a dynamic network of companies and innovation.

The vast literature reveals that RIS involves many tangible and intangible components, actors, functions, and activities (Pino & Ortega, 2018). The capability of a region to produce and access innovation depends on the combination of components, interactions among actors, and efficient functions within the system (Lopes et al., 2019). Figure 1 shows the infrastructure, actors, and activities of a RIS ecosystem.

2.1.1. Infrastructure

From the perspective of the relationship between innovation and geography, an area's innovation capacity was determined by geographic embeddedness, regional and local conditions, as well as the general macroeconomic situation in which the regions are embedded (Ho, 2009; Muscio, 2006; Capello et al., 2008; Pino & Ortega, 2018). First, innovation certainly needs ample financial resources and human resources. Markard and Truffer (2008) mentioned that the configuration of RIS can be assessed by linking the region to its financial capacity and its jurisdiction capacity. Cooke and Morgan (1993) emphasized the importance of high-grade

[1] There are different representative research in each approach: the organizational approach (Christopherson & Clark, 2007; Muller & Zenker, 2001); the institutional approach (Asheim et al., 2011; Li, 2015); the capability approach (Lau & Lo, 2015; Zhao et al., 2015); the national approach (Carrincazeaux & Gaschet, 2015; Lengyel & Leydesdorff, 2011; Sun & Liu, 2010); the assessment approach (Leydesdorff & Fritsch, 2006; Zabala-Iturriagagoitia et al., 2007).

[2] Representative RIS researches in each trend include: the knowledge management research (Muller & Zenker, 2001; Fritsch & Franke, 2004; Asheim & Coenen, 2005; Rodriguez-Pose & Crescenzi, 2008); the innovation system research (Cooke et al., 1997; Todtling & Trippl, 2005; Freeman, 1995; Oh et al., 2016). The entrepreneurial ecosystems (Yam et al.., 2011; Spigel, 2017; Audretsch & Belitski, 2017).

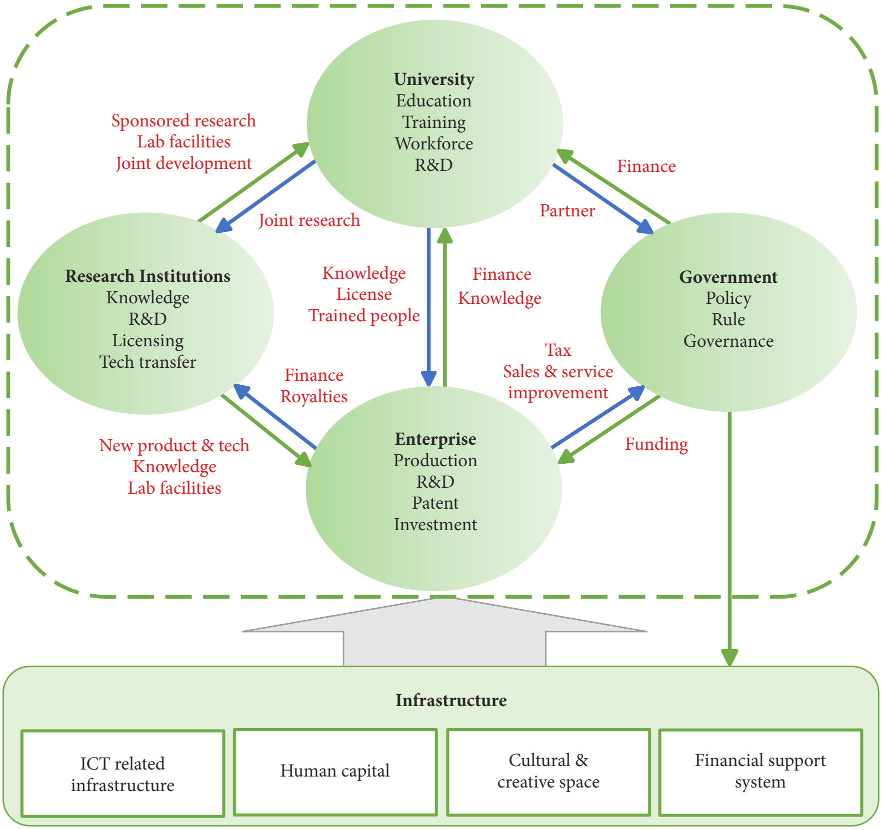


Figure 1. Regional innovation system model for special municipalities in Taiwan

labor market intelligence and associated vocational training. Leitner (2011) also revealed that human capital, one of the components of intellectual capital, is an essential element in a firm's innovation. Crescenzi and Rodríguez-Pose (2013) argued that institutional conditions, human capital quantity and quality, demographic and social factors, and social capital are crucial to innovative efforts and the generation of economically valuable knowledge. In addition, information and expertise outside a company affect its capability to innovate. Information and communication technologies related infrastructures that help the horizontal or vertical transfer of knowledge among knowledge organizations and industries (Arungu-Olende, 2007; Stejskal et al., 2018) are essential for enhancing technological innovation capabilities (Yam et al., 2011). The influence of social-cultural conditions and respective policies on innovation interaction at the regional level has been emphasized in the past years (Cooke et al., 2004; Trippl & Tödtling, 2008). Cultural and creative spaces intersect with innovation and innovativeness and embody diverse values such as collaboration, openness, and sustainability (Oksanen & Ståhle, 2013).

2.1.2. Actors and activities

The actors of regional innovation refer to the main participants in regional industrial activities, which have a strong demand for innovation activities and can innovate. They influence other innovation elements of RIS by adopting institutional and technical means. The triple helix innovation model refers to interactions among academia, industry, and government (Etzkowitz & Leydesdorff, 2000). Carayannis and Grigoroudis (2016) developed the quadruple and quintuple innovation helix framework to describe the interactions among university, industry, government and public-environment within a knowledge economy. Overall, the main actors in a RIS include university, research institute, government, and enterprise.

In a RIS, universities play a developmental role that involves different and closely interconnected mixes of diversity activities, such as research, teaching, knowledge transfer, regeneration (Uyarra, 2010). Except producing codified and commodified knowledge and human capital such as faculties and trained masters and PhDs, actively participating in building and sustaining local networks and flows of knowledge are also the critical functions of universities in regional innovation (Bramwell & Wolfe, 2008). Universities could also contribute directly and indirectly to regional economic development through the mechanisms of research collaboration, human capital, licenses, and patents (Brekke, 2021). The role of research institutes is to support the technological development of industry, and the critical interactions between them include contract research, licensing, bridging industry with the university, provision of extensive scientific facilities, and R&D (Intarakumnerd & Goto, 2018).

Porter and Stern (2001) claimed that interaction between private sector strategies and public sector policies influence innovation behavior and performance. Innovation policies must consider each region's specificities, which depend on political, economic, and socio-cultural factors, as well as the legal, technological, and environmental context (López-Rubio et al., 2020). Zhao et al. (2015) point out that governments should take charge of setting an appropriate political and regulatory framework to encourage collaboration, and technology development and exploitation. Public administrations often through the design, implementation, and evaluation of innovation policies (Edler & Fagerberg, 2017; European Commission, 2014b; OECD, 2015a) to stimulate innovation processes and improve the business environment. For example, governments could provide financial support for firms' research and development (R&D) or reduce the taxes owed on the economic returns to R&D (OECD/Eurostat, 2018).

From the perspective of regional development, the role of entrepreneurs in the functioning and performance of regional innovation systems has been a rising interest for research (Cooke & Leydesdorff, 2006; Farinha et al., 2019; Fernandes et al., 2021). Entrepreneurs that invest large sums in R&D can create a firm-level stock of knowledge (Hall et al., 2010), patents, and new products (Artz et al., 2010) and then increase their technological intensity (Zawislak et al., 2018). Building innovative networks is one of the innovative strategies that a company can adopt (Belussi et al., 2010) to contribute to the knowledge production, transformation, and dissemination activities in a RIS. The spillovers within the private sector and from universities and other public research institutions positively affect private-sector R&D (Fritsch & Slavtchev, 2011). Productive entrepreneurs could further boost economic growth by developing new products or process, and creating new jobs, technologies, and markets (Kritikos, 2014).

2.2. International assessments of RIS

Besides the academic research, many supranational organizations have developed various architecture and indexes and empirically evaluated RIS's innovation capabilities. OECD National Innovation System focuses on the systemic relationship between national innovation policies and the overall system, emphasizing the interaction among industry, government, academia, and research (OECD, 2015b). The evaluation architecture of OECD Science, Technology, and Industrial Scoreboard (OECD, 2015c) has 5 dimensions (i.e., investing in knowledge, talent, and skills; connecting to knowledge; unlocking innovation in firms; competing in the global economy; empowering society with science and technology), and 50 criteria. European Innovation Scoreboard reviews the research and innovation effectiveness of the EU Member States and their relative strength and weakness, with a framework of 4 major dimensions (i.e., framework conditions, investment, innovation activates, and impacts), ten criteria, and 27 indicators. Japan Institute of Science and Technology Policy releases "the 2018 Regional Science and Technology Indicators Report", which employs four levels, twelve standards, and 30 indicators to analyze 47 prefectures in Japan. China developed the "Monitoring Report on China's Regional Innovation Capability" in 2013, which divides regional innovation capacity into five basic structures (i.e., innovation environment, innovation resources, enterprise innovation, innovation outputs, and innovation performances), each of which has a total of 124 monitoring indicators. In the fifth basic plan for science and technology starting in 2016.

3. A CFPR-VIKOR framework for RIS evaluation

MCDM methods cover a wide range of quite distinct approaches, such as AHP, ANP, PROMETHEE, etc. Opricovic and Tzeng (2004) proposed the basic theoretical structure and execution steps of VIKOR, presented it with many MCDM methods, and confirmed many of the advantages of VIKOR. Before using VIKOR to rank the degree of regional innovation, the weight of the evaluation criteria must be measured, and experts in the relevant fields must conduct the scientific measurement of the criteria. In many studies of MCDM, decisions on the weighting of evaluation criteria are often measured employing pairwise comparisons, and the most well-known is AHP. However, AHP's approach becomes quite complex and difficult to maintain consistency within and among all experts when there are many criteria. Based on the characteristics of fuzzy preference relationships with additive transitivity, the proposed consistent fuzzy preference relation (CFPR) significantly reduces and improves the insistency issues in AHP (Herrera-Viedma et al., 2004). In the traditional AHP pairs comparison method, if there are n items in the evaluation criteria, $n(n-1)/2$ pairs comparison is required. With the application of CFPR, only $n-1$ pairs comparison needs to be carried out. The advantages of using the CFPR method are computationally efficient and straightforward. We summarize the essence of CFPR (Herrera-Viedma et al., 2004) and VIKOR (Opricovic & Tzeng, 2004) as follows:

3.1. CFPR

The matrix $\boldsymbol{M} \subseteq \boldsymbol{X} \times \boldsymbol{X}$ is represented as the $\boldsymbol{X}$ criteria/alternatives formed by the multiplication preference relationship set $\boldsymbol{M}$, here $\boldsymbol{M} = (m_{ij})$, m_{ij} represents the comparative value of the preference intensity for criteria/alternatives x_i and x_j, Saaty (1977) recommended the measuring value on a scale of 1 to 9, if $m_{ij} = 1$ indicating that there is indifference between criteria/alternatives x_i and x_j, $m_{ij} = 9$ indicates that criteria/alternatives x_i is absolutely important than x_j, and are called multiplication preference relationships when m_{ij} and m_{ji} are reciprocal and multiplicative as 1, i.e.:

$$m_{ij} \times m_{ji} = 1,\ i \in \{1, \cdots, n\},\ j \in \{1, \cdots, n\}. \tag{1}$$

(1) Fuzzy preference relationships

A preference matrix $\boldsymbol{P}$ formed by the $\boldsymbol{X} = \{x_1, x_2, \cdots, x_n,\ n \geq 2\}$ criteria/alternatives is a preference relationship of the product $\boldsymbol{X} \times \boldsymbol{X}$ with a membership function $\mu_p : \boldsymbol{X} \times \boldsymbol{X} \rightarrow [0,1]$, where p_{ij} is the degree of preference of the criteria/alternatives x_i compared to the x_j. If $p_{ij} = 0.5$ means x_i as good as x_j ($x_i \sim x_j$), $p_{ij} = 1$ means x_i definitely better than x_j, $p_{ij} = 0$ means x_i definitely worse than x_j, $p_{ij} > 0.5$ means x_i is relatively better than x_j $\left(x_i \succ x_j\right)$, $p_{ij} < 0.5$ means x_i is relatively worse than $x_j \left(x_i \prec x_j\right)$. Therefore, in the preference matrix $\boldsymbol{P}$, p_{ij} and p_{ji} are reciprocal and additive as 1, the equation is as follow:

$$p_{ij} + p_{ji} = 1,\ \ i \in \{1, \cdots, n\},\ \ j \in \{1, \cdots, n\}. \tag{2}$$

(2) Construct a fuzzy preference relationship matrix of consistency complementarity

$\boldsymbol{X} = \{x_1, x_2, \cdots, x_n, n \geq 2\}$ is a set of attributes/criteria, the decision matrix $\boldsymbol{M} = (m_{ij})$ is established by preference intensity pairwise comparisons for attributes/criteria and it is a reciprocal multiplicative preference relations matrix, here $m_{ij} \in [\frac{1}{9}, 9]$. Then, it can transfer matrix $\boldsymbol{M} = (m_{ij})$ to corresponding additive reciprocal fuzzy preference relationin matrix $\boldsymbol{P} = (p_{ij})$ by equation $p_{ij} = f(m_{ij}) = \frac{1}{2}(1 + \log_9 m_{ij})$ (Herrera-Viedma et al., 2004). Therfore, the elements of matrix $\boldsymbol{P} = (p_{ij})$ are between 0 and 1, and $\log_9 m_{ij}$ is due to the value of m_{ij} between $\frac{1}{9}$ and 9. The following formula is true if the complementary fuzzy preference relationship matrix $\boldsymbol{P} = (p_{ij})$ conforms to additive transitivity consistency.

$$\begin{cases} p_{12} + p_{23} + p_{34} \cdots + p_{(m-1)m} + p_{m1} = (m-1+1)/2 \\ p_{23} + p_{34} + p_{45} \cdots + p_{(m-1)m} + p_{m2} = (m-2+1)/2 \\ p_{34} + p_{45} + p_{56} \cdots + p_{(m-1)m} + p_{m3} = (m-3+1)/2 \end{cases},$$

$$p_{n(n+1)} + p_{(n+1)(n+2)} + p_{(n+2)(n+3)} \cdots + p_{(m-1)m} + p_{mn} = (m-n+1)/2,\ \forall n < m. \tag{3}$$

Therefore, we only need $n - 1$ value $\{a_{12}, a_{23}, \cdots, a_{n-1n}\}$ from the pairwise comparisons in adjacent sequence of attribute/criterion $\boldsymbol{X} = \{x_1, x_2, \cdots, x_n,\ n \geq 2\}$. Then, through the tranformation equations and formula (2) and (3), the other elements of the entire fuzzy preference relationship decision matrix $\boldsymbol{P}$ can be obtained. However, if some elements of this calculated matrix $\boldsymbol{P}$ are not within the interval [0, 1], but within the interval $[-a, 1 + a]$, in order to obtain a consistent, complementary fuzzy preference relationship matrix, it must be converted through the transformation function to achieve the requirement. The following function $\boldsymbol{P}' = f(p)$, can maintain the fuzzy preference relationship decision matrix $\boldsymbol{P}' = (p'_{ij})$ as consistency and complementarity, therefore the transformation function is:

$$\boldsymbol{P}' = f(p) = \frac{p+a}{1+2a}, \quad a = -\min(p_{ij};\ p_{ij} \in \boldsymbol{R}). \tag{4}$$

(3) Assess the weighting of the evaluation factors

Finally, the consistency obtained from the previous step complements the fuzzy preference relationship matrix $\boldsymbol{P}' = (p'_{ij})$. It then uses the following method to find the relative impact (weight) of each evaluation attribute/criterion:

$$A_i = 1/n\left(\sum\nolimits_{j=1}^{n} p'_{ij}\right), \quad W_i = A_i \Big/ \sum\nolimits_{i=1}^{n} A_i. \tag{5}$$

3.2. Essences of VIKOR

VIKOR is an optimized compromise solution in the decision-making of many criteria proposed by Opricovic (1998), which is based on the use of good advantages and acceptable stability concepts in the selection criteria in conflict with each other, the order and choice of many options. The basic concept is to define the best condition and the worst condition of each evaluation criterion at first. That is, in this study, the best condition of each evaluation criterion refer to the numberical value of the most resources in the evaluation region of each evaluation criterion, while the worst condition of each evaluation criterion is the lowest resources in the evaluation region of each evaluation criterion. The priority between the evaluation alternatives is then ranked by comparing the values of the total closeness of the best condition and the worst condition for each evaluation alternative. That is, when calculating the closeness of the indicators to the ideal value for each evaluation region, the assessment values for each assessment item must be added up. This study mainly uses the performance values of each evaluation area in each evaluation project to determine the ideal solution and negative ideal solution and uses the concept of the compromise planning method, to sum up, the distance between each evaluation area and positive and negative ideal solution (proximity degree), and obtains the advantages and disadvantages and ranking situation of each evaluation area. The following is a brief description of the operation steps of VIKOR (Opricovic & Tzeng, 2004).

(1) Determine the best performance value (BPV) and the the worst performance values (WPV)

This step determines the best and the worst performance values for each evaluation factor, so as to be the basis for calculating the closeness to the best alternative on each factor, which is obtained as follows:

$$e_i^+ = \max_j e_{ij}, \ e_i^- = \min_j e_{ij},$$
$$i = 1, 2, \cdots, \text{number of factors}, \quad j = 1, 2, \cdots, \text{number of alternatives}, \tag{6}$$

where e_j^+ is the best value of evaluated alternatives for j factor, e_j^- is the worst value of evaluated alternatives for j factor.

(2) Calculate the S_j value and the R_j value

This step is used to calculate the distance ratio to the best performance value (BPV) with considering factors weights for every evaluated alternative with respect to each factor, as follows:

$$S_j = \sum_{i=1}^{n} w_i \left(e_i^+ - e_{ij}\right) \Big/ \left(e_i^+ - e_i^-\right), \quad j = 1, 2, \cdots, \text{number of alternatives}; \tag{7}$$

$$R_j = \max_i \left[w_i \left(e_i^+ - e_{ij}\right) \Big/ \left(e_i^+ - e_i^-\right)\right], \quad j = 1, 2, \cdots, \text{number of alternatives}, \tag{8}$$

where S_j is the weighted total distance ratio of the j alternative to the BPV with respect to each factor, R_j is the weighted distance ratio of the j alternative to the WPV, w_i represents the relative weight of each factor, that is, the results of the CFPR in this study.

(3) Calculate the comprehensive indicator Q_j

$$Q_j = v\left[\frac{S_j - S^+}{S^- - S^+}\right] + (1-v)\left[\frac{R_j - R^+}{R^- - R^+}\right], \quad j = 1, 2, \cdots, \text{number of alternatives}, \tag{9}$$

where $S^+ = \min_j S_j$, $S^- = \max_j S_j$, $R^+ = \min_j R_j$, $R^- = \max_j R_j$, $[S_j - S^+ / S^- - S^+]$ indicates the distance ratio of the j alternative to the BPV, it represents the proportion of positive views of the majority. $[R_j - R^+ / R^- - R^+]$ indicates the distance ratio of the j alternative to the WPV. Finally, we can rank the alternatives by the Q_j value. The value closer to 0, the closer to the BPV, and the closer to 1 is closer to the WPV.

The v is the decision mechanism coefficients, when $v > 0.5$ indicates that the indicator used is more towards the majority decision, and $v < 0.5$ indicates that the indicator used is towards the decision with the least opposition. In many studies, v is set to 0.5, it can make the decision-making process to take into account both of group utility maximization and individual regret minimization.

(4) Rank the alternatives, sorting by the relationship between Q_j, S_j and R_j

When the following two conditions are satisfied, it can sort by the value of Q_j (the smaller is better)

Condition 1: Threshold conditions for acceptable advantage.

$$Q(A^2) - Q(A^1) \geq 1 \big/ (J-1), \tag{10}$$

where $Q(A^1)$ is the Q value of the first-ranking alternative. $Q(A^2)$ is the Q value of the second-ranking alternative, and so forth. J represents the number of all alternatives to be evaluated. The difference value between the comprehensive indicator Q_j of the two alternatives with a ranking difference of one order must exceed the threshold of $1/(J - 1)$. It just can be determined that the first-ranking alternative is indeed significantly better than the second-ranking one. As the same process, it can sequentially compare the third-rank and fourth-rank and so on for the ranking decision.

Condition 2: Acceptable decision stability.

After ranking by the Q value, the S value of the first-ranking alternative $S(A^1)$ must also better than the S value of the second-ranking alternative $S(A^2)$. As the same, the R value of the first-ranking alternative $R(A^1)$ must also better than the R value of the second-ranking alternative $S(A^2)$. When there are several alternatives, then compared the S and R values sequentially for the first, second, third, fourth ranking alternative, etc. to check the "Condition 2".

The judgment rule:

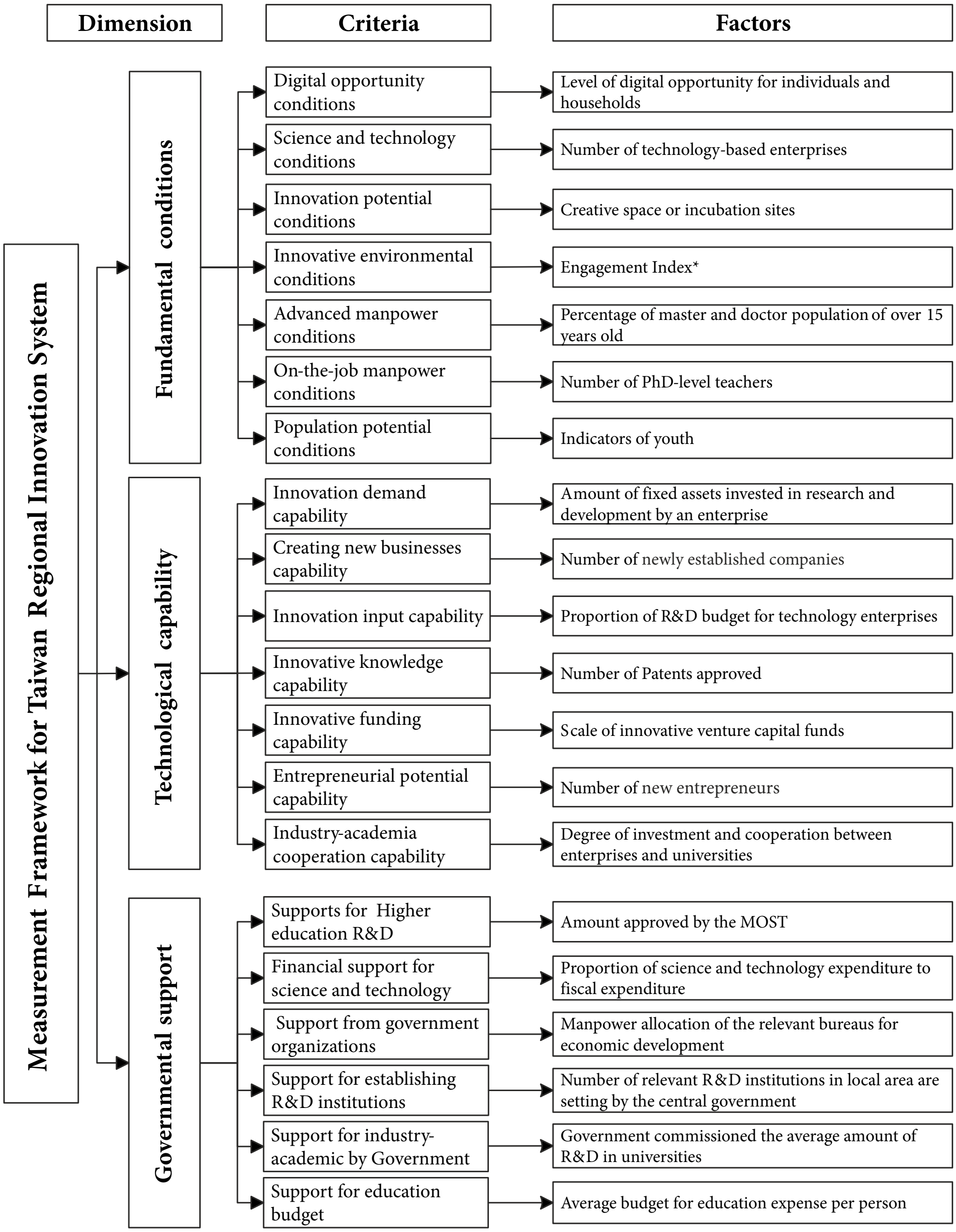
If "Condition 1" is not satisfied and $Q(A^m)-Q(A^1)<1/(J-1)$, then m-ranking alternative A^m and first-ranking alternative A^1 can be considered as the same advantages. However, A^1does not have a comparative advantage, so we can regard the comprehensive ranking of A^1, $A^2, \ldots, A^m$ are the same. If "Condition 2" is not satisfied, it shows the insufficient stability in decision-making, although A^1 has a comparative advantage. In this situation, comprehensive ranking of A^1 and A^2 can consider as the same.

4. An example for evaluating the RIS hierarchical structure in Taiwan

4.1. Building the hierarchy model and its criteria

We first proposed over thirty criteria of RIS evaluation based on the amalgamation of available literature, methods, and assessment reports of OECD, EU, China, and Japan. We first proposed a hierarchy model and then conducted seven expert seminars to review the model for its feasibility in RIS evaluation. We invited thirty-six experts related to technology and public policy from academia, think tanks, and government. During the seminars, we discussed with the experts thoroughly and modify the model directly. After the experts carefully examined and revised the descriptions and definitions of all the criteria, we finally constructed a hierarchical RIS evaluation framework based on current Taiwan policies and the availability of data (see Figure 2). Three dimensions of the evaluation framework are as follows:

5. *Fundamental Conditions*: These basic conditions include the infrastructure to facilitate information diffusion and collection, the synergy and cluster effects of science and technology-based enterprises, the incubation sites, and the environment facilitating innovation in general. Certainly, basic human resources are also important for innovation and entrepreneurship, especially the human resources of higher education, the high-end human quality employed by enterprises, and the potential of the distribution of young people within the region. At the Fundamental Conditions' level, the study has developed seven assessment criteria, namely, "Digital opportunity conditions (C1)," "Science and technology conditions (C2)," "Innovation potential conditions (C3)," "Innovative environmental conditions (C4)," "Advanced manpower conditions (C5)," "On-the-job manpower conditions (C6)," and "Population potential conditions (C7)."
6. *Technological Capability*: The success of a RIS requires physical or technological capabilities (Pino & Ortega, 2018). Product innovation, process innovation, marketing innovation, and organizational innovation are important innovation activities of enterprises. These activities require financial investment in research and development (R & D), the ability to create and preserve intellectual property rights, and the level of investment and cooperation with academia. In addition to being a major source of innovative capital resources, the scale of innovative venture capital funds available in



Note: * Number of libraries, museums, and exhibition halls per 10,000 Population.

Figure 2. Evaluation framework for Taiwan regional innovation system

the region also creates relevant technological capabilities. At the level of "Technological Capability," the study developed seven criteria, namely, "Innovation demand capability (C8)," "Creating new businesses capability (C9)," "Innovation input capability (C10)," "Innovative knowledge capability (C11)," "Innovative funding capability (C12)," "Entrepreneurial potential capability (C13)" and "Industry-academia cooperation capability (C14)."

7. *Government Support*: In the operation of regional innovation activities and regional innovation networks, both the central government and local government play a very important role, especially in the allocation of higher education funding, the allocation of scientific research funding, the organization of related departments, and government-supported industry-university cooperation projects. Much will affect the extent of regional innovation activities and the display of scientific and technological capabilities. At the level of Governmental Support, the study developed six criteria, namely, "Supports for Higher education R&D (C15)," "Financial support for science and technology (C16)," "Support from government organizations (C17)," "Support for establishing R&D institutions (C18)," "Support for industry-academic by Government (C19)" and "Support for education budget (C20)."

Table 1 shows the explanations of all the above RIS evaluation criteria. The indicators proposed for the criteria C1~C7 are "Level of digital opportunity for individuals and households," "Number of technology-based enterprises or institutions," "Creative space or incubation sites," "Engagement Index," "the proportion of the population who have completed an advanced degree," "Number of PhD-level teachers" and "Indicators of youth"; the indicators proposed for the criteria C8~C14 are "Amount of fixed assets invested in R&D by an enterprise," "Number of newly established companies," "Proportion of R&D budget for technology enterprises," "Number of patents approved," "Scale of innovative venture capital funds," "Number of new entrepreneurs" and "Degree of investment and cooperation between enterprises and universities"; and the indicators proposed for the criteria C15~C20 are "Amount approved by the MOST[3]," "Proportion of science and technology expenditure to fiscal expenditure," "Manpower allocation of the relevant bureaus for economic development," "Number of relevant R&D institutions in local area are setting by the central government," "Government commissioned the average amount of R&D in universities," and "Average budget for education expense per person".

Considering the limitations of the availability of data, measurements of some indicators are modified. For example, "on-the-job manpower conditions (C6)" is measured by the number of full-time doctoral teachers in the region available from ministry statistics. Moreover, the percentage of the population who complete higher education between the ages of 25 and 34 in EU countries is an important potential basis for young people to drive innovation and technological development. As Taiwan's current database does not yet have full access to the data in a certain region, "population potential conditions (C7)" refers to the proportion of the population aged 16 to 40 in the region. "Industry-academia cooperation capability (C14)" is measured by the number of cooperative programs in technological colleges and schools in the region.

[3] MOST is the Ministry of Science and Technology, Taiwan, R.O.C.

Table 1. Explanations of RIS evaluation criteria

Criteria	Explanations
(C1) Digital opportunity conditions	The network connection rate and information equipment ownership in the region.
(C2) Science and technology conditions	The number of science and technology-based enterprises, such as enterprises specializing in communication and communication, science and technology service industries, should be the basis for the potential and capabilities of scientific and technological innovation in the supporting region.
(C3) Innovation potential conditions	The number of creative spaces or incubation sites is an essential element in the region that can generate and encourage innovative entrepreneurial opportunities, such as innovation centers.
(C4) Innovative environmental conditions	The literature points out that the potential for cooperation among regional members can be quantified and defined as an "Engagement index" by per capita public gathering places such as libraries, museums, and exhibition halls, which can be regarded as a basic condition of the important environmental factors for developing innovation.
(C5) Advanced manpower conditions	In literature and practice, regional innovation requires the population that has attained a master's or doctoral degree with certain abilities and degrees as the basis for the development of innovation and related scientific and technological capabilities.
(C6) On-the-job manpower conditions	The participation of PhDs in the workplace is important for innovation and the development of technological capabilities in the region and is also a factor in the evaluation of organizations in advanced regions such as the OECD and the European Union.
(C7) Population potential conditions	Young people are an important potential foundation for innovation and technological development. In particular, the proportion of the population aged 16 to 40 in the region is regarded as an indicator of youth and is a condition of population potential.
(C8) Innovation demand capability	Enterprises in the region that are willing to invest in research and development are a specific manifestation of their innovation needs, and the amount of investment demonstrates their innovative needs.
(C9) Creating new businesses capability	The number of newly established companies in the region is a kind of technical ability to show their start-ups, and it is one of the important indicators used in the regional innovation assessment.
(C10) Innovation input capability	The research and development funds invested by science and technology enterprises in the region account for the proportion of operating income, which is the display of their innovation input ability and one of the important indicators used in the regional innovation evaluation.
(C11) Innovative knowledge capability	The number of patent applications or technology transfer is not only an important technical ability to show innovation activities but also an important link to the ability of scientific and technological knowledge, and one of the important indicators used in regional innovation assessment.
(C12) Innovative funding capability	The scale of innovative venture capital funds provided in the region is a major source of innovative capital resources and one of the important indicators used in regional innovation assessment.

End of Table 1

Criteria	Explanations
(C13) Entrepreneurial potential capability	Entrepreneurship is a showcase of innovation potential, and the average number of new entrepreneurs per 10,000 people in the region is an important representation of their potential entrepreneurial capabilities.
(C14) Industry-academia cooperation capability	The level of investment and cooperation between enterprises in the region and the university can be regarded as a display of the technical ability of production and learning cooperation.
(C15) Supports for Higher education R&D	The approved department of the Ministry of Science and Technology project is dominated by innovative research programs, so the amount approved by the Ministry of Science and Technology for the thematic research programs of tertiary institutions in the region should be regarded as the level of government support for higher education research and development.
(C16) Financial support for science and technology	The proportion of government departments' expenditure on education, science, culture, and economic development in the budget can be regarded as the extent of the government's financial support for science and technology in regional innovation ability.
(C17) Support from government organizations	The manpower allocation of the relevant bureaus for the economic development of governments in the region represents the level of organizational support that the government is willing to provide in promoting innovative scientific and technological capabilities in the region.
(C18) Support from the central government	The central authority has set up research and development institutions for local governments to indicate the level of central government support for the region's scientific and technological capabilities for the sake of innovation and development in the region.
(C19) Support for industry-academic by Government	The average amount of the government-commissioned regional university-school cooperation program shows the support of the regional government sectors for their innovative scientific and technological capabilities through cooperation in production and learning.
(C20) Support for the education budget	The average allocation of education funds by the government in the region contributes to its innovation and technological competence.

4.2. Weights of evaluation criteria

Considering the nature of regional innovation, we interviewed 36 experts and scholars from the fields of public policy, economics, and science and technology. Using a scale of 1 to 9, the experts compared the criteria in pares to judge which of each entity is preferred and completed the CFPR questionnaire. The purpose of the in-depth interview was to collect the experts' weight values of the RIS criteria and their suggestions to our CFPR-VIKOR approach and the RIS policy in Taiwan. In adjacent sequence, Table 2 shows the results of pairwise comparison for the criteria.

Table 2. Results of pairwise comparison in adjacent sequence for the criteria by experts

	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	E_{10}	E_{11}	E_{12}	E_{13}	E_{14}	E_{15}	E_{16}	E_{17}	E_{18}	
C_1	1/6	1	1	1	5	1/7	8	1/7	2	1/3	8/7	1	1	7/6	1	6	1	1	C_2
C_2	5	1/4	1	1	1/6	6	7	7	1/5	5	7/8	1	7/6	1	1/5	7	1/5	1/7	C_3
C_3	1/6	5	1/6	1	1/8	5	7	8	1/5	3	8/7	9	6/7	1	5	1/6	1/3	1/3	C_4
C_4	6	1/4	7	1	7	1/8	1/7	1/6	2	1/8	7/8	1/7	7/8	6/5	1/7	1	2	9	C_5
C_5	1/6	1/4	4	1	1/7	1/6	1/7	8	3	4	8/6	1	6/7	1	7	6	1/3	1/3	C_6
C_6	6	1/4	4	1	6	1/7	7	7	1/4	3	6/7	1	5/8	1	1/5	1/4	1/3	1/3	C_7
C_8	1/6	1/3	1	1	1/6	6	1/6	9	1/4	2	8/7	7	8/7	1	5	3	1	1/5	C_9
C_9	1/7	3	1/3	1	7	1/7	6	1/9	1/4	1/2	1	1/8	5/7	1	1	7	2	5	C_{10}
C_{10}	6	1/4	1/5	1	5	7	6	8	1/4	2	1	5	7/8	6/7	1	1/5	1/3	1/7	C_{11}
C_{11}	1/8	1/3	1/5	1	8	1/6	1/6	1/6	4	1/2	7/8	1/8	1	6/7	1	7	1/3	1/7	C_{12}
C_{12}	8	4	5	1	1	1/5	1/6	7	1/5	2	8/7	7	5/7	8/6	5	1/5	3	1/3	C_{13}
C_{13}	1/6	1/3	1/5	1	1/2	5	1/7	1/9	4	2	7/8	1/8	7/8	5/6	3	1/7	3	1/5	C_{14}
C_{15}	1/5	1	1/4	1	1/5	5	6	8	1/4	1	8/7	1	1	5/7	1/7	7	1/3	1/7	C_{16}
C_{16}	5	1/5	3	2	6	6	1/5	1/9	1	1	1	1	8/7	7/5	5	1/7	2	1/7	C_{17}
C_{17}	6	1	1/4	1	1/6	1/6	1/6	1	1	3	1	1	6/8	6/5	1/7	1/2	1/3	1/3	C_{18}
C_{18}	1/6	1/4	1	1	5	5	6	7	1	1	1	1	7/8	5/6	1	5	3	1	C_{19}
C_{19}	6	1/4	1/4	1	1/7	5	1/6	5	4	1	7/8	1	8/9	6/7	1	6	3	1	C_{20}

	E_{19}	E_{20}	E_{21}	E_{22}	E_{23}	E_{24}	E_{25}	E_{26}	E_{27}	E_{28}	E_{29}	E_{30}	E_{31}	E_{32}	E_{33}	E_{34}	E_{35}	E_{36}	
C_1	1	1/6	1/7	1	7	1/7	6	7	1	5	7	1/4	1/4	7	1	1/4	1	5	C_2
C_2	3	6	6	1	1/7	6	1/5	1/7	1/6	1/7	1/4	1/4	2	1/7	1/4	6	4	1/5	C_3
C_3	3	1/6	1/8	3	7	3	6	1/7	2	1/3	1/6	5	1/2	1/7	1/8	1/6	4	1	C_4
C_4	1/4	6	1/7	1/2	1/7	1/4	1/7	1	4	1/5	1/6	1/4	1/7	1/7	1/6	5	1/4	5	C_5
C_5	1/4	1/7	7	1/2	1/7	1/2	7	1/5	1/2	4	1	5	2	7	1/5	1/5	1/6	1/3	C_6
C_6	1	7	1/6	2	1/7	3	6	1	1	1/4	1/2	5	5	7	8	4	5	3	C_7
C_8	1/3	1/6	1/8	2	1/7	2	6	6	6	7	3	1/7	3	1/6	9	3	7	1/3	C_9
C_9	1/3	1/6	1/7	1/2	1/7	1/2	1/4	6	1/2	1/4	1/3	6	1/3	1/6	1/8	6	1/8	3	C_{10}
C_{10}	3	7	1/6	2	1/7	3	1/5	6	2	1/3	1/3	1/7	1/7	7	1/8	5	7	1	C_{11}
C_{11}	1	1/7	8	2	1/7	1/3	7	6	1/5	1/5	1/3	5	4	7	1	1/8	1	1	C_{12}
C_{12}	1	7	1/8	1/3	1/7	6	1/6	6	5	3	1/3	6	5	7	1/7	7	4	1	C_{13}
C_{13}	1/3	1/6	1/7	1/2	1/7	2	6	6	5	4	1	6	1/6	1/5	6	1	4	1	C_{14}
C_{15}	1	1/6	8	1/4	1/7	1/4	1/7	1/4	1/4	7	1	1/4	2	1/7	1/7	1/4	1/4	3	C_{16}
C_{16}	3	6	7	1/3	1/7	5	7	1/6	6	1/3	1	5	6	1/7	9	1/7	5	3	C_{17}
C_{17}	1	6	1/7	1/2	7	1/3	7	9	1/4	1/5	1/3	1/5	1/8	7	1/8	1	1/6	1/3	C_{18}
C_{18}	1/4	1/7	1/8	1/3	1/7	3	6	1	6	6	1/3	5	1	1/7	7	7	6	1/3	C_{19}
C_{19}	1/4	7	7	1/2	1/7	1/2	1/5	5	1	4	3	5	4	8	1	1/7	3	1/3	C_{20}

We view every expert's evaluation as equally important and use the geometric average method to obtain the distribution of the relative weight of each criterion. Moreover, we divided these 36 experts into three groups to compare expert opinions in different groups: eight experts from the government sector (G1), eighteen experts from think tanks (G2), and ten experts from academia (G3). Table 3 shows the calculated weights and ranks of the three dimensions. Table 4 shows the calculated weights and ranks of all the evaluation criteria.

Table 3. The weights and ranks of the three evaluation dimensions

Dimensions	Total		G1		G2		G3	
	weights	Rank	weights	Rank	weights	Rank	weights	Rank
Fundamental Conditions	30.84%	2	29.77%	2	32.50%	2	26.19%	2
Technological Capability	27.20%	3	24.16%	3	29.98%	3	22.11%	3
Governmental Support	41.97%	1	46.06%	1	37.52%	1	51.71%	1

Table 4. Calculation results of the criteria weight survey

Dimensions	Criteria	Total		G1		G2		G3	
		weights	Rank	weights	Rank	weights	Rank	weights	Rank
Fundamental Conditions	C1	9.50%	6	6.40%	6	6.17%	6	26.20%	1
	C2	8.83%	7	6.06%	7	5.67%	7	20.16%	2
	C3	10.34%	5	8.01%	5	10.21%	5	11.84%	4
	C4	11.44%	4	12.33%	3	13.63%	4	5.82%	7
	C5	19.26%	2	10.22%	4	20.67%	2	17.17%	3
	C6	23.25%	1	30.68%	1	26.12%	1	11.20%	5
	C7	17.38%	3	26.30%	2	17.53%	3	7.61%	6
Technological Capability	C8	10.83%	6	7.37%	7	13.18%	5	15.36%	3
	C9	9.55%	7	10.61%	6	10.30%	7	9.25%	7
	C10	14.85%	3	17.26%	3	14.71%	3	13.32%	4
	C11	14.24%	4	11.60%	5	15.74%	2	11.66%	6
	C12	19.22%	1	20.92%	1	20.51%	1	16.35%	2
	C13	13.89%	5	12.68%	4	13.41%	4	13.23%	5
	C14	17.43%	2	19.56%	2	12.15%	6	20.82%	1
Governmental Support	C15	11.56%	6	7.30%	6	10.58%	6	14.51%	4
	C16	18.65%	2	22.74%	2	15.85%	3	19.44%	3
	C17	14.48%	5	22.88%	1	13.22%	4	13.11%	5
	C18	22.26%	1	10.90%	5	30.94%	1	19.87%	2
	C19	18.16%	3	22.17%	2	17.43%	2	12.33%	6
	C20	14.88%	4	14.01%	4	11.99%	5	20.73%	1

The "Government Support" of the third category of this evaluation framework is calculated with a weight of 41.97%, which is the most important dimension in the framework. It shows that the experts believe that the improvement of regional innovation and technology capabilities is greatly affected by government support. The criterion "Support for establishing R&D institutions (C15)", which reflects the number of relevant R&D institutions in a local area supported by the central government, is not only the most important criterion under this dimension but also the most important one among all criteria. The central government allows the region to develop innovation and technological capabilities to develop specific industries with this support. The criterion "Financial support for science and technology (C16)", which reflects government support for regional fiscal science and technology expenditure, regional science and technology budget, and local public sector research and development expenditure, ranks the second important criterion under this dimension. The third-ranking in this dimension is "Support for industry-academic by Government (C19)", which indicates that the innovative technology developed by regional colleges and universities could be entirely improved with the support of government funds.

The "Fundamental Conditions" has a calculated weight of 30.84%, ranking the second among the three dimensions. The most important criterion for assessing the first ranking under this dimension is "(C6) on-the-job manpower conditions", which shows that PhDs involved in the workplace are essential for innovation and technological capability development in the region, and is one of the assessment factors that OECD, EU, and other organizations attach importance to. The result that "Advanced manpower conditions (C5)" ranks the second important criterion under this dimension reflects that regional innovation requires higher education institutions in the region to train master and Ph.D. students with certain abilities as the basis for the development of innovation. The third-ranking is "population potential conditions (C7)" which refers to the indicator of youth. This study considers the proportion of the population aged 16 to 40 years in the region as an indicator of youth. Because it is an important potential basis for driving innovation and technological development.

The "Technological Capability" of the second category of this evaluation framework has a calculated weight of 27.20%, which is regarded as less important than the other two dimensions. The first important criterion in this dimension is "Innovative funding capability (C12)", which reflects that the size of innovative venture capital funds available in the region, in addition to being a major source of innovative financial resources is a driving force for effective technological capabilities. "Industry-academia cooperation capability (C14)" ranks second, which shows that most of the experts believe that the level of investment and cooperation between enterprises and academic entities will help the innovation development in the region. The third in the ranking is "Innovation input capability (C10)", which indicates that the investment of the technology companies in the region on research and development as a proportion of revenue to show its innovative technology capabilities is crucial.

The importance orders of the three dimensions are the same in the three expert groups. The results indicate that the experts as a whole generally believe that the development of scientific and technological capabilities in RIS, with the first emphasis on "government support" level, can effectively accelerate the promotion of regional innovation and technological capabilities, primarily through government funding and the formulation of relevant policies, the establishment of appropriate incentives and incentive mechanisms, and even the adjustment, amendment and formulation of relevant legislation. The importance orders of some indicators between experts from the government sector (G1) and experts from think tanks (G2) are different, but overall the gap is not significant. Experts from academia (G3), significantly different from experts from G1 and G2, emphasize the importance of "Support for the education budget (C20)", which may reflect the long-term effects of the average allocation of education funds by the government in the region to its innovation and technological competence.

4.3. Degrees of innovation and technology capabilities among the six special municipalities

Based on the weights of all criteria obtained from the 36 experts and the data corresponding to each criterion collected by the government and various research institutions (see Appendix), the Q values are calculated via the VIKOR to rank the innovation capability of the six special municipalities in Taiwan (see Table 5). Overall, the top three special municipalities with the best performance of numerical results are Taipei, Taichung, and Tainan. Taipei ranks first in both "fundamental conditions" and "government support" but fifth in "technological capability". Except for Kaoshiung, the "Innovation demand capability (C8)", "Innovation input capability (C10)", "Innovative funding capability (C12)", and "Industry-academia cooperation capability (C14)" scores of Taipei are lower than the other cities, indicating that the R & D investment and academic cooperation of enterprises located in Taipei are insufficient. This may be due to most companies setting up their headquarters in Taipei, while locating their production R&D bases in other areas. Taichung and New Taipei are the two regions with better performance in terms of "technological capability", which should be the fact that they have more large-scale industrial parks. Tainan ranks second in the "government support" advantage, only second to Taipei. This should be the case that the government has begun to set up relevant technological innovation parks in southern Taiwan in recent years to balance Taiwan's long-standing economic development policy of focusing on the north and over the south. This policy also attracts large international companies to settle in and take advantage of the opportunities of regional innovation to accelerate their expansion and consequently makes Tainan rank third among the six special municipalities in terms of "technical capabilities."

Table 5. Innovation and technology capabilities for the six metropolitan areas-Total 36 experts

Municipal	Total Qi	Rank	Fundamental Conditions Qi	Rank	Technological capability Qi	Rank	Government support Qi	Rank
Taipei	0.000	1	0.099	1	0.775	5	0.000	1
New Taipei	0.656	4	0.814	4	0.165	2	0.705	4
Taoyuan	0.848	5	0.985	6	0.687	4	0.794	5
Taichung	0.473	2	0.336	2	0.083	1	0.533	3
Tainan	0.574	3	0.860	5	0.317	3	0.529	2
Kaohsiung	1.000	6	0.712	3	1.000	6	1.000	6

We also calculate the Q values and analyze the ranking differences of the six special municipals across the G1~G3 expert groups (see Tables 6–8). Except from Tables 6–8, Table 7, and Table 8, Figure 3 to Figure 6 show the rank changes among these three groups. For the "overall" comprehensive evaluation, the rank orders among the three groups are slightly different in the degree of regional innovation in Taipei, Taichung, Taoyuan. Kaohsiung, however, is unanimously regarded as the worst among the six special municipalities. Moreover, these experts' evaluations on New Taipei and Tainan are divergent.

Table 6. Innovation and technology capabilities for the six metropolitan areas-8 Govt. sector experts

Municipal	Total Qi	Rank	Fundamental Conditions Qi	Rank	Technological capability Qi	Rank	Government support Qi	Rank
Taipei	0.000	2	0.099	2	0.775	5	0.000	3
New Taipei	0.656	5	0.814	4	0.165	2	0.705	5
Taoyuan	0.848	4	0.985	6	0.687	4	0.794	2
Taichung	0.473	1	0.336	1	0.083	1	0.533	4
Tainan	0.574	3	0.860	5	0.317	3	0.529	1
Kaohsiung	1.000	6	0.712	3	1.000	6	1.000	6

Table 7. Innovation and technology capabilities for the six metropolitan areas-18 Res. Inst. experts

Municipal	Total Qi	Rank	Fundamental Conditions Qi	Rank	Technological capability Qi	Rank	Government support Qi	Rank
Taipei	0.000	1	0.099	1	0.775	5	0.000	1
New Taipei	0.656	2	0.814	4	0.165	2	0.705	2
Taoyuan	0.848	5	0.985	6	0.687	4	0.794	5
Taichung	0.473	3	0.336	2	0.083	1	0.533	4
Tainan	0.574	4	0.860	5	0.317	3	0.529	3
Kaohsiung	1.000	6	0.712	3	1.000	6	1.000	6

Table 8. Innovation and technology capabilities for the six metropolitan areas-10 University Scholars

Municipal	Total Qi	Rank	Fundamental Conditions Qi	Rank	Technological capability Qi	Rank	Government support Qi	Rank
Taipei	0.000	1	0.099	1	0.775	4	0.000	1
New Taipei	0.656	3	0.814	3	0.165	3	0.705	3
Taoyuan	0.848	4	0.985	4	0.687	6	0.794	4
Taichung	0.473	2	0.336	2	0.083	1	0.533	2
Tainan	0.574	5	0.860	6	0.317	2	0.529	5
Kaohsiung	1.000	6	0.712	5	1.000	5	1.000	6

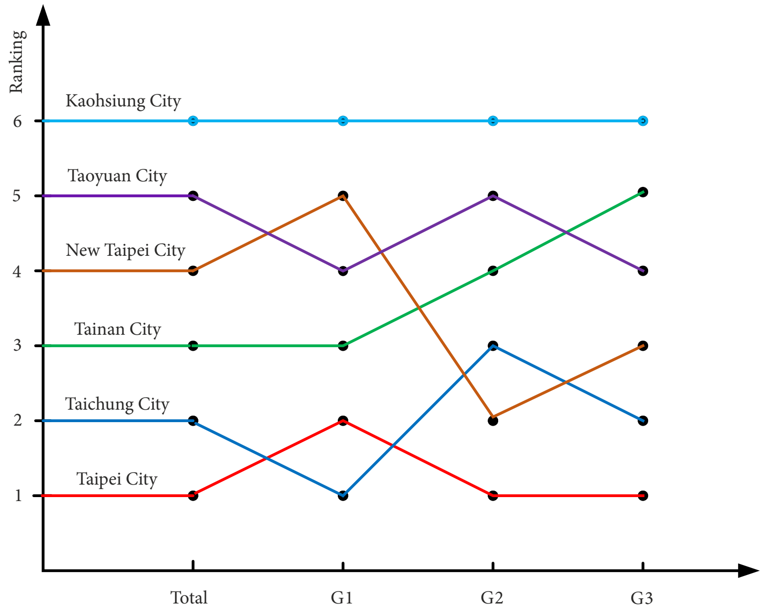


Figure 3. Ranking of the six cities for different groups in total aspects

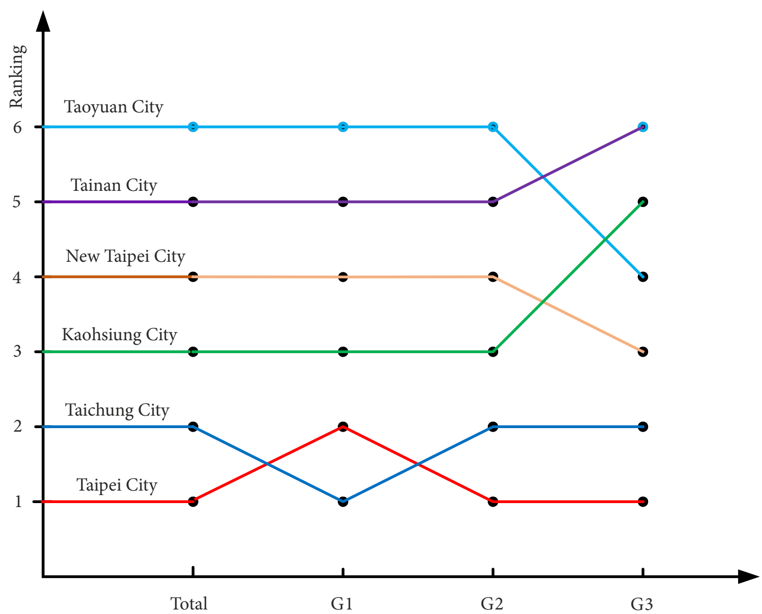


Figure 4. Ranking of the six cities for different groups in fundamental conditions aspect

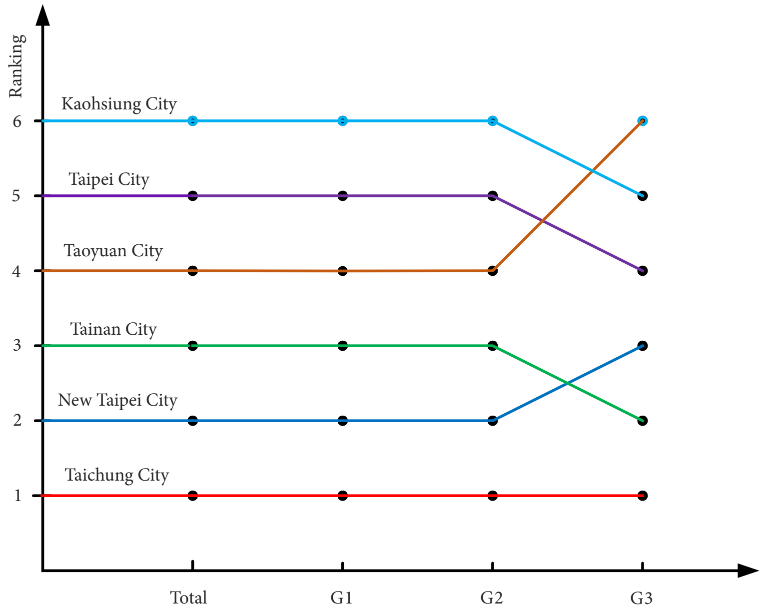


Figure 5. Ranking of the six cities for different groups in technological capability aspect

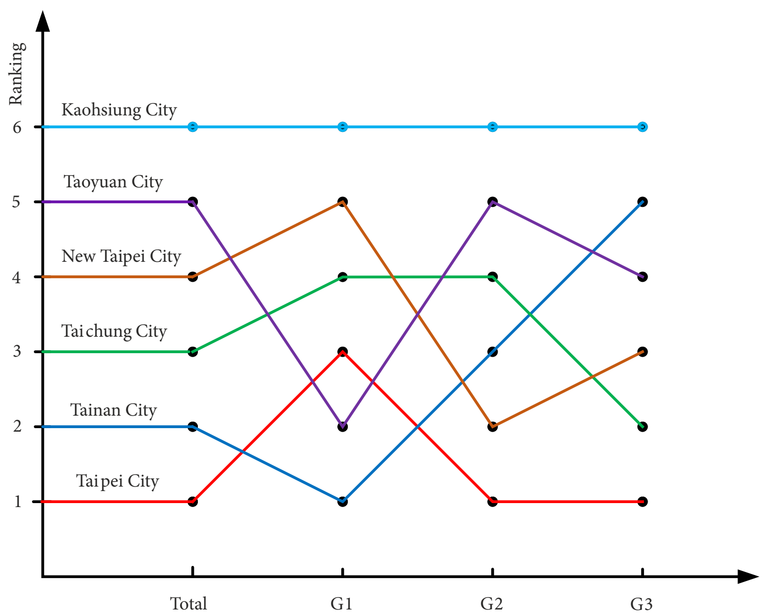


Figure 6. Ranking of the six cities for different groups in government support aspect

Regarding "fundamental conditions" and "technological capability," G3 experts rank Taoyuan and Kaohsiung differently from the other two groups of experts but rank the other four special municipalities similarly. To some extent, the outcomes most likely result from the weight difference of "fundamental conditions" and "technological capability" assigned by academic experts. Therefore, the policymakers need to maintain the delicate balance between academia and government to make regional innovation policies more comprehensive and optimized.

Finally, in terms of "government support," Figure 6 shows that the ranking results of "government support" in the special municipalities vary due to criteria weights assigned by experts from different groups. However, Kaohsiung is consistently ranked last, indicating that Kaohsiung lacks government resources. Therefore, the central government departments should provide Kaohsiung with more resources to accelerate its innovation capabilities. Moreover, all the three groups of experts, different in degree, view "government support" as the most important factor of regional innovation. The role of the central government needs to be further discussed to reduce imbalances among the regions to promote equitable innovation capabilities.

5. Incorporating with sensitivity analysis

VIKOR introduces *Q*-value as the basis of rank calculation. The obtained compromise solution provides a maximum group utility[4] of the "majority" and a minimum of the individual regret[5] of the "opponent." v is introduced as the *weight* of the decision-making strategy, i.e., "the maximum group utility." By changing the value of v from 0~1[6], our model can simulate the changes of Q values, i.e., the municipality rankings by all experts. The simulation results are shown in Figures 7–10.

Considering all the evaluation criteria, the ranking of the six special municipalities has not changed significantly, but Taoyuan and Taichung have more advantages as the v value increases (see Figure 7). The result Taoyuan could rank higher than New Taipei when v varies indicates that some disadvantage items exist to affect its overall degree of innovation. As the v value increases, New Taipei's advantages decrease, implying that New Taipei could have a better position under particular specific strengths. However, its degree of innovation decreases when considering more items are considered.

From the perspective of "fundamental conditions", the result that the *Q*-value difference of other cities with Taipei becomes larger when v value increases imply Taipei, as the capital of Taiwan, apparently has abundant resources compared to the other five special municipalities (see Figure 8). It might cause an imbalance in regional innovation and development. As for the "technological capability" (see Figure 9), the results that the regional innovation advantages of Taichung and Taipei increase (Q values decrease) when v increases indicate these two regions have more advantageous technological items. However, the Q values of New Taipei and Tainan are relatively small when v is small, meaning that these two regions might only have comparative advantages in certain items and many technological items need to be

[4] It is represented by min S in Section 4.

[5] It is represented by min R in Section 4.

[6] The v values vary from v = [0.5, 1] (each region has the most advantageous items) to v = [0, 0.5] (each region has relatively disadvantaged items.

improved. The *Q* values of Taoyuan and Kaohsiung, far from the ideal values, rarely change and fluctuate, indicating that the enterprises in these two regions need to invest aggressively to improve their technological capabilities.

As for "government support" (see Figure 10), the results that the *Q* values of Taoyuan and Tainan decrease significantly when *v* increases indicate that the more items supported by the government, the higher the degree of regional innovation. However, the ranking might be affected due to insufficient support in some individual items. For example, Taoyuan's "the number of R&D institutions set by central governments" is relatively low. Thus it ranks the last when the model calculates the disadvantage item. The result that the *Q*-value difference between Taipei and Tainan increases when the *v* value increases implies that the central government might need to give more support to larger cities with more population.

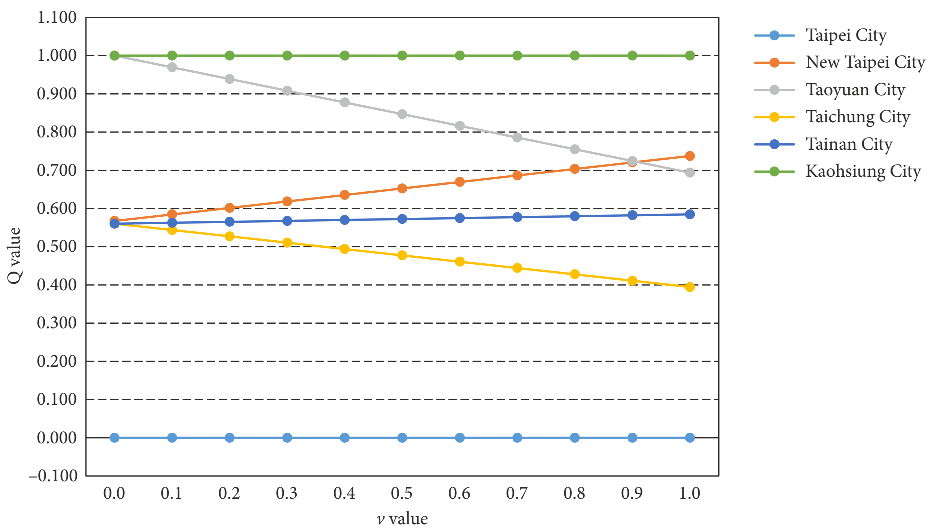


Figure 7. Simulation of the six cities for different *v* value in total aspects

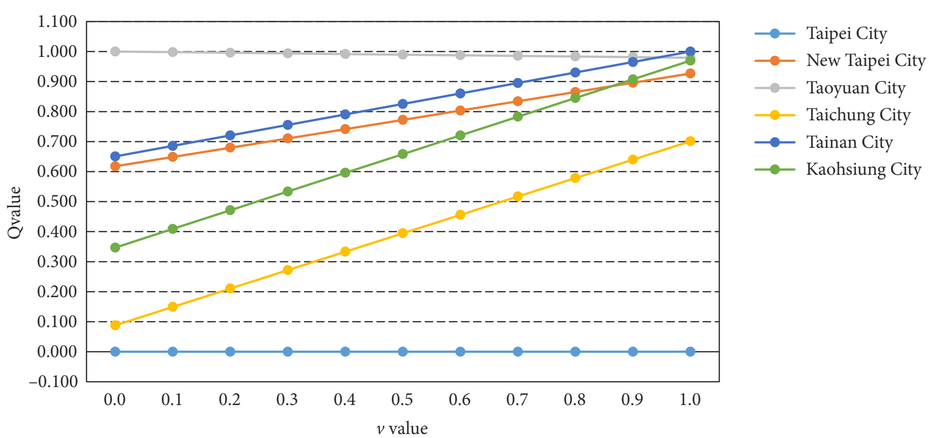


Figure 8. Simulation of the six cities for different *v* value in basic conditions aspects

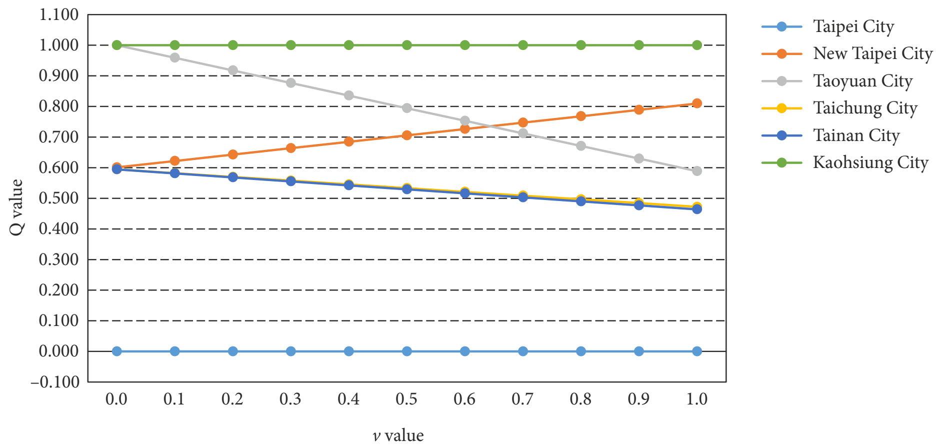


Figure 9. Simulation of the six cities for different *v* value in technological capability aspects

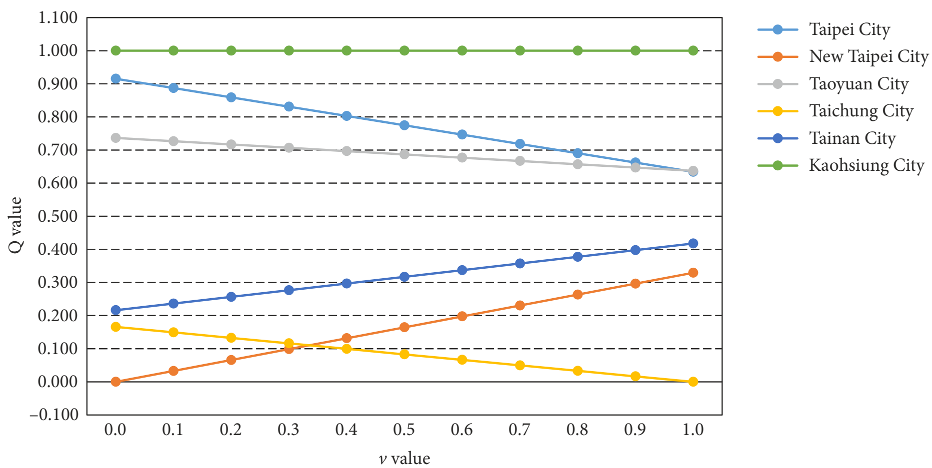


Figure 10. Simulation of the six cities for different *v* value in government support aspects

6. Important implications to RIS policy in Taiwan

6.1. A structural and hierarchical evaluation system is crucial for implementing RIS policies

In the past, the central government took the lead in making the S&T policies. Since the formation of the six special municipalities in Taiwan, the central government has enhanced intergovernmental cooperation with the six special municipalities and seeks regional balance in the country simultaneously. From the perspective of evidence-based policymaking, the central government needs objective data regarding the industrial development status and advantages and disadvantages of different regions. On the one hand, the decision of industrial development can be made based on the overall S & T goals and different regional characteristics. On the other hand, after determining the critical layout of regional industries, the government can fill in the gaps, allocate a budget to meet the demands, and accelerate innovation. Thus, the construction of sound regional industrial innovation indicators becomes critical.

In the final review meeting of our project, the chief of BOST RIEO acknowledged the structural and hierarchical model in our study and expressed that the approach can assist policymakers differentiate various RIS capabilities and make better decisions in resource allocation. The chief instructed that the concepts and conclusions of our study are highly feasible and urged us to further refine the structure by incorporating indicators in line with international trends.

6.2. The need for fundamental data and regional resources assessments is becoming increasingly apparent

Our CBPR-VIKOR approach integrates different objective data sources with multiple experts' subjective judgment in the RIS evaluation process. This MCDM approach has been recognized for its decision-making capabilities to address complex decision problems. However, as mentioned above, measurements of some indicators in our model are modified due to the limitations of the availability of data. We presented that the criteria structure in our hierarchy structure is sufficient, but the results may be affected by data quality. We urged to improve the measurement data to advance the quality of decision-making and the effect of communication and proposed that the government should build a regional information system and integrate data from various administrative departments. Taiwan's Cabinet has put forth to establish a Ministry of Digital Affairs. Under the Ministry, the Department of Data Governance is expected to take charge of and promote the inter-ministerial data governance programs.

6.3. The role of the central government needs to be adapted to rapid changes

Although the role of local governments has become increasingly important in the primary industrial development practices, most of the policies are led by the central government. For example, the development of green energy's offshore wind power industry involves complicated domains such as marine meteorology, underwater exploration, port construction, electricity industry regulations, subsidies and grants, talent cultivation, etc. All these challenges require budget support and inter-ministerial coordination and cooperation led by the central government. Moreover, the central government in Taiwan plays a crucial role in regional innovation and development governance. It encourages the six special municipalities to compete with each other and strives to make them invest in the different industries. Our research results that the interviewed experts have high expectations for the central government reflect its importance.

In the long run, the central government aims to optimize the policy environment to establish an excellent innovation ecosystem, promote R & D, and create a balance among these regions. Especially Taiwan has been facing the phenomenon of low birth rate, so it is urgent to attract young and talented people to invent in regional innovation work.

Conclusions

Many studies use MCDM to evaluate various RIS; however, the evaluation process of nationwide RIS is discussed less. As a reference for policymakers, this study employs the CFPR-VIKOR method to assess the RIS of the six special municipalities in Taiwan. The aim is to understand the relative importance of the criteria under the assessment framework through the subject views of experts and to rank the municipalities with objective data. When the innovation and technology capabilities in a region are initially examined, decision-makers can decide how to allocate resources such as manpower and funding properly and further contribute to the development of regional innovation through the design and adjustment of the regulatory system.

We employ a simulation to identify variations in municipality rankings when the decision-makers changes their levels of optimism. We also interview executives and experts to verify the applicability of our theoretical approach and the RIS policy implications. Thus, our study successfully extends the MCDM application for RIS policies in the public sector. The CFPR-VIKOR approach proposed in this study shows some advantages: (1) One methodological advantage of the CFPR over the AHP is the smaller number of questionnaire items required to ask the corresponding experts. Thus, it is very convenient for domain experts and policy decision-makers. (2) Based on the particular measure of "closeness" to the ideal solution, VIKOR has an advantage in providing a ranking procedure for both positive and negative attributes and determining a compromise solution for policy decision-makers.

Although the CFPR approach in this study, which is based on AHP, has been demonstrated to be appropriate for RIS evaluation, some limitations still exist. First, all criteria in our model are considered independent. Additional model refinement is necessary to comprehend the correlations among evaluation criteria better. Alternative methods to model interactive relationships among criteria such as Interpretive Structural Modeling, Analytic Network Process, and Decision Making Trial are suggested. Moreover, we were unable to get specific inter-ministerial data because of the limitation of data availability even though we made lots efforts to seek official data of the six special municipalities to validate our research results. Further studies incorporating complete data are necessary.

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APPENDIX

Dimension		Criteria	Indicators	Unit (year)	Taipei	New Taipei	Taoyuan	Taichung	Tainan	Kaohsiung
Fundamental Condition	C1	Digital opportunity conditions	Level of digital opportunity for individuals and households	Frequency / each 100unit	363.5	353.9	355.4	354.5	345.2	347
	C2	Science and technology conditions	Number of technology-based enterprises or institutions	Number of companies	36,713	17,283	6,793	12,315	3,750	8,936
	C3	Innovation potential conditions	Creative space or incubation sites	Number of sites	35	16	9	20	14	17
	C4	Innovative environmental conditions	Engagement Index	Percentage	0.525	0.288	0.219	0.301	0.445	0.375
	C5	Advanced manpower conditions	The percentage of the population who have completed an advanced degree	Percentage	0.128	0.066	0.065	0.070	0.068	0.067
	C6	On-the-job manpower conditions	Number of PhD-level teachers	Person	8,568	3,446	2,899	4,935	3,399	3,834
	C7	Population potential conditions	Indicators of youth	Population ratio of under 40	0.3284	0.3619	0.3827	0.3784	0.3566	0.3541

Continue of Appendix

Dimension		Criteria	Indicators	Unit (year)	Taipei	New Taipei	Taoyuan	Taichung	Tainan	Kaohsiung
Technological Capability	C8	Innovation demand capability	Amount of fixed assets invested in R&D by an enterprise	Thousand dollar per enterprise	38,628.59	46,802.31	81,538.73	40,503.18	83,118.05	37,082.52
	C9	Creating new businesses capability	Number of newly established compannies	Number of companies	3,194	3,242	2,298	4,105	1,349	2,367
	C10	Innovation input capability	Proportion of R&D budget for technology enterprises	R&D amount / turnover	0.0436	0.0721	0.0848	0.0513	0.0564	0.0351
	C11	Innovative knowledge capability	Number of Patents approved	Numbers	6,250	7,644	4,017	6,014	3,105	3,050
	C12	Innovative funding capability	Scale of innovative venture capital funds	Dollars	1,396,500	4,200,000	3,197,250	7,750,393	5,706,666	1,200,000
	C13	Entrepreneurial potential capability	Number of new entrepreneurs	Persons / 10,000people	0.3131	0.0853	0.0868	0.0646	0.0583	0.0612
	C14	Industry-academia cooperation capability	Degree of investment and cooperation between enterprises and universities	Cases	144	176	124	220	230	267

End of Appendix

Dimension		Criteria	Indicators	Unit (year)	Taipei	New Taipei	Taoyuan	Taichung	Tainan	Kaohsiung
Government Support	C15	Supports for Higher education R&D	Amount approved by the MOST	Million dollars	4,403.63	514.72	1,371.41	1,630.80	1,730.33	1,216.91
	C16	Financial support for science and technology	Proportion of science and technology expenditure to fiscal expenditure	Percentage	0.536	0.513	0.572	0.585	0.559	0.488
	C17	Support from government organizations	Manpower allocation of the relevant bureaus for economic development	Persons	170	217	102	211	251	153
	C18	Support for establishing R&D institutions	Number of relevant R&D institutions in local area are setting by the central government	Number	8	10	12	15	18	20
	C19	Support for industry-academic by Government	Government commissioned the average amount of R&D in universities and colleges	Dollars / project	2,854,952	1,238,384	1,860,386	1,638,863	2,164,974	1,332,564
	C20	Support for education budget	Average budget for education expense per person	Dollars / person	20,801.6	15,259.0	15,672.6	17,128.0	14,259.0	16,836.0