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# Configuring the Knowledge Diffusion Policy Portfolio of Higher Education Institutes

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## ABSTRACT

The research proposes an analytic framework to configure the policy portfolio for diffusing knowledge embedded in higher-education institutes. A modified Delphi method was first proposed to derive the key factors for enabling and enhancing the diffusion mechanism. The influence relationships between these factors were derived using the Decision-Making Trial and Evaluation Laboratory (DEMATEL). The analytic network process (ANP) derived weights associated with the key factors. Finally, the Grey Relational Analysis (GRA) was used to derive the policy instruments based on the Grey Relationships between the key factors and the policy instruments. An empirical study based on Taiwanese higher-education institutes also/then verified the feasibility of the proposed analytic framework. These findings suggest that research and development activities, publications, and networks of academic exchange play primary roles in knowledge diffusion in higher-education institutions. Motivation, human resources, and investment are the most important policy instruments to use for improving knowledge diffusion in the higher-education system.

**Keywords:** knowledge diffusion, higher-education policy, policy instrument, university-industry (UI) collaboration, catch-up economy

## INTRODUCTION

In the era of the knowledge-based economy, knowledge leads to innovation and has become the main driver for economic development and national competitiveness (Heitor & Bravo, 2010; Block, Thurik, & Zhou, 2013; Robin & Schubert, 2013). Knowledge workers, who work with intangible resources, have become the most important assets in this knowledge-based economy (Drucker, 1999). Knowledge diffusion plays a dominant role for knowledge workers in general, and also sufficient science, technology, engineering and mathematics (STEM) workers (OECD, 2005; Beach, 2013) in particular. Knowledge diffusion also helps to develop innovation capabilities for catching up economies and regional and industrial development (Mathews, Hu, & Wu, 2011) from the aspects of building technology capacity, decreasing research and development (R&D) costs, and shortening development time. Apparently, the mechanism associated with the creation, diffusion and commercialization of evolving knowledge in higher-education systems is important (Leisyte & Horta, 2011).


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**State of the literature**

- Knowledge diffusion embedded in higher education institutes could contribute to advancing innovations, knowledge activities, industries and regions development via providing high quality human resources and R&D productivity.
- During the past years, the interest in researching knowledge diffusion mechanisms in higher-education systems and how national governments can best provide appropriate support to develop or enhance such mechanisms has been increasing.
- The knowledge diffusion mechanism of higher-education institutes and the policy instrument for developing and enhancing such mechanisms are very significant, but few studies have paid attention to the issue.

**Contribution of this paper to the literature**

- This study presents macro-level approach of knowledge diffusion and knowledge activities in higher education institutes.
- The research proposes an analytic framework to configure the policy portfolio for diffusing knowledge embedded in higher-education institutes. The researcher also proposs an empirical case study based on Taiwanese higher-education system.
- The analysis of the results indicates that research and development activities, publications, and networks of academic exchange could advance knowledge diffusion in higher-education institutions.
- Motivation, investment, and human resources are the most important policy instruments to use for improving knowledge diffusion in the higher-education system.

Higher-education institutions have played key and very critical roles in the knowledge-based economy, from the aspects of providing high quality academic knowledge and talents for innovations and new entrepreneurial activities (Hussler & Rondé, 2007) as well as the diffusing of knowledge. The dominant roles of higher-education institutions in knowledge diffusion are three-fold, namely, student learning improvement in STEM (Fairweather, 2008); the provision of sufficient knowledge workers in general and STEM workers in particular; enabling firms to overcome the new challenges introduced by the knowledge-based economy, globalization, and the rapid effects of fast paced technology evolution (Acworth, 2008).

From the aspect of student learning improvement through STEM, Hutchinson and Huberman (1994) summarized the outcomes of knowledge dissemination and its use in science and mathematics education to include increased awareness, the ability to make informed choices between alternatives and the exchange of information, materials, or perspectives. Fairweather (2008) argued that the diffusion of knowledge in the research on effective instructional practices from other academic disciplines dissemination may be helpful for STEM (Fairweather, 2008). Later, Henderson et al. (2011) argued that Rogers's (1995) diffusion of innovations, of which knowledge and information diffusion is a very critical part of the innovation diffusion process (Swan & Newell, 1995), has significantly influenced the thinking of faculty development researchers (FDR) and STEM education researchers (SER) fields (Henderson, Beach, & Finkelstein, 2011). For example, Pundak and Rozner (2008) used the processes of decision-making during the diffusion of innovations proposed by Rogers (1995) as an organizing perspective for promoting and studying change in STEM faculty teaching practices (Pundak & Rozner, 2008). Hazen, Wu, & Sankar (2012) suggested that designing for knowledge dissemination may be important to ensure engineering educators adopt and use an educational innovation.

From the aspect of knowledge worker provisions, knowledge dissemination, namely, the diffusion that is directed and managed (Rogers, 2003), plays a dominant role in higher education in STEM. The well-developed higher education of STEM can resolve the problem of knowledge worker shortage, which resets primarily in the STEM area (OECD, 2005; Beach, 2013). In terms of the roles of higher education institutes for the knowledge diffusion to firms, Kwon (2011) argues that higher-education institutes provide well-educated talent, while the industrialization of knowledge, and academic findings advance the process of technological applications and innovation in industries and firms (Kwon, 2011). A typical example of higher-education institute diffusion of knowledge is the successful diffusion of knowledge being generated by advanced research efforts into new industries that is being done by the Massachusetts Institute of Technology (Etzkowitz, 2003a).

Apparently, the knowledge diffusion mechanism of higher-education institutes is critical for the provision of knowledge workers, industry and economic development, and national competitiveness. Therefore, during the past years, the interest in researching knowledge diffusion mechanisms in higher-education systems (Heitor & Bravo, 2010; Robin & Schubert, 2013) and how national governments can best provide appropriate support to develop or enhance such mechanisms has been increasing. So national governments of both the developed and developing countries urge the defining of policy and provide public support to improve the development of higher-education institutes (Etzkowitz, Webster, Gebhardt, & Terra, 2000; Kim & Park, 2009; Cowan & Zinovyeva, 2013) so as to extend the knowledge processes as well as the benefits of having knowledge (Heitor, Horta, & Mendonça, 2014).

However, the current knowledge diffusion mechanism is not sufficient. According to Beach (2013), scientists, technologists, engineers, and mathematicians, are the high-end knowledge workers in the global economy, and many business leaders fear shortages of STEM talent in the coming years (Craig, Thomas, Hou, & Mathur, 2012; Beach, 2013). From the aspect of knowledge work provision, the biggest barrier to improving STEM education in higher education institutes and thus, the needed provision of sufficient knowledge workers, is the insufficiency of knowledge for how to effectively diffuse/disseminate the use of currently available and tested research-based instructional ideas and strategies (Henderson & Dancy, 2011). For example: "In many institutions of higher education, there is no organized knowledge management system in place or even an understanding that such a system could be useful if not necessary. Since higher education is about the creation, transformation, and transmission of knowledge, such an oversight is striking" (Serban & Luan, 2002).

Universities lack the consistent ability to use that knowledge as Knowledge Management tools for organizational innovation and for cooperation between the society and the economy (Buckley, 2012). In specific economies, the diffusion of university knowledge to private sectors is still insufficient. For example, there is full understanding that policy-makers in Europe have "an urgent need for evidence-based policy recommendations to promote appropriate strategies for the governance, incentives, and conduct of scientific research and of knowledge transfer between public and private entities" (Buckley, 2012).

Apparently, significant problems exist in the actual diffusion of knowledge from higher education institutes. However, most of the previous studies on higher education institutes and knowledge management have focused on the role of higher-education institutes in national innovation systems and only analyzed the commercial outcomes of UI (University-Industry) collaboration via patents and patent citations, licensing, employment flows, startups, etc. (Nelson, 2012). Less attention has been paid to actual knowledge diffusion mechanisms between higher-education institutes and other sectors.

The modified Humboldt model based higher-education institutes' focus on teaching, research, and enhancing university–industry links and intellectual property rights (IPR) to generate and diffuse knowledge. Such institutes are more directly connected with economic development (Segarra-Blasco & Arauzo-Carod, 2008). Based on the rationality of the modified Humboldt model, many countries have designed policy instruments to encourage knowledge diffusion from their higher-education institutes (Robin & Schubert, 2013) to industries. For example, in East Asian late- coming economies, knowledge diffusion plays a dominant role in developing strategic high-technology industries (Mathews et al., 2011) and the diffusion of knowledge have achieved significant results. In many catch-up economies, governments provide more funding for R&D activities than do the industries, especially SMEs (Small and Medium-sized Enterprises).

Based on the author's very limited knowledge, the knowledge diffusion mechanism of higher-education institutes and the policy instrument definitions for developing and enhancing such mechanisms are very important, but were less recognized and thus not pursued fully. More extensive research is needed to explore these issues to enhance higher-education knowledge diffusion further. In order to enhance knowledge diffusion mechanisms in higher-education institutes, this research defined higher-education policy instruments through an analysis of the known factors of knowledge diffusion. This paper thus has the following purposes: (a) identify the key knowledge diffusion factors and policy instruments in higher-education; (b) derive the relationship between the key factors; (c) derive the different weights of these key factors; (d) define policy instruments to enhance key factors for knowledge diffusion mechanisms in higher-education institutes; and (e) define key policy instruments to use for enhancing the knowledge diffusion capabilities of higher-education institutes. The results may indeed serve as a basis for the context of higher-education institutes' pursuit of academic excellence and greater industrial collaboration.

To achieve these research purposes, the modified Delphi method was used to summarize key knowledge diffusion factors and the policy instruments found in higher-education. Based on these key knowledge diffusion factors being derived using the modified Delphi method, the Decision-Making Trial and Evaluation Laboratory (DEMATEL) technique was introduced to derive an influence relationship map (IRM) applying the key factors. Then, the weights being associated with the criteria were derived using the analytic network process (ANP) based on the IRM. Finally, policy instruments for developing and enhancing the knowledge diffusion mechanism were derived using the Grey Relational Analysis (GRA) proposed by Deng (1986) and based on the Grey relationships between the key factors and the higher-education policy instruments.

An empirical study based on the opinions of Taiwanese experts was introduced to verify the feasibility of the analytic framework. Policy instruments for developing and enhancing the knowledge diffusion mechanism of Taiwanese higher-education institutes were also derived. The successful verification of the analytic framework proved the feasibility of the proposed analytic framework. The policy instruments could serve as governmental policy. The policy instruments could also serve as references for policy definitions of other catch-up economies.

The organization of the paper, therefore, is as follows. Section 2 reviews the literature of knowledge diffusion, the knowledge diffusion process and mechanism, the roles of higher-education institutes in knowledge diffusion, and key factors and policy instruments used for enabling the knowledge diffusion capabilities of higher-education institutes. Section 3 offers the empirical framework and method used in the research. Section 4 presents the empirical results. Section 5 discusses the impact of these key factors and policy instruments on knowledge diffusion from higher-education institutes to industries, the correlations between policy instruments, the key factors for knowledge diffusion from higher-education institutes to industries, and the limitations of the study. Section 6 summarizes the article with both concluding remarks and discussion of future research possibilities.

## LITERATURE REVIEW

The literature review begins with examples of works on knowledge diffusion, then summarizes the works on the knowledge diffusion process and its mechanisms. Next, the literature related to the roles of higher-education institutes in knowledge diffusion are reviewed. Lastly, key factors and policy instruments enabling knowledge diffusion capabilities in higher-education institutes are summarized. The literature review thus provides the basis for the development of an analytic framework in the ensuing sections of the paper.

### Knowledge Diffusion

In science, diffusion is the transport process of substance, including solid, liquid, and gas, from an area of high concentration to an area of low concentration that then leads to complete mixing of the concentration (Mehrer & Stolwijk, 2009; Shackelford & Moore, 2013). In the field of innovation, economics, and management, diffusion is the process by which innovations or technologies are communicated through certain channels over time to the members of a social system. It is a special type of communication, in that the messages are concerned with new ideas (Rogers, 2003).

Knowledge can be diffused using direct interactions between agents operating in social systems and a social network (Morone & Taylor, 2010). Appleyard and Kalsow (1999) suggested that knowledge diffusion is the movement of ideas between organizations. Singh (2005) and Ho, Lin, and Liu (2014) mentioned knowledge diffusion as knowledge that flows across regional and firm boundaries. However, Chen and Hicks (2004) proposed that knowledge diffusion is the adaptations and applications of knowledge documented in scientific publications and patents. Huang, Wei, and Chang (2007) argued that knowledge diffusion is the delivery of knowledge to others and that the transfer of such knowledge leads to value production.

The benefits of knowledge diffusion depend on its integration and implementation by users (Chen & Hicks, 2004). Knowledge diffusion is helpful in the innovation process only if the various bits of knowledge, expertise, and availability of research services can be used by industry (Wong, 2011). Public research institutions produce new knowledge, which may or may not have direct industrial applications, but the ultimate goals of such information may diffuse this new knowledge to firms and thereby promote firm-level innovations. Since knowledge diffusion can be limited by individual ability of comprehension and memorization, firms must realize its relevant factors, overcome obstacles, and specify effective methods of assessment and reward (Huang, Shyu, & Tzeng, 2007) to improve the overall efficiency of knowledge diffusion.

Knowledge diffusion helps to develop innovation capabilities for economic latecomers, which are those countries late to industrialize, as they are catching up (Mathews et al., 2011). Latecomers' catch-up activities include building technology capacity, decreasing R&D costs, and shortening development time through knowledge diffusion. Many countries use policy instruments to encourage knowledge transfer and diffusion of knowledge from public research institutes, higher-education institutes, and industries (Robin & Schubert, 2013). In the East Asian latecomer countries, knowledge diffusion has played a key role in evolving the development of strategic high-tech industries, including personal computers (PCs), semiconductors, optoelectronic, and solar Photo Voltaic (Mathews et al., 2011).

## Knowledge Diffusion Processes and Their Mechanisms

Knowledge is developed by direct interactions with agents' operating in social systems and networks (Morone & Taylor, 2010). Individuals accumulate new knowledge via interactive social learning processes with their peers in face-to-face interactions (Morone & Taylor, 2004). Since personal interactions do influence the accumulation of new knowledge, there is no doubt that knowledge diffusion mechanisms are affected by geographic localization. Indeed, interpersonal ties in collaborative networks are associated with a greater probability of knowledge flow (Singh, 2005; Lööf & Broström, 2008). Moreover, the benefits of intellectual property rights may affect knowledge diffusion. Ho et al. (2014) analyzed the patent citation network by path analysis to invest in the evolution process of technology knowledge over different periods and construct how the knowledge of core technology diffuses among nations. In their studies, the brokerages of patents also affect the diffusion of technological knowledge.

Some research has argued that knowledge diffusion is a barter process in which pairs of agents located in a small-world regions trade knowledge with other agents nearby (Cowan and Jonard, 2004). Many studies present the concept that small-world networks diffuse knowledge more efficiently than other structures or larger networks do (Cowan & Jonard, 2004; Kim & Park, 2009). Luo, Du, Liu, Xuan, and Wang (2015) focused on a co-evolution of knowledge diffusion and the social network structure.Yang, Hu, and Liu (2015) further investigated the performance of knowledge diffusion by knowledge absorptive capability and the knowledge diffusion mechanism. In their study, the speed of knowledge diffusion is determined by hypernetwork size, so that the smaller the hypernetwork is, the faster and more easily knowledge in that network diffuses. Moreover, as each individual's self-study capability improves, the knowledge stock is able to continue to diffuse. Wang, Guo, Yang, and Liu (2015) selected highly knowledgeable nodes, hypernetwork sizes, and hypernetwork structures for knowledge diffusion and showed how knowledge spreads from the target node to all its neighbors via a hyperedge and knowledge stock. They also found that closer network structure and smaller network size could increase the speed of that knowledge diffusion.

## The Roles of Higher Education Institutes in Knowledge Diffusion

Heitor and Bravo (2010) argued that scientific and technological development is related to the relationship between knowledge and the social network in the process of knowledge producing and sharing. Higher-education institutes play a dominant role in such knowledge producing and sharing. The most significant missions of higher-education institutes are teaching and research, which embrace all knowledge processes, including knowledge creation, sharing, transferring, storing, and diffusion. Therefore, higher education institutions can significantly affect knowledge diffusion by using high quality embedded academic knowledge to contribute to innovation, industry and country development, and technology evolution (Hussler & Rondé, 2007; Acworth, 2008; Etzkowitz & Zhou, 2008).

Traditionally, teaching has been regarded as the most important mission of higher-education institutes since the Middle Ages. Higher education institutes transfer knowledge of liberal arts to students through instruction. Moreover, instructors or masters of higher education institutes' have had freedom to lecture everywhere and relocate the location of higher-education institutes, so knowledge can then diffuse to other regions. With the Industrial Revolution, higher-education institutes had to adapt their roles to respond to the changes in production and how to interact with industries. In the knowledge economy, higher-education institutes provide well-educated talent and the industrialization of knowledge, and academic findings to advance the process of technological applications and innovation in industries and related firms (Kwon, 2011), and thus, advance the development of industrialization. Knowledge dissemination, the diffusion of knowledge that is directed and managed (Rogers, 2003), plays a dominant role in higher education in Science, Technology, Engineering, and Mathematics (STEM). The well-developed higher education of STEM can also help resolve the problem of knowledge worker shortage, which exists primarily in the STEM area (OECD, 2005; Beach, 2013).

In the 19th century, the Humboldt model became the standard for the university focus on conducting fundamental scientific research and also training future researchers (Albulescu & Albulescu, 2014). Recently, higher-education institutes have modified the Humboldt model, which focuses on teaching and research, and enhanced the university–industry links to generate and diffuse knowledge that is more directly connected with actual industrial and economic development (Segarra-Blasco & Arauzo-Carod, 2008). Academic research on commercial performance has offered abundant rewards for knowledge diffusion, technology transfer, and industrial evolution. At the same time, firms that collaborate with higher-education institutes gain more profit from new products than do non-UI collaborating firms (Lööf & Broström, 2008). Higher-education institutions can provide for the transfer of tacit and codified knowledge to industries in areas of spin-offs, licensing, and patents (Wright, Clarysse, Lockett, & Knockaert, 2008). Technology transfer, patent application, joint ventures in research, and new start-ups are some of the ways to diffuse knowledge and technology from higher-education institutes to companies. UI collaborations are part of these scientific networks and exchange knowledge in a non-codified form. Higher-education institutions also transfer technology to industries through the informal networks that exist for UI collaboration rather than through the more formal channels of a technology transfer office (Colyvas et al., 2002).

To advance human capital and produce new knowledge, governments and policy makers should define a policy to enhance the collaboration inside higher-education institutions, research organizations, and corporations via education programs, research projects, strategic alliances, and partnerships, as well as providing for advanced research systems to strengthen knowledge production at the highest level (Borrás & Edquist, 2013; Heitor et al., 2014). Many researchers have focused on higher-education institutes becoming one of the primary sectors and actors of national innovation systems, which assume that higher-education institutes by collaborating with industries, government, and research institutes can increase a country's innovative capabilities and thus contribute to national competitiveness (Etzkowitz et al., 2000; Leydesdorff, 2000; Inzelt, 2004). In most national innovation systems, higher-education institutes are one of the critical research performing sectors that conduct basic research.

Much of the contribution of higher-education institutes to knowledge diffusion involves tacit knowledge, which is unexpressed and experience based, but academics are not cognizant enough to communicate all the details of their skills. Tacit knowledge is of course difficult to standardize and articulate and is best transferred by close social interaction between people (Wright et al., 2008). The mechanisms associated with the creation, diffusion, and commercialization of knowledge that is evolving in higher-education systems is important (Leisyte & Horta, 2011). The knowledge diffusion mechanism in the higher-education system increasingly has been the object of study in recent years (Heitor & Bravo, 2010; Robin & Schubert, 2013). The issue is very critical for enabling innovation. Although the issue is essential for major catch-up economies, related research on the issue is still very limited. Researchers have paid less attention to knowledge diffusion mechanisms between higher-education institutes and other institutes. More research is needed to explore these issues and further enhance higher-education knowledge diffusion to benefit the catch-up economies.

## Key Factors to Enable Knowledge Diffusion Capabilities in Higher Education Institutes

The importance of higher-education institutes' roles in creating and diffusing knowledge was discussed here in Section 2.3. Much of the literature shows an increasing level of academic knowledge activities, such as teaching, academic publication, research joint ventures, consulting services, and patent application (D'Este & Patel, 2007; Rosell & Agrawal, 2009). A growing number of studies are now available to shed further light on knowledge diffusion in higher-education systems (Nelson, 2012; Hsu & Yuan, 2013). Following is a summary of the key factors based on literature review results for that topic.

### *Instruction*

Higher-education institutions provide high quality academic knowledge and teaching activities, including the creation, sharing, transferring, storing, and diffusion of knowledge (Hussler & Rondé, 2007; Acworth, 2008; Etzkowitz & Zhou, 2008). The major difference between higher education institutes and other research institutes is the focus on cultivating talent. In higher education institutes, individuals gain professional knowledge and capabilities to do higher value-added work both efficiently and effectively, so well-educated labor forces can then advance t industrialization (Just & Huffman, 2009). Knowledge diffusion is achieved when these graduates are recruited into industry.

In higher-education institutes, instruction is the traditional way that teachers have transferred knowledge to students and still is the most fundamental activity of knowledge diffusion in most higher-education institutes (Nawaz & Gomes, 2014). With the development of information technology and the ideals of greater openness in education, massive open online courses or MOOCs (Burd, Smith, & Reisman, 2014) have begun to provide free and open online educational materials to learners, so knowledge can now be diffused more freely. Recently, higher-education institutes not only have modified their teaching styles and curriculums, but also have provided interdisciplinary, entrepreneurship courses to empower students to develop their own abilities at problem solving, entrepreneurship, patent applications, and business plan writing (Albulescu & Albulescu, 2014). These theoretical and practical learning changes have led students not only to diffuse their new created knowledge or ideas to other individuals and organizations, but also to foster greater innovation (Acworth, 2008).

### *On-the-job training*

Applying the human-capital theory, a well- trained workforce contributes to enhancing business performance, an organization's competitive advantage, and general economic development (Mollahoseini & Farjad, 2012). Curriculum reform in higher education systems tends to enhance the connection between practical and theoretical principles, and many stakeholders both inside and outside these higher education institutes become involve in the design process for curricula that then provides students with more and greater industry-relevant competencies (Mälkki & Paatero, 2015). To engage individual productivity and capabilities and improve job performance, employees receive courses or programs while on the actual job. Thus, workers can gain and transfer knowledge through on-the-job training (Sampson, 2013). After training, the knowledge, skills, and attitudes of these employees have changed, and they can then apply those new skills and knowledge in the workplace (Mollahoseini & Farjad, 2012). Employees not only receive training from their managers and their company, but also often from higher-education institutes and other institutes. Higher education institutes often provide short-duration professional workshops, executive education programs, or degree programs to engage industry professionals more closely with university activities and empower more knowledge and skills for the job (Acworth, 2008).

### *Experience Sharing*

Ruiz, Kamsu-Foguem, and Noyes (2013) argued that in the process of experience sharing, people use in-depth analysis to understand the context and risk criteria of problems. The solutions are defined and implemented, and people obtain knowledge or lessons learned from their own set of experiences. Most academics have industrial or business experience, management, and commercial skills, so they need consultants who have specialist professional knowledge and practical experience in the operation of companies and can advise academics how to commercialize academic achievement (Berbegal-Mirabent, Ribeiro-Soriano, & Sánchez García, 2015). Industrial experts share their practical experience in speeches, workshops, and conferences for faculty members at many higher-education institutes. Technicians, managers, and masters in special fields have various implicit and tacit knowledge gained from practice over the years. By delivering lectures and speeches, they can externalize their knowledge, transfer it to others, and cultivate a more educated workforce.

### Internships

In many disciplines, like business and medicine, experiential learning is more important than lecturing to students in the classroom without connecting to the real world (Abioye, Ibrahim, Odesanya, & Wright, 2012; Pernar, Corso, Lipsitz, & Breen, 2013; Khalil, 2015). Students have to be engaged in practice and apply what is learned in the classroom to the real world (Khalil, 2015). An internship or academic-service partnership can transmit theoretical knowledge to practice and expand students' capacities (Murray & James, 2012; De Geest et al., 2013). Educators, students, and practical experts not only share knowledge with each other, but also explore new knowledge fields by participating in internships. Either during a semester or while on vacation, students can work at a firm or institute related to their fields of study. This opportunity offers students a bridge to the real world to find their interests and position in an individual industry, and accumulate practical experience for the future (T.-L. Chen & Shen, 2012).

### R&D Activities

Academics conduct research to acquire new knowledge and broaden and explore their understanding of the fundamental aspects of their discipline without dealing with specific applications or products (Ranga, Debackere, & Tunzelmann, 2003). Responding to the change in the knowledge model to address the demands for the development of country and industries, higher-education institutes have enlarged their business-oriented research and transferred advanced technology into other enterprises. Meanwhile, public funding has been strengthened for mission-oriented projects, contract-based strategic allocation procedures and academic performance (Auranen & Nieminen, 2010). With joint research, funding support, and equipment donation, universities can collaborate with industries on R&D. When user benefits increase, researchers can gain more funding for research (Belkhodja & Landry, 2007). Universities will conduct more empirical studies to fulfill the demands of the grant providers, so they can gain more financial supports. Intensive UI collaboration may decrease researchers' academic freedom and lead universities to conduct industry-driven, short-term, problem- solving research, rather than long-term original research (Giuliani & Arza, 2009). Thus, higher-education institutes have transformed the research approach from being curiosity-driven basic research to problem-driven applied research (Tijssen, 2006).

### Publication

University professors and scholars transfer their knowledge through journal papers, books, and other forms of documentation. Scholarly publications usually mention the number of citations for the articles they publish, the number of different journals that cited the paper being published, and the number of publications in the journal under study (Bar-Ilan, 2008). With such analysis of diffusion by publications citations, Liu and Rousseau (2010) argue that research fields are increasingly diffusing knowledge to nearby and related fields, such as mathematics to physics, engineering, chemistry, and Computer Science. Knowledge diffusion in different academic fields can also be measured through publication and publication citations (Bar-Ilan, 2008). Given modern social networks, people are also more willing to trust each other and exchange tacit knowledge (Marrocu, Paci, & Usai, 2013). The network structures of collaborations, hypernetwork sizes, and knowledge evolution mechanisms reflect the growing number of collaborative papers (Yang et al., 2015).

## *Academic Exchange Networks*

The modern university is genuinely universal in nature, both in its internal structure and its ambitions for the generation and communication of new knowledge (Schamp, Schmid, & Agbakoba, 2008). With the internationalization of higher education , higher education institutes can improve academics and students mobility, promote global academic collaboration of teaching and research and enhance networking between higher education institutes and industries from different regions (Heitor, 2014). International academic exchange programs now reflect and encompass the knowledge of diverse societies and cultures (Muchtar, Amri, Mustafa, & Bakar, 2012). Academics can develop professional, social, and cultural competencies and improve the internationalization process in higher-education through international academic exchange programs (Muchtar et al., 2012). Research skills and the latest information, knowledge, and technology are transferred and diffused to multiple academics and industries via professional associations, meetings, conferences, and seminars (Crespi, D'Este, Fontana, & Geuna, 2011). There have always been shifting centers from which new ideas and new knowledge have been spread to other universities (Schamp et al., 2008). Recently, this global flow of scientific and technological (S&T) resources has developed at a faster rate. International S&T resources can be strengthened further still to promote economic development and a general accepted consensus between government and the business community; using collaboration, regions can share and pass on knowledge, set up networks of academic exchange, and generate new academic thinking and outcomes (Xie, 2013).

## *Consultation*

Academic consultation by faculty in higher-education institutes is a channel of interaction between university and industry that transfers knowledge and technology between academics and industry (Jensen, Thursby, & Thursby, 2010). Consultation and technical assistance from faculty are common ways for faculty members to draw upon their expertise for the welfare of society, such as when they are asked to analyze certain data, solve a problem, or evaluate a program (Checkoway, 2001). When a faculty member draws upon his or her expertise in this way, it is another form of knowledge development and an appropriate professional role that contributes both to the civic mission of the university and improves the quality of life overall (Checkoway, 2001). Consulting enables the transfer of knowledge between academics and external organizations, and it enhances interactive and problem-solving knowledge that then leads to technical or organizational innovation (D'Este, Rentocchini, Grimaldi, & Manjarrés-Henríquez, 2013; Rentocchini, D'Este, Manjarrés-Henríquez, & Grimaldi, 2014).

Perkmann and Walsh (2008) discussed three types of academic consulting: Opportunity-driven, commercialization-driven, and research-driven. Opportunity-driven consulting does not deliver a direct research or teaching contribution, but it leverages existing knowledge and technology to resolve short-term problems and provides improvements rather than completely new ideas. With long-term academic research and financial support, commercialization-driven consulting involves not only inventors' hiring academics to commercialize technology or products using consulting and contract research, but also academics building spin-off companies and licensing technology. Rather than involving inventors in opportunity-driven and commercialization-driven consulting, research-driven consulting only accesses academic paper authors and patent research authors. Research-driven consulting focuses on improving industrial problems or gaining research materials via conferences, informal interaction, and joint research. With long-term academic research and knowledge accumulation, commercialization-driven consulting becomes the main way for universities to enlarge the benefits of gathered knowledge.

## *Patent Applications*

Knowledge embedded in university patents, which are one source of commercial technology, tends to diffuse more rapidly to corporate users (Bacchiocchi & Montobbio, 2009). The patent process is one of the major channels used to diffuse the commercialization of academic knowledge to industries or other users (Perkmann et al., 2013). Academic inventors who invent or discover new and useful processes, machines, or technology can apply for patents to protect their intellectual property (IP) rights (Alexander & Martin, 2013). The Bayh-Dole Act of 1980 facilitated the retention by universities of intellectual property rights. Universities thus changed from doing basic research to applied research, and the number of patents and licenses rose rapidly. Compared to tacit knowledge, explicit knowledge is more easily expressed. Therefore, universities have advanced various IP strategies to protect the value of explicit knowledge (Wright et al., 2008; Rosell & Agrawal, 2009). An increased number of technology transfer activities, academic patenting, intellectual property offices (OIPs), and Technology Transfer Offices (TTOs) have occurred in universities (Just & Huffman, 2009).

Knowledge creation and diffusion in higher-education systems can be traced with patent citation analysis (Liu & Rousseau, 2010). With patent agreements and collaborative partnerships, universities can conduct more market-oriented research or change research agendas to apply patented technology to the actual market place (Crespi, D'Este, Fontana, & Geuna, 2011). Patent disputes in which a technology transfer office is involved to invoke complex contracting arrangements make knowledge transfer more time-consuming; informal relationships and mobility of personnel also now play a more important role in the environment than simple formal technology transfer (Colyvas et al., 2002).

## Technology Transfer

Technology transfer is organized work to achieve a goal and make the necessary technical information move reasonably (Liu, Fang, Shi, & Guo, 2009). Transferring technologies that are developed at universities to industry vastly expands the resource base by providing companies with no internal R&D effort for that capability and augmenting the R&D of companies with a basic level of internal effort already in place (Nagel, 2001). By taking advantage of university technology transfer, all companies and policymakers can emphasize innovation as a goal that is included in a competitive business strategy. Having universities as participants in technology transfer activities maximizes the benefits and minimizes the costs of the technology R&D by providing for shared equipment, personnel, and laboratory facilities (Nagel, 2001). This fact is particularly clear in situations where precompetitive research is being undertaken at university-based centers or consortiums that draw their members from wide groups of industry participants (Nagel, 2001). Academics, members of companies, and other types of organizations exchange knowledge, technology, and documents through formal pathways, including research collaborations, contract research, consultancy, spinoffs, meetings, and conferences (Resende, Gibson, & Jarrett, 2013).

## Strategic Alliances

Strategic alliances are joint efforts between two or more firms wherein the organizations combine their resources to achieve mutually compatible goals that these organizations may find difficult to achieve alone (Wilkinson & Kannan, 2013). To speed up innovation diffusion and gain more resources and funding, some companies do R&D activities with networked partners, including internal R&D departments, higher education institutes, research institutes, and networked partners' R&D laboratories (Gupta & Maltz, 2015). With international partnerships in science, technology and higher education systems, higher education institutes, companies, research centers and other institutes from the world can form strategic alliances to gain highly qualified talent and resources to innovate further (Filieri, McNally, O'Dwyer, & O'Malley, 2014).

Strategic alliances are a recent addition to the armory interaction means with industry and consist of a rather extensive mode of partnership between a company and a university (Roundtable, Commission on Physical Sciences, Council, & Sciences, 2000). Strategic alliances share resources with partners in flexible ways to achieve more benefits (Veugelers, 2012). The characteristics of such alliances are that they will become long-term partnerships across a number of university departments or disciplines, usually beyond the life of a single research project or contract, and also normally involve a large multinational company (Roundtable et al., 2000). The alliances are open- ended with no limitations on what sort of interactions might be involved, so that they can include staff exchanges, undergraduate recruitment, and student prizes or endowments (Roundtable et al., 2000). On a number of campuses, collaborative efforts between academia and industry have resulted in the creation of a new educational space, advanced technology center. Such centers as the MIT Media Lab and Rock Valley College's

Advanced Technology Center share important distinguishing features (Ecker & Staples, 1997). Both provide a physical site to house donations of technical equipment from many different donors (Ecker & Staples, 1997). Both are interdisciplinary, meeting the needs of both industry and educational partners in the context of each institution's unique educational mission, namely, basic research for MIT and teaching of applied technologies for Rock Valley (Ecker & Staples, 1997).

### *Start-ups*

Academic research commercialization can contribute to knowledge diffusion. Academic inventors undertake the development and commercialization of technologies through the creation of spin-off companies. Professors in universities usually offer consultancy to these enterprises. Students also may join UI research collaboration during their studies. They commercialize ideas from universities and science parks to build spin-off companies. University-related spin-off/start-up firms with university funding and specialized university research are usually either high-tech or knowledge intensive firms (Bathelt, Kogler, & Munro, 2010). In Bathelt et al. (2010), sponsored spin-offs develop their core technology via university research projects and apply specific knowledge inputs; unsponsored spin-offs develop innovative products and services based on extensive knowledge bases. University-related spin-off/start-up firms will improve regional growth and modernization processes (Bathelt et al., 2010).

Costs in the information technology industry have been lower than any other industries; people can start up a new company with just some equipment. Thus, like B. Gates, J. Yang, and D. Filospin, some students or alumni, have successfully founded companies like Microsoft and Yahoo using their creativeness combined with lessons they received in their universities. Universities also benefit from their graduate students. The most well-known case is Stanford University and Google. Stanford became the most famous by selling out its Google bonds and receiving the highest technological transfer funds. L. Page and S. Brin, graduates from Stanford University, set up Google with the help of Stanford, and traded its bond as a Stanford University premium. In 2004 when Google went public, Stanford sold its bond and received $336,000,000, which turned out to be the highest technological transfer fund in a university ever.

## Policy Instruments Enabling Knowledge Diffusion Mechanisms in Higher-Education Institutes

Heitor et al. (2014) argue that, to advance human capital and lead to new knowledge, governments and policy makers should build their policies to enhance collaboration within higher-education institutions, research organizations, and corporations. This focus can be accomplished through education programs, research projects, alliances, partnerships, and advanced research systems that strengthen knowledge production at the top level. Many governments have introduced an increasing range of policy instruments to enhance knowledge diffusion in higher education (Borrás & Edquist, 2013). Based on these works of previous studies, the policy instruments for knowledge enhancement are summarized below.

### *Legal and Regulatory*

Higher-education systems play an important role in knowledge creation and diffusion in their regions. Universities not only lease land and facilities to high-tech companies; these enterprises also employ professors are consultants and hire these universities' graduates. Responding to dynamic knowledge processes and advanced academic production, diffusion, and commercialization, governments have applied specific policy instruments to emphasize research priority-setting, research evaluation, and performance-based funding (Leisyte & Horta, 2011). Based on the innovation of policy tools, Rothwell and Zegveld (1981) have argued for a variety of regulations for patents, environmental and health regulation, inspectorates, and monopoly regulation. Regulations for higher-education institutes, including UI collaboration projects, Science Park, patent and internship regulation, degree recognition, inspectorate regulations, and global recruitment mechanisms can enhance knowledge diffusion. Some science parks, such as Silicon Valley, Tsinghua Science Park, and Hsinchu Science Park, were set up near top universities and built as high-tech clusters. (Saxenian, 1994; Chyi, Lai, & Liu, 2012).

## *Ownership and Utilization*

To gain more funding support for research, more and more academics struggle between doing basic research activities and commercializing their academic inventions. Commercial interests can pose a threat to research and knowledge diffusion. With the emergence of supply-driven knowledge networks and the desire for capitalizing and commercializing knowledge, both ownership and utilization of intellectual property rights (IPRs) had become a significant issue. Researchers pay attention to what constitutes intellectual property and what types of knowledge can be owned and traded. Using new knowledge and the latest research findings, the research fields of chemistry and biology have allowed ownership of gene sequences by creating an interpretation of intellectual property known as anticommons, and thus applied for patents (Arocena, Göransson, & Sutz, 2015). At the industry level, an IPR is not only a kind of resource; it is also a part of a management strategy. Some researchers are discouraged in using their studies that are restricted by IPRs for advanced research (Foray & Lissoni, 2010). Researchers need to be freer and more flexible to use their intellectual property rights.

## *Information*

New Information and Communication Technologies (ICT), especially the Internet, which broke traditional boundaries and increased the speed of communication, changed the ways of problem- solving, generation, and application of knowledge. ICT extended local knowledge systems to reach global knowledge systems (Arocena et al., 2015). ICT has accelerated the knowledge diffusion process, reuse, and learning of knowledge and increased the personal mobility of knowledge workers (Gassmann, 2006). Information policy instruments include information and telecommunication networks, databases, operating system, libraries, advisory and consultancy services, liaison services, and centers ( Rothwell & Zegveld, 1981; Huang et al., 2007). ICT can democratize knowledge via intellectual commons, open source, wiki-initiatives, and telecenter movements (Arocena et al., 2015). The improvement in microprocessors and operating systems and the expansion of interactive telecommunication networks produce the Internet boom. The Linux operating system is an open source freely available to everyone. Anyone can modify the source code of Linux. Linux decreased the costs of computers and drove the development of Information Communication Technology. Additionally, Linux made internal open sources come into vogue around the world.

## *Infrastructure*

To cultivate talent and conduct research, governments can play a significant role by providing buildings, construction, transport, telecommunications, research laboratories, and scientific and technological infrastructure for such knowledge development (Rothwell & Zegveld, 1981; Huang et al., 2007). The development of scientific and technological infrastructure can help support research, diffusion, and the promotion of shared values (Cassi, Corrocher, Malerba, & Vonortas, 2008). Science parks also are an important part of the infrastructure used to create, share, transfer, and diffuse knowledge. Science parks near higher-education institutes provide industrial and business clusters that bring high-tech firms and science-based businesses together, so knowledge and technology can flow from these higher-education institutes to the industries and produce innovation-based start-ups (Berbegal-Mirabent et al., 2015).

## *Investment*

The funding and income of higher-education institutes is diversified and comes from different sectors, including governmental sources, university-generated income, and private organized sources (Clark, 2001). Universities leverage their research infrastructure via research funding from government and industry (Jensen et al., 2010). After the Second World War, governments set up massive universities and offered scholarships to veterans to stabilize the societies. Therefore, governments invested their public funding in higher-education, so universities could focus on more basic research and teaching (Auranen & Nieminen, 2010). In recent years, universities in most countries have experienced a decrease in public funding. Firms obtain greater profit from new products via UI collaboration (Lööf & Broström, 2008), and thus, firms are willing to fund higher-education institutes. To create new sources of income, universities not only participate in government-funded research collaboration programs, but they also enlarge the business-orientation toward research and joint research (Just & Huffman, 2009). In a knowledge intensive society, higher-education institutes have enhanced R&D activities in different sectors and joined UI collaboration and global collaboration with other research and academic institutions (Mohrman, Ma, & Baker, 2008).

### *Support System*

Governments stimulate universities to develop intellectual capital via knowledge management to reduce the gap between universities and industry. Knowledge management in higher-education systems address interdisciplinary knowledge integration via expert systems, information systems and databases, semantic networks, decision support systems, and technical writing and communication (Nawaz & Gomes, 2014). Interviews reveal that professors and graduates express difficulty with administrative matters, including accounting, filling in various forms, and other areas. To enhance knowledge diffusion from higher-education institutes to businesses, higher-education systems need support systems to deal with administrative matters, such as applying for research grants more support for R&D activities, intellectual property, and financial strategies (Edler & Georghiou, 2007).

### *Motivation*

Faculty members spend considerable time and effort conducting research and designing learning activities. Motivation for knowledge creation, sharing, transformation, and diffusion is based on faculty promotion, honors and awards, salaries, and evaluation of teaching and research. Many more active and competitive academics are devoted to instruction, research, or UI projects (Jarohnovich & Avotiņš, 2013). On the one hand, academics should be evaluated according to their research productivity for promotion and tenure. Research productivity can be evaluated by gauging the quality of the journal in which an article is published (Matherly & Shortridge, 2009). On the other hand, academics should pay more attention to inspiring students. the identities of academics as teachers are characterized by aspirations to teaching and learning-related activities and being good teachers. Academics with high teacher identities will devote their efforts to more efficient diffusion of knowledge to students (Nevgi & Löfström, 2015) Therefore, both new and experienced faculty who have multiple role expectations and missions should balance research, teaching, and service responsibilities during their career trajectories rather than focusing exclusively on research or publication (Garand et al., 2010) to detriment of learning

### *Human Resource*

Human resource, knowledge, and intellectual property are the main sources of development for academics (Nawaz & Gomes, 2014). Higher-education institutes provide high-quality talent for both country and industrial development (Li, 2011). Lu (2012) argued that human capital within higher-education institutions consists of its faculty's knowledge foundation, ability to innovate, work motivation, and teamwork skills. To provide well-educated talent and the industrialization of knowledge, higher-education systems need a large labor pool that includes educators, researchers, legal commissioners, and patent attorneys so as to create, transfer and diffuse knowledge (Kwon, 2011). The quality of talent relies on teachers who depend on human resource development and management of higher-education institutes (Xing, 2009). Government can provide a sound research environment and also encourage brain migration and talent outflow (Jarohnovich & Avotiņš, 2013). Some developed countries like the U.S., Finland, Japan, and Germany have high rates of researchers per each 1000 count of workforce (OECD, 2014).

### *Diffusion Channels*

The social networks of industries and higher-education institutes are often separate, so higher-education institutes need intermediaries to bridge the gap between universities and industry to facilitate the diffusion of knowledge between them. Intermediaries help span the complexity of the boundary between industries and higher-education institutes (Wright, Clarysse, Lockett, & Knockaert, 2008). The patenting process is one of the major channels through which universities commercialize academic knowledge and foster new links with firms and industries. Universities have set up certain intermediaries like incubators, technology transfer offices, and research centers with enterprises to react to the development of these industries, obtain greater financial support, and set up collaborative networks (Clark, 1998; Leslie, Oaxaca & Rhoades, 2000; Slaughter & Rhoades, 2004; Wright, Clarysse, Lockett, & Knockaert, 2008). These diffusion channels gather academics together, foster experience sharing, and conduct world-class research in a creative atmosphere (Berbegal-Mirabent et al., 2015). Moreover, intermediaries can help manage revenue generation from intellectual property (Just & Huffman, 2009).

## RESEARCH METHODS

While there is a strong link between knowledge diffusion and higher-education, little empirical evidence has been found to establish a direct relationship between the two variables. The purpose of this paper is to examine the relationship between knowledge diffusion and the higher-education system. The study was designed to answer the following research question: What factors and policy instruments advance knowledge diffusion in higher-education institutions? How can the goals be evaluated?

Both qualitative and quantitative data analyses were performed. To prove and demonstrate the discussed concept, we have presented a framework to demonstrate our research design. Achieving the goals required multiple research methods, data sources, and viewpoints from experts. An analytical process was used to develop a higher-education policy portfolio for improving knowledge diffusion in higher-education institutions. A modified Delphi method was used to derive factors influencing knowledge diffusion in higher-education institutions. Since the factors being derived by the modified Delphi method may influence each other, the influence relationships between the factors were derived using the DEMATEL. The weight being associated with every factor was derived by ANP based on the influence relationships being derived by using the DEMATEL. Finally, the appropriate higher-education policy instruments were derived by using the GRA based on the weights being derived by the ANP. The research framework is demonstrated in **Figure 1**.

Based on the analytical frame for expanding them, key factors and policy instruments were selected by using the Delphi. Then, the structure of the relationship between factors defining the problem was established by DEMATEL. After that, the weights of each key factor for the decision structure were decided by using the ANP. The key factors for developing higher-education policy were derived by thirteen experts from Taiwanese universities, research institutes, and government and were introduced as possible key factors for developing higher-education policy. The key factors were confirmed as suitable for research regarding the higher-education system and policy instruments by using the second-round Delphi. Meanwhile, the relationships between key factors of knowledge diffusion in the higher-education system and the ANP derivations of the weights of each knowledge diffusion key factor also were derived for the case study.

The key factors of knowledge diffusion in higher-education systems and related policy instruments were surveyed based on the opinions of thirteen experts. The experts are working or have worked in universities and include college deans, professors, researchers, UI collaboration senior managers, and authorities in Taiwan higher-education research. Nine of the thirteen experts both received interdisciplinary training in M.S. (or above) degrees and have UI collaboration experience. Seven of the thirteen experts have already been engaged in UI collaboration for more than six years. Another two experts have been engaged in UI collaboration over ten years. The experts are familiar with the Taiwanese higher-education system in all aspects, including teaching, R&D activities, policy, and regulatory matters as well as UI collaboration mechanism. In addition, knowledge diffusion key factors of other countries' higher-education system will be surveyed based on the experts' opinions as the benchmark.

With the understanding of the key factors of higher-education systems in late coming countries, appropriate higher-education policy will be defined based on the opinions being provided by the experts to close the gap, as measured by key factors, between a late coming country and advanced countries. The proposed higher-education policies are intended to assist late-coming countries to diffuse knowledge and improve innovation capability.

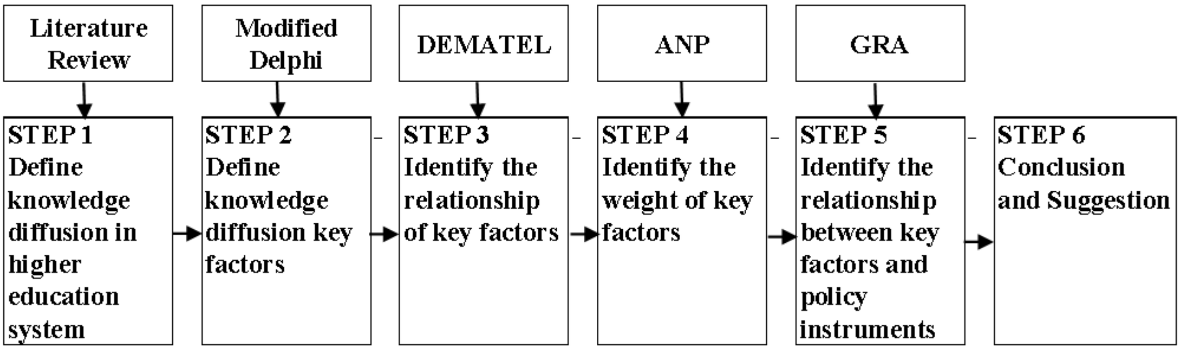



**Figure 1.** The research framework

## The Delphi method

The Delphi method originated in a series of studies conducted by the RAND Corporation in the 1950s (Jones and Hunter 1995). The objective was to develop a technique to obtain the most reliable consensus from a group of experts (Dalkey and Helmer 1963). While researchers have developed variations of the method since its introduction, Linstone and Turoff (1975) captured its common characteristics in the following description: Delphi may be characterized as a method for structuring a group communication process; so the process is effective in allowing a group of individuals, as a whole, to deal with a complex problem.

To accomplish this 'structured communication', certain aspects should be provided: some feedback of individual contributions of information and knowledge; some assessment of the group judgment or viewpoint; some opportunity for individuals to revise their views; and some degree of anonymity for individual responses (Linstone and Turoff 1975). The Delphi technique enables a large group of experts to be surveyed cheaply, usually by mail using a self-administered questionnaire (although computer communications also have been used), with few geographical limitations on the sample. Specific situations have included a round in which the participants meet to discuss the process and resolve any uncertainties or ambiguities in the wording of the questionnaire (Jones and Hunter 1995).

The modified Delphi simplified the step of conducting the first round of a survey and replaced the conventionally adopted open style survey (Sung, 2001). The purpose of the modified Delphi method is to save time, and the experts can focus on research themes, eliminating the need for speculation on the open questionnaire, and to improve the response of the main topic (Sung, 2001; Lee, Huang., & Hsu, 2008). In this research, the modified Delphi method was used to summarize the opinions of experts'. Those criteria being recognized by over two third of experts will serve as the criteria for evaluating the courses.

## DEMATEL Method

The DEMATEL method was developed by the Battelle Geneva Institute: (1) to analyze complex 'world problems' dealing mainly with interactive man-model techniques; and (2) to evaluate qualitative and factor-linked aspects of societal problems (Gabus & Fontela, 1972). To apply the DEMATEL method smoothly, the authors refined the definitions by Hori and Shimizu (1999), Chiu, Chen, Tzeng, & Shyu (2006), and Huang, Hong, & Tzeng (2011), and produced the essential definitions indicated in **Appendix 1**.

## The ANP Method

The ANP is a coupling of two parts. The first consists of a control hierarchy or network of criteria and subcriteria that control the interactions. The second is a network of influences among the elements and clusters. The network varies from criterion to criterion and a different supermatrix of limiting influence is computed for each control criterion. Finally, each of these supermatrices is weighted by the priority of its control criterion and the results are synthesized through addition for all the control criteria (Saaty, 2004). The researchers will introduce the detailed procedure of the ANP method in **Appendix 2**.

## GRA

Since Deng proposed Grey theory in 1982 (J.-L. Deng, 1989), related models have already been developed and applied to MCDM problems. Similar to the fuzzy set theory, the Grey theory is a feasible mathematical means to be used to deal with systems analysis characterized by poor information. Fields covered by the Grey theory include systems analysis, data processing, modeling, prediction, decision-making and control. In this section, some relevant definitions and the calculation process for the Grey Relation Model will be reviewed. This research modified the definitions by Chiou and Tzeng and produced definitions as indicated below.

The GRA (Grey Relational Analysis) is used to determine the relationship between two sequences of stochastic data in a Grey system. The procedure bears some similarity to the pattern recognition technology. One sequence of data is called the "reference pattern" or "reference sequence," and the correlation of the other sequence to the reference sequence is to be identified (J. Deng, 1986; Tzeng & Tasur, 1994; Mon et al., 1995; Wu et al., 1996). The detailed procedure of the GRA method will be introduced in **Appendix 3**.

# AN EMPIRICAL STUDY ON CONFIGURING THE KNOWLEDGE DIFFUSION MECHANISM FOR THE TAIWANESE HIGHER EDUCATION SYSTEM

In this section, an empirical case study based on the Taiwanese higher-education system is presented. First, the development of Taiwan's higher-education system is briefed in Section 4.1 as useful background. In Section 4.2, the key knowledge diffusion factors and policy instruments derived using the Delphi method are given. Next, in Section 4.3, the use of DEMATEL to derive the relationships between the key knowledge diffusion factors is described. Then, Section 4.4 describes how we derived the weights associated with the key factors by using the ANP. Finally, in Section 4.5 we introduce the GRA to derive the relationship between the key factors and policy instruments, and in Section 4.6 we demonstrate key factor evaluations and introduce and discuss appropriate policy instruments.

## Taiwan's Higher Education System and the Current Status of Knowledge Diffusion

The development of the Taiwanese higher education system can be discussed based on updates in the recent publication by the Minister of Education (MOE), Taiwan and the works by Chou (2012), Wang, Cheng, & Liu (2013) and Shen et al. (2015).

The first Taiwanese higher-education institute, Taipei Imperial University, was established in 1928 when Japanese occupied Taiwan, It was established with an Agricultural Department and a Politics Department (Chou & Ching, 2012). During the past decades, the capacity of Taiwan's higher education has expanded rapidly (Shin, Postiglione, & Huang, 2015). According to the statistics provided by the MOE, between 1950 and 1970, the number of higher-education institutions surged from 7 to 92, and private institutions comprised 67% of that group. With the establishment of its first technical college in 1974, Taiwan began to place technical education and higher education on the same track; higher education thereafter found different paths for its future development (Department of Higher Education, 2012).

Since the 1990s, Taiwan higher education has expanded dramatically, with respect to both the number of institutions and the number of enrolled students (Wang et al., 2013). In 1996, authorities began to encourage junior colleges to be upgraded to colleges and universities of technology, with a view toward creating unimpeded access to vocational education. Therefore, during the period from 1985 to 2014, the number of higher-education institutions increased from 105 to 156 (Ministry of Education, 2014). These quantitative increases lifted Taiwan from the stage of mass higher-education, when only 15% of the age grade had access to higher-education (Trow, 1973), to that of universal access to higher education and generally reduced education inequality (Wang et al., 2013). However, the expansion has also produced several concerns, particularly how to enhance Taiwan's global competitiveness (Wang et al., 2013). In response to the competitiveness issue in higher education, the Taiwanese government started to reform its higher-education system in the late 1990s, with a particular focus on provision, regulation, and financing (Mok, 2002).

During these past years, the Taiwanese higher-education institutes have played a daily dominant role in knowledge creation and its delivery. In addition to the traditional knowledge diffusion approach, which is lecturing, Taiwanese higher-education institutes have adopted certain novel approaches. The current knowledge diffusion mechanism of the Taiwanese Higher Education System is summarized below as a basis for this empirical study.

### *Instruction*

Currently, the majority of students in most countries receive education in school through instruction (Park, Chen, Gil, & Yen, 2014). Knowledge is delivered to learners by professional instruction using textbooks, various teaching resources (Park et al., 2014) and interaction between academics. In Taiwanese schools, the widespread use of the teaching method means that teachers function as knowledge dispensers instead of as learning facilitators.

### *On-the-Job Training*

Education and training programs stand out as the primary mechanism of UI collaboration. The basic idea is to analyze the competence development needs of the organization and transfer them into lifelong learning programs that are advantageous for employees' and can be purchased from universities. Unlike other UI collaborative mechanisms, training programs offer informal, short-term, and inexpensive research linkages that are especially attractive to Taiwanese firms with limited R&D budgets (Chang, Chen, Hua, & Yang, 2005). Responding to the industrial development and engagement of individual professionals, more and more higher-education institutes in Taiwan have set up in-service Master degree programs for their employees who want to receive on-the-job training. To improve job performance and engage individual capabilities further, 52,197 employees attended higher-education institutes to get Master's degrees in 2014 (Ministry of Education, 2015).

### *Experience Sharing*

Experience sharing and professional training are other important issues. Higher-education institutes in Taiwan invite industrial experts to share their experience in practice. For example, since 2005, National Cheng Kung University, Tainan, Taiwan has invited great masters and industrial experts in humanities and art, social sciences, and science and technology to share their learning and professional experiences with undergraduate students to inspire their learning motivation and global vision (National Chiao Tung University Center for General Education, 2015). Given the fact that technology transfer managers are encouraged to spin off new technology, it will be crucial to find qualified successors for them and provide professional training for the smoothest technology transfer function (Wong, 2011).

### *Internship*

Knowledge diffusion from higher-education institutes is achieved when graduates are recruited. To enhance the efficiency of knowledge diffusion from higher-education institutes, the government established a job-match platform, and urged higher-education institutes provide internship courses to solve serious talent mismatch problems between supply and demand. Internship programs can assist students in exploring career options, expanding their practical experience and enhancing the links between higher-education institutes and the workplaces. Almost all internship programs in Taiwan are compulsory and take place during the academic program that is leading to the attainment of a degree (Kuo, 2015). Internships seem more popular at the undergraduate level and during the third year in particular (Kuo, 2015). The length or tenure of an internship program may affect the development of the proper understanding of practical aspects of administration (Kuo, 2015). However, there is no standard time for internships across these internship programs (Kuo, 2015). Duration of tenure ranges from weekly attendance of 75 hours to a 240- hour summer program (Kuo, 2015). A weekly internship, however, puts greater time pressure on both the management of the host organization and the practicing interns (Kuo, 2015).

## R&D Activities

Higher-education institutes also collaborate with industries on R&D via joint research, funding supports, and equipment donation. With UI collaboration, especially R&D collaboration, higher-education institutes spill over the knowledge production function and share R&D resources with SMEs to help SMEs upgrade their technology capabilities and innovate continuously (Wright et al., 2008; Guan & Zhao, 2013). The Taiwanese government invests abundantly in projects to enhance UI collaboration and improve R&D capability and the competitiveness of SMEs. Therefore, research universities in Taiwan area doing more applied research than before and set up many UI collaboration institutes to improve the diffusion of knowledge to industries. However, numerous potential problems still exist in the UI collaboration of Taiwanese higher-education institutes. Statistical data from the National Science Council (NSC, 2010) states that the density of higher-education institutes in Taiwan is extremely high, at 164 universities (Lin, Chang, & Chung, 2012). Total R&D funding for higher-education institutes has gradually increased in the past decade, including funds from both the public and private sectors. However, these funds have flowed into only a limited number of universities (Lin et al., 2012).

## Publication

Faculty performance evaluation was introduced to universities in Taiwan between the late 1990s and the early 2000s (Kuo, 2015). The evaluation programs in almost all the universities use bibliometric data to assess faculty research performance at both individual and departmental levels (Kuo, 2015). University faculty members have to publish as much research work as possible, for promotion, tenure, and even grants or salaries. Although the concept is intended to evaluate the quantity of research output more than the quality or impact of that research, university presidents continue to use this particular evaluation tool (Kuo, 2015). This evaluation tool is not all negative, however. It allows for "research management" to be operated (Kuo, 2015). However, the government has overemphasized academic journal papers with respect to SSCI and SCI results, resulting in their misuse in Taiwan and also a decrease in the number of books published in the humanities and the social sciences (Shin & Kehm, 2012).

## Network of Academic Exchange

According to Law (1996), in the late 1980s, the State of Taiwan began to modify its policy towards international educational relations in two respects (Law, 1996)-- the promotion of Taiwan's experience in economic and political developments and the extension of academic exchange with mainland China and the former socialist countries (Law, 1996). Later, the Program to Promote International Competitiveness of Universities (PPICU) was initiated in August 2002, specifically targeting advancement of international competitiveness of Taiwan's universities. Promoting international academic exchange activities is one of the major strategies (Song & Tai, 2007). During these past years, the Web has become an important means of academic information exchange in Taiwan and is used to give new insights to patterns of informal scholarly communication (Thelwall & Tang, 2003).

## Consultation

Consultation and technical assistance by faculty are common ways for faculty members to draw on their expertise for the welfare of society, such as when they are asked to analyze certain data, solve a problem, or evaluate a program (Checkoway, 2001). In assisting start-ups to develop firm technology competence, Taiwanese incubator centers now offer these firms the opportunity to get involved in academic research facilities, faculty consultations, and research network build-ups (Chang et al., 2005).

## Patents

The reforms in the 1990s have been accompanied by self-governance, but all within a centrally determined policy framework and accountability evaluations, using reduced resources. Governmental grants have dramatically decreased, but those grants from the external and industrial sectors have increased. Higher-education institutes have started focusing on grants. Higher-education institutes must manage their intellectual capital to produce and diffuse knowledge and invest in research and human resources. Higher-education institutes also try to leverage the benefits of knowledge and enhance their intellectual capital performance (Lu, 2012). A comparison of IPRs reveals that although the annual number of patents granted to Taiwanese universities before 2007 exceeded 900, the efficacy of licensed patents and licensing income was limited (Lin et al., 2012). The primary reasons for this outcome was the policy of the NSC for increasing the number of granted patents and the insufficient number of personnel for technology transfer (Lin et al., 2012). After 2008, both licensed patents and licensing income have grown significantly due to the promotion of integrated UI collaboration (Lin et al., 2012). With regard to business incubation of HEIs, funding and human resources are currently the two major challenges (Lin et al., 2012). The key performance index (KPI) of business incubation centers granted by the government focuses on increasing the number of incubated SMEs (Lin et al., 2012). Although professors provide technology consulting services, many business incubation centers only provide a place for incubation rather than delivering comprehensive assistance (Lin et al., 2012).

## *Technology Transfer*

The Minister of Science and Technology (MOST) is the leading academic funding organization that is in charge of promoting industry-academia collaboration in Taiwan. To encourage academia to become involved in patenting activities, the National Science Council (NSC), the former institute of the MOST, implemented the Principles of Management and Promotion of Academia R&D Results in 2002. To facilitate the transformation of research output from universities into economic fruit, the Ministry of Education (MOE) has put in place an incentive program (the Incentive Program of the Performance of Academia-industry Collaboration) to further advance academia-industry collaboration (Department of Higher Education, 2012). Operation centers have been installed at 11 universities where specialized managers are brought in to help consolidate their respective R&D resources and incubation centers as well as technology transfer projects (Department of Higher Education, 2012). The objective is to provide industry with a friendly, competent service platform. Between 2008 and 2010, the profits from academic intellectual property rights increased by 48% (Department of Higher Education, 2012).

SMEs make up the majority of Taiwanese companies, comprising 97.91 % of total enterprises in Taiwan (Roberts, Chou & Ching, 2010; Lin et al., 2012). Due to insufficient human resources, capital, equipment, and innovative R&D operational models to support their commercial activities, SMEs usually cooperate with academic institutions to satisfy their needs for innovation (Lin et al., 2012). Some large enterprises have a certain number of employees for R&D, but they also cooperate with academic institutions to search for innovative concepts and shorten R&D time (Lin et al., 2012). However, Taiwan's industry structure poses particular difficulties for university technology transfers. Most industries in Taiwan are dominated by SMEs, which prefer to have full ownership of their patents and prefer to engage universities through commissioned research rather than pursue licensing arrangements (Wong, 2011).

## *Strategic Alliances*

To improve national competitiveness, the MOE encourages universities to pursue academic excellence. The MOE has brought together the necessary resources for developing research universities and promoting strategic alliances and mergers between universities (Narayanan & O'Connor, 2010). Further, to enhance the quality of education and the pursuit of excellence in universities, the Ministry of Education encourages schools to increase their competitiveness by integrating resources (Ministry of Education, 2002b; Shin et al., 2015). To integrate teaching, learning, and research resources and expand interaction with other institutes, many higher-education institutes in Taiwan form strategic alliances with other higher-education institutes and firms around the world. A school that desires to merge must submit a merger plan and undergo government review. Schools can also engage in inter-institution cooperation; for example, they can hold interschool classes and teacher and student exchanges as well as jointly plan the use of research facilities and research environments (Shin et al., 2015). When the time is right for planning a merger, the resistance to merging is generally minimized (Ministry of Education, 2001b; (Shin et al., 2015). Compared to other world-class universities, higher-education institutes in Taiwan are smaller in scale, have fewer resources and lack complete discipline areas within their institutions. National Central University, National Chiao Tung University, National Tsing Hua University, and National Yang-Ming University—four outstanding educational and research institutions in Taiwan—thus gathered together and set up the University System of Taiwan (UST). The UST integrates resources and combines the energy of these four universities for teaching and research to enhance the quality of teaching and research and achieve academic excellence. The UST integrates educational resources from the four universities and collaborates by sharing books, equipment, and courses, thus offering mutual recognition of credits, opening up inter-campus selection of classes and curriculum, inter-campus transfers, joint recruitment and admission, exchanges of teachers, joint appointment of approved teachers, and inter-institution research collaboration.

### *Start-ups*

Entrepreneurship is a telling feature that sets Taiwan apart from most of its Asian neighbors (Department of Higher Education, 2012). The higher-education institutes further commercialize research achievement to gain more profits so as to maintain operation via new start-ups. Against the dominance of a few conglomerates in many countries, SMEs account for 98% of Taiwan's economy, as local people have a natural disposition for starting their own businesses (Department of Higher Education, 2012). In such an entrepreneur-led society, universities have a lot to offer when it comes to R&D. In the *IMD World Competitiveness Yearbook* 2011, Taiwan's "science in schools" was ranked 3rd among the 59 countries surveyed (Department of Higher Education, 2012). Further, the Taiwanese university creates its own venture strategy of a "surrogate-incubation" rather than the MIT "champion and spin-off " model (Chang et al., 2005).

## Knowledge Diffusion of Key Factor Competence Derivations by Delphi

In terms of the 12 key factors and 9 policy instruments that are needed for knowledge diffusion in higher-education system were derived using the Delphi results. Based on the literature review results, this research selected and then categorized relevant key factors and policy instruments. The derivations of the key factors and policy instruments are based on the opinions of 13 experts who are familiar with the Taiwanese higher-education system and all its aspects, including teaching, R&D activities, policy and regulatory areas, and UI collaboration mechanism. These experts include college deans, professors, researchers, and UI collaboration senior managers, as well as experts on Taiwanese higher-education research. Two of the experts are college deans who have worked in Taiwan leading research and teaching universities. Of these experts, 9 out of the 13 received interdisciplinary training in M.S. or Ph.D. degrees and have UI collaboration experience. Further, 7 of the 13 have been engaged in UI collaboration for more than six years.

The knowledge diffusion key factors for analysis were: (a) instruction ($a_1$); (b) on-the-job training ($a_2$); (c) experience sharing ($a_3$); (d) internship ($a_4$); (e) R&D activities ($b_1$); (f) publication ($b_2$); (g) network of academic exchange ($b_3$); (h) consultation ($c_1$); (i) patent application ($c_2$); (j) technology transfer ($c_3$); (k) strategic alliances ($c_4$); and (l) start-ups ($c_5$). The traditional concepts of the missions of higher-education institutes are teaching, research and service (Sánchez-Barrioluengo, 2014; Guerrero, Cunningham, & Urbano, 2015). Based on this literature review and the experts' opinions, the study concluded that there are 12 e key factors of knowledge diffusion that could be used for classifying factors as grouped into three aspects. Teaching aspects included instruction ($a_1$), on-the-job training ($a_2$), experience sharing ($a_3$) and internship ($a_4$). Research aspects included R&D activities ($b_1$), publications ($b_2$) and networks of Academic Exchange ($b_3$). Service aspects included consultation ($c_1$), patent application ($c_2$), technology transfer ($c_3$), strategic alliances ($c_4$), and start-ups ($c_5$). The definitions and corresponding symbols for these factors are offered in **Table 1**.

Policy instruments included: (a) legal and regulatory ($p_1$); (b) ownership and utilization ($p_2$); (c) information ($p_3$); (d) infrastructure ($p_4$); (e) investment ($p_5$); (f) support system ($p_6$); (g) motivation ($p_7$); (h) human resource ($p_8$); and (i) diffusion channel ($p_9$). Using the experts' opinions, the research classified the higher-education policy instruments into demand, supply, and environment categories. Environment side included legal and regulatory ($p_1$), ownership and utilization ($p_2$) and information ($p_3$); the supply side included infrastructure ($p_4$), investment ($p_5$) and support system ($p_6$); demand side was motivation ($p_7$), human resource ($p_8$) and diffusion

**Table 1.** Key Factors of Knowledge Diffusion

| Aspect | Key Factor | Definition |
|---|---|---|
| Teaching | Instruction ($a_1$) | Both theoretical and practical curricula and activities diffuse knowledge from teachers to students and foster innovation (Acworth, 2008). |
| | On-the-job training ($a_2$) | Employees receive training from higher-education institutes to empower individual productivity, capabilities, and improve job performance (Acworth, 2008; Mollahoseini & Farjad, 2012). |
| | Experience sharing ($a_3$) | Industrial experts with specialist professional knowledge and practical experience share their practice experience and advise academics how to commercialize academic achievement (Berbegal-Mirabent et al., 2015). |
| | Internship ($a_4$) | During a semester or vacations, students work at a firm or institute to transition theoretical knowledge into practice, find their interests and position in an industry, and accumulate practical experience (Khalil, 2015). |
| Research | R&D activities ($b_1$) | Academics conduct R&D activities to acquire new knowledge and broaden and explore understanding of the fundamental aspects (Ranga et al., 2003). |
| | Publications ($b_2$) | Academics present research accomplishments through journal papers, books, and other forms of documentation and publication (Bar-Ilan, 2008). |
| | Network of Academic Exchange ($b_3$) | Research skills, latest information, knowledge, and technology are transferred and diffused to academia and industries via professional associations, meetings, conferences and seminars (Crespi et al., 2011). |
| Service | Consultation ($c_1$) | Academic consultation by faculty in higher-education institutes transfers knowledge and technology between the academic world and industry (Jensen et al., 2010). |
| | Patent Application ($c_1$) | The patenting process is the major channel for diffusing the commercialization of academic knowledge to industries or users (Perkmann et al., 2013) and protect their intellectual property rights in any application to new and useful processes, machines, and/or technologies. |
| | Technology Transfer ($c_3$) | Technology transfer is organized work used to achieve a goal and make necessary technical information move reasonably (Liu et al., 2009). |
| | Strategic Alliances ($c_4$) | Strategic alliances share resources with partners in flexible ways to achieve greater benefits (Veugelers, 2012) |
| | Start-ups ($c_5$) | University-related spin-off/start-up firms have university funding to commercialize research accomplishments and build high-tech and knowledge extensive firms (Bathelt et al., 2010). |

channel ($p_9$). **Table 2** summarizes the 9 policy instruments for higher-education policy and defines the corresponding symbols.

**Table 3** demonstrates the importance and satisfaction of the key factors of knowledge diffusion using the modified Delphi method. In **Table 3**, the most important key factors are instruction ($a_1$), on-the-job training ($a_2$), R&D ($b_1$) and technology transfer ($c_3$). For all the factors, the satisfaction of internship was the lowest that could be improved by policy instruments.

Based on the experts' opinions summarized using the Delphi method, policy instruments were (a) legal and regulatory ($p_1$); (b) ownership and utilization ($p_2$); (c) information ($p_3$); (d) infrastructure ($p_4$); (e) investment ($p_5$); (f) support system ($p_6$); (g) motivation ($p_7$); (h) human resources ($p_8$); and (i) diffusion channel ($p_9$). **Table 4** illustrates human resource ($p_8$), motivation ($p_7$), legal and regulatory ($p_1$) and infrastructure ($p_4$) as the most

**Table 2.** Policy Instruments of higher Education Knowledge Diffusion

| Dimension | Policy Instrument | Definition |
|---|---|---|
| Environment | Legal and Regulatory ($p_1$) | Legal and regulatory aspects for higher-education institutes include UI collaboration projects, science parks, patents and internship regulation, degree recognition, inspectorates regulations, global recruitment mechanism, to enhance knowledge diffusion (Saxenian, 1994; Chyi et al., 2012) |
| | Ownership and Utilization ($p_2$) | With use of knowledge and research findings, academics allow ownership and utilization of joint research, licensing copyright, and patents of inventions (Arocena et al., 2015) |
| | Information ($p_3$) | Information policy instruments include information and telecommunication networks, databases, operating systems, libraries, advisory and consultancy services, liaison services and centers (Rothwell & Zegveld, 1981; C.-Y. Huang et al., 2007) |
| Supply | Infrastructure ($p_4$) | Governments provide buildings, construction, transport, telecommunications, research laboratories, and the establishment of a scientific and technological infrastructure designed for knowledge development (Rothwell & Zegveld, 1981; Huang et al., 2007). |
| | Investment($p_5$) | Financial support of higher-education institutes is diversified from governmental sources, university-generated income, private organized sources, and the privatization of discoveries (Clark, 2001). |
| | Support System ($p_6$) | Support systems deal with administrative matters, such as support for R&D activities, intellectual property, financial management, and application documents (Edler & Georghiou, 2007). |
| Demand | Motivation ($p_7$) | Academic devotion to teaching and research may be motivated by faculty promotion, honor and awards, salary, and evaluations (Matherly & Shortridge, 2009). |
| | Human Resources ($p_8$) | Higher-education systems need a large labor pool that include the roles of educator, researcher, legal commissioner, and patent attorney so as to create, transfer, and diffuse knowledge (Kwon, 2011). |
| | Diffusion Channel ($p_9$) | Universities set up incubators, technology transfer offices, and research centers to bridge gaps and diffuse knowledge to other universities and enterprises (Clark, 1998; Leslie, Oaxaca & Rhoades, 2000; Slaughter & Rhoades, 2004; Wright, Clarysse, Lockett, & Knockaert, 2008). |

important policy instruments. However, most of these policy instruments received lower satisfaction, especially ownership and utilization, support system, and human resources.

## The Relationship between Factors by DEMATEL

Since the inter-relationships between the 12 key factors and 9 policy instruments summarized via the above Delphi process seem too complicated to be analyzed, decision problem structure will be deducted using the DEMATEL method introduced in Section 3.2. The detailed calculation procedures are demonstrated in **Appendix 4**. The total relationships being derived will be referenced for calculating the weights between Key factors in the following ANP processes. The $d_i$+$r_i$ and $d_i$-$r_i$ values calculated from the total relation matrices $\boldsymbol{T}_{\text{aspect}}$ and $\boldsymbol{T}_{\text{factors}}$ are demonstrated in **Table 5** and **Table 6** present the causal diagram for the total relationship of aspects and factors. **Figure 4** to **Figure 6** present the key factors of three dimensions and the influence relationships between the aspects. The results reflected in **Figure 7** to **Figure 15** indicate the cause-and-effect relationship of instruction ($a_1$), on-the-job training ($a_2$), experience sharing ($a_3$), internship ($a_4$), R&D activities ($b_1$), publication ($b_2$), consultation ($b_3$), patent application ($c_2$), technology transfer ($c_3$) and start-ups ($c_5$).

**Table 3.** Importance and Satisfaction of the Key Factors of Knowledge Diffusion

| Aspects | Key Factors | Importance | | Satisfaction | |
|---|---|---|---|---|---|
| | | Average | S.D. | Average | S.D. |
| Teaching | Instruction | 4.88 | 0.35 | 3.38 | 0.92 |
| | On-the-job Training | 4.25 | 0.71 | 3.50 | 0.93 |
| | Experience Sharing | 3.63 | 0.52 | 3.38 | 0.92 |
| | Internship | 3.50 | 0.76 | 2.63 | 0.52 |
| Research | R&D activities | 4.25 | 0.71 | 3.38 | 0.52 |
| | Publication | 3.25 | 0.71 | 3.50 | 0.76 |
| | Network of Academic Exchange | 3.63 | 0.74 | 3.13 | 0.83 |
| Service | Consultation | 3.38 | 0.74 | 2.88 | 0.64 |
| | Patent Application | 3.38 | 0.74 | 2.75 | 0.71 |
| | Technology Transfer | 4.13 | 0.83 | 3.00 | 0.76 |
| | Strategic Alliances | 3.50 | 0.53 | 3.25 | 0.71 |
| | Start-ups | 4.63 | 0.52 | 2.63 | 0.74 |

Remark: 1. The key factors being recognized by the experts as important (with the average score which are higher than 3.35, or 5×2/3, will be selected as the final key factors. 2. S.D. is the abbreviation of Standard Deviation

**Table 4.** Importance and Satisfaction of Policy Instruments of Knowledge Diffusion

| Aspects | Policy Instrument | Importance | | Satisfaction | |
|---|---|---|---|---|---|
| | | Average | S.D. | Average | S.D. |
| Environmental Side | Legal and Regulatory ($p_1$) | 4.38 | 0.70 | 3.29 | 0.70 |
| | Ownership and Utilization ($p_2$) | 3.88 | 0.60 | 2.14 | 0.83 |
| | Information ($p_3$) | 4.00 | 0.71 | 3.86 | 0.83 |
| Supply Side | Infrastructure ($p_4$) | 4.38 | 0.48 | 3.14 | 0.83 |
| | Investment ($p_5$) | 4.13 | 0.60 | 2.71 | 0.70 |
| | Support System ($p_6$) | 3.38 | 0.48 | 2.29 | 0.70 |
| Demand Side | Motivation ($p_7$) | 4.50 | 0.50 | 2.29 | 0.70 |
| | Human Resource ($p_8$) | 4.50 | 0.71 | 2.43 | 0.73 |
| | Diffusion Channel ($p_9$) | 4.13 | 0.60 | 3.00 | 0.76 |

Remark: 1. The policy instruments being recognized by the experts as important (with the average score which are higher than 3.35, or 5×2/3, will be selected as the final policy instruments. 2. S.D. is the abbreviation of Standard Deviation

**Table 5.** $d_i+r_i$ and $d_i-r_i$ values calculated from the direct/indirect matrix $\boldsymbol{T}_{\text{aspect}}$

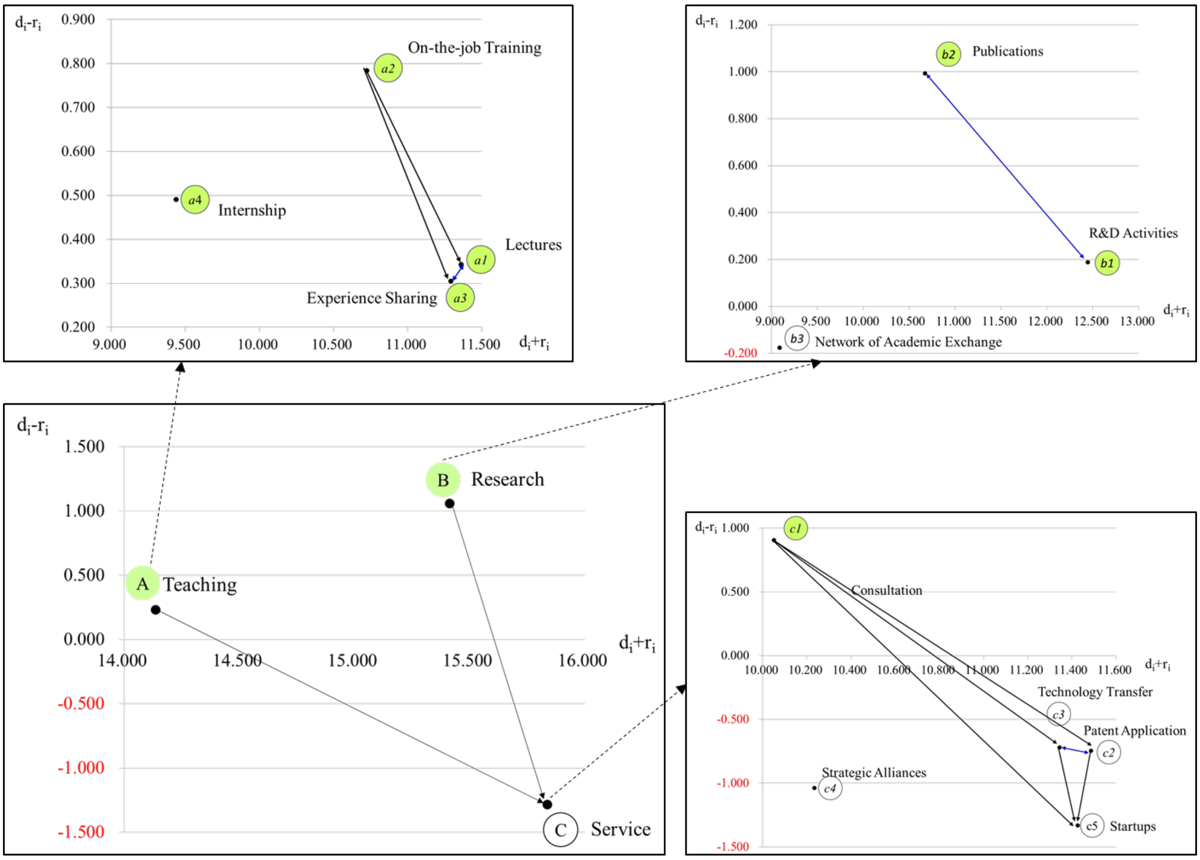
| Aspect | Teaching | Research | Service |
|---|---|---|---|
| $d_i+r_i$ | 14.137 | 15.415 | 15.838 |
| $d_i-r_i$ | 0.229 | 1.058 | -1.288 |

**Table 6.** The $d_i+r_i$ and $d_i-r_i$ values calculated from the total relationship matrix $\boldsymbol{T}_{\text{factors}}$

| Key factor | $a_1$ | $a_2$ | $a_3$ | $a_4$ | $b_1$ | $b_2$ | $b_3$ | $c_1$ | $c_2$ | $c_3$ | $c_4$ | $c_5$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $d_i+r_i$ | 11.361 | 10.723 | 11.291 | 9.439 | 12.447 | 10.675 | 0.090 | 10.051 | 11.486 | 11.344 | 10.233 | 11.427 |
| $d_i-r_i$ | 0.343 | 0.784 | 0.305 | 0.491 | 0.188 | 0.993 | -0.176 | 0.906 | -0.746 | -0.720 | -1.037 | -1.332 |

**Table 7.** *Weights Associated with Each Criterion*

| Criteria | $a_1$ | $a_2$ | $a_3$ | $a_4$ | $b_1$ | $b_2$ | $b_3$ | $c_1$ | $c_2$ | $c_3$ | $c_4$ | $c_5$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Weight* | 0.083 | 0.075 | 0.082 | 0.067 | 0.125 | 0.099 | 0.094 | 0.059 | 0.08 | 0.079 | 0.073 | 0.083 |




(Threshold = 0.513)

**Figure 4.** The causal diagram for the total relationship of factors for the aspects

## Derivation of the Weights of Key Factors by ANP

By setting and developing higher-education policy to improve knowledge diffusion as the goal, pair- wise comparisons of the key factors were executed based on the experts' opinions collected from 13 authorities in Taiwan higher-education research. Following are illustrations based on the ANP. First, based on the decision problem structure (as in **Figure 4**) which was derived by DEMATEL in **Appendix 1**, the pair- wise comparison of the importance of the factors and the decision problem structure serve as inputs for the ANP. With the aid of Super Decisions (Creative Decisions Foundation, 2006), software that is used for decision-making with dependence and feedback by implementing the ANP, the limit super matrix $\boldsymbol{W}$ is calculated and shown in **Figure 16**. Weights corresponding to each key factor are demonstrated in **Table 1**. These weights will be used for calculations of the Grey grades in Section 4.5.

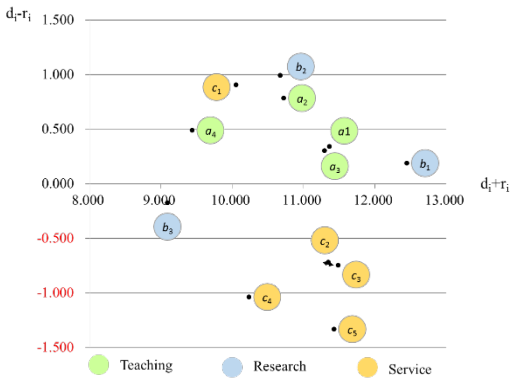



**Figure 5.** The key factors of three aspects

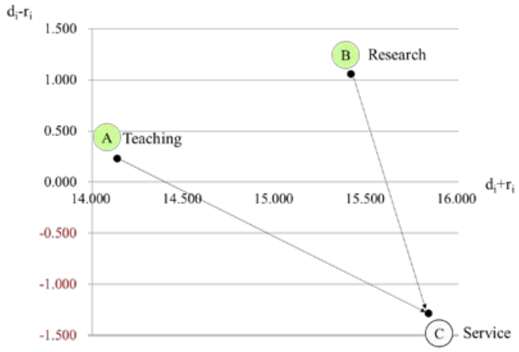



**Figure 6.** The causal diagram for the total relationship of aspects

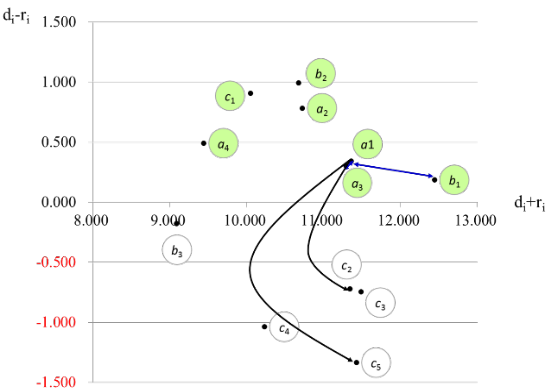



**Figure 7.** The causal diagram for Instruction ($a_1$)

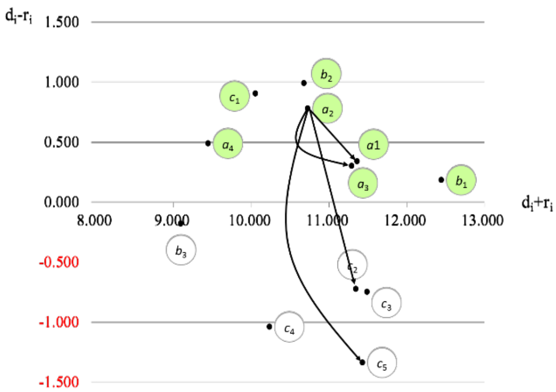



**Figure 8.** The causal diagram for On-the-job Training ($a_2$)

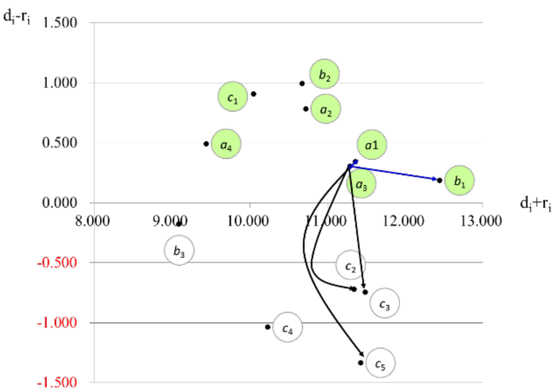



**Figure 9.** The causal diagram for Experience Sharing ($a_3$ )

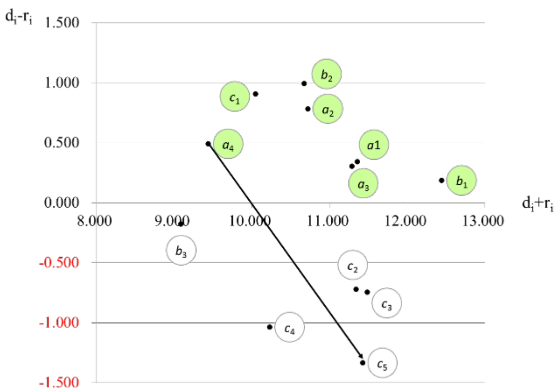



**Figure 10.** The causal diagram for Internships ($a_4$)

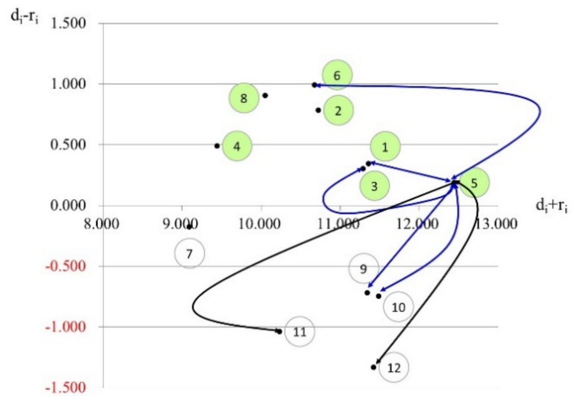



**Figure 11.** The causal diagram for R&D Activities ($b_1$)

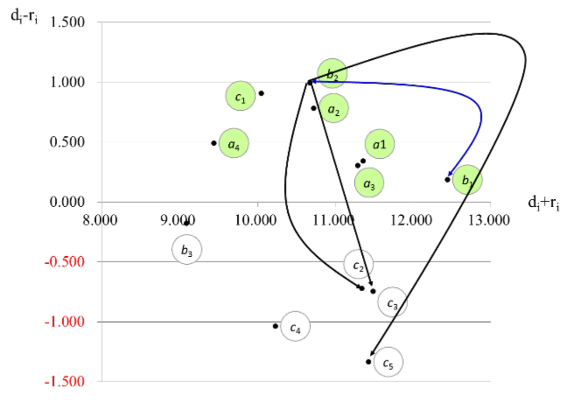



**Figure 12.** The causal diagram for Publication ($b_2$)

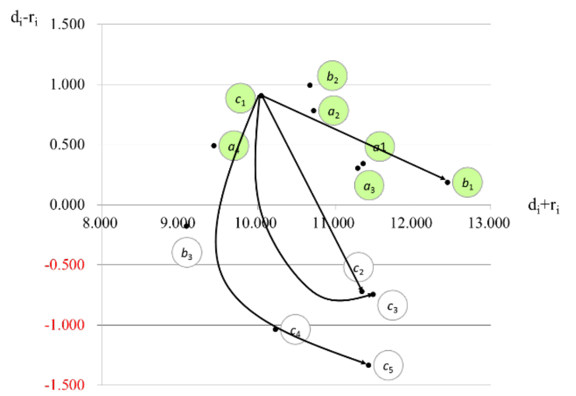



**Figure 13.** The causal diagram for Consultation ($c_1$)

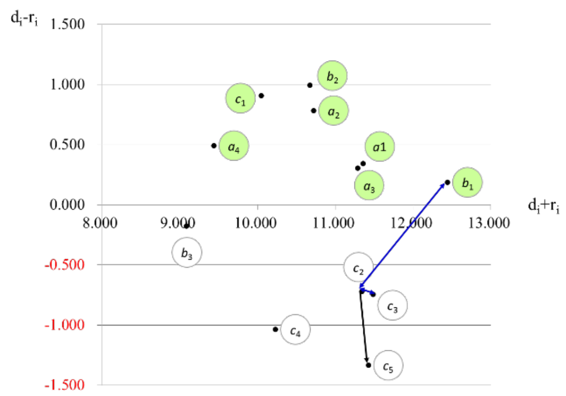



**Figure 14.** The causal diagram for Patent Applications ($c_2$)

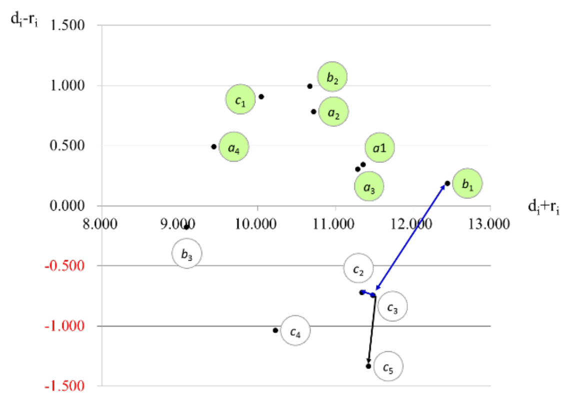



**Figure 15.** The causal diagram for Technology Transfer ($c_3$)

$$\begin{array}{cc}
\begin{matrix} a_1 & a_2 & a_3 & a_4 & b_1 & b_2 & b_3 & c_1 & c_2 & c_3 & c_4 & c_5 \end{matrix} & \\
\begin{bmatrix}
0.083 & 0.083 & 0.083 & 0.083 & 0.083 & 0.083 & 0.083 & 0.083 & 0.083 & 0.083 & 0.083 & 0.083 \\
0.075 & 0.075 & 0.075 & 0.075 & 0.075 & 0.075 & 0.075 & 0.075 & 0.075 & 0.075 & 0.075 & 0.075 \\
0.082 & 0.082 & 0.082 & 0.082 & 0.082 & 0.082 & 0.082 & 0.082 & 0.082 & 0.082 & 0.082 & 0.082 \\
0.067 & 0.067 & 0.067 & 0.067 & 0.067 & 0.067 & 0.067 & 0.067 & 0.067 & 0.067 & 0.067 & 0.067 \\
0.125 & 0.125 & 0.125 & 0.125 & 0.125 & 0.125 & 0.125 & 0.125 & 0.125 & 0.125 & 0.125 & 0.125 \\
0.099 & 0.099 & 0.099 & 0.099 & 0.099 & 0.099 & 0.099 & 0.099 & 0.099 & 0.099 & 0.099 & 0.099 \\
0.094 & 0.094 & 0.094 & 0.094 & 0.094 & 0.094 & 0.094 & 0.094 & 0.094 & 0.094 & 0.094 & 0.094 \\
0.059 & 0.059 & 0.059 & 0.059 & 0.059 & 0.059 & 0.059 & 0.059 & 0.059 & 0.059 & 0.059 & 0.059 \\
0.080 & 0.080 & 0.080 & 0.080 & 0.080 & 0.080 & 0.080 & 0.080 & 0.080 & 0.080 & 0.080 & 0.080 \\
0.079 & 0.079 & 0.079 & 0.079 & 0.079 & 0.079 & 0.079 & 0.079 & 0.079 & 0.079 & 0.079 & 0.079 \\
0.073 & 0.073 & 0.073 & 0.073 & 0.073 & 0.073 & 0.073 & 0.073 & 0.073 & 0.073 & 0.073 & 0.073 \\
0.083 & 0.083 & 0.083 & 0.083 & 0.083 & 0.083 & 0.083 & 0.083 & 0.083 & 0.083 & 0.083 & 0.083
\end{bmatrix} &
\begin{matrix} a_1 \\ a_2 \\ a_3 \\ a_4 \\ b_1 \\ b_2 \\ b_3 \\ c_1 \\ c_2 \\ c_3 \\ c_4 \\ c_5 \end{matrix}
\end{array}$$

**Figure 16.** The unlimited supermatrix $\boldsymbol{W}$ used for deriving weights of key factors

## The Relationship between Factors and Policy Instruments per GRA

The GRA was used to derive the Grey relationships between key factors and policy instruments. The initial relationship matrix $\boldsymbol{G}$, a 9×12 matrix mapping the Grey relationships between 9 policy instruments and 12 key factors, was obtained by collecting opinions from the experts (see **Table 8**). The correlations between policy instruments and key factors can be illustrated as follows: instruction ($a_1$) are related to human resource ($p_8$), motivation ($p_7$), and investment ($p_5$); On-the-job Training ($a_2$) is associated with motivation ($p_7$), human resource ($p_8$), and infrastructure ($p_4$); experience sharing ($a_3$) is a correlation of human resource ($p_8$), motivation ($p_7$), diffusion system($p_9$), and investment ($p_5$); internship ($a_4$) is related to human resources ($p_8$), motivation ($p_7$) and diffusion system ($p_9$); R&D activities($b_1$) is related to investment ($p_5$), human resources ($p_8$), and motivation ($p_7$); publication ($b_2$) is related to motivation ($p_7$), human resources($p_8$), and investment ($p_5$); network of academic exchange ($b_3$) is associated with motivation ($p_7$), human resources ($p_8$), and diffusion system ($p_9$); consulting ($c_1$) is associated with motivation ($p_7$), human resources ($p_8$), investment ($p_5$), and diffusion system ($p_9$); patent applications ($c_2$) are associated with ownership and utilization ($p_1$), motivation ($p_7$), and legal and regulatory ($p_2$); technology transfer ($c_3$) is correlated with ownership and utilization ($p_1$), legal and regulatory ($p_2$), motivation ($p_7$), and investment; strategic alliances ($c_4$) is correlated with ownership and utilization ($p_1$), human resource ($p_8$), investment ($p_5$), legal and regulatory ($p_2$), diffusion system ($p_9$), and motivation ($p_7$); start-ups ($c_5$) is correlated with legal and regulatory, investment ($p_5$), motivation ($p_7$), human resources ($p_8$), and ownership and utilization ($p_1$). Symbols for the key factors follow the definitions in **Table 1**.

## Key Factors of Evaluations and Introductions of Appropriate Policy Instruments

Based on experts' opinions, the current levels of each key factor of knowledge diffusion in the Taiwanese higher-education system was surveyed. To overcome the competence gaps, the 9 policy instruments summarized from previous studies are introduced. By calculating the Grey grades of each policy instrument based on the opinions of the experts (see **Table 8**) and the weights of each key factor derived by ANP (Refer to **Table 7**) versus the goal of the decision problem that was calculated based on the DEMATEL results by ANP, we summarize the Grey grades in **Table 8** and the strength of the relationship between factors and policy instruments in **Table 9**. We find that policy instruments including motivation ($p_7$), human resources ($p_8$), and investment ($p_5$) are the most important factors to be introduced to expand the higher-education system's knowledge diffusion key factor.

**Table 8.** The Grey Grades of Policy Instruments

| Rank | Policy Instruments | Grey Grade | Rank | Policy Instruments | Grey Grade |
|---|---|---|---|---|---|
| 1 | Motivation ($p_7$) | 0.894 | 6 | Legal and regulatory ($p_1$) | 0.530 |
| 2 | Human Resource ($p_8$) | 0.751 | 7 | Support systems ($p_6$) ($p_4$) | 0.508 |
| 3 | Investment ($p_5$) | 0.734 | 8 | Infrastructure ($p_4$) | 0.501 |
| 4 | Ownership Utilization($p_2$) | 0.587 | 9 | Information ($p_3$) | 0.443 |
| 5 | Diffusion system ($p_9$) | 0.562 | | | |

**Table 9.** The strength of the relationship between factors and policy instruments

| | $p_1$ | $p_2$ | $p_3$ | $p_4$ | $p_5$ | $p_6$ | $p_7$ | $p_8$ | $p_9$ |
|---|---|---|---|---|---|---|---|---|---|
| $a_1$ | 0.178 | 0.175 | 0.263 | 0.360 | 0.466 | 0.257 | 0.466 | 0.524 | 0.225 |
| $a_2$ | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| $a_3$ | 0.313 | 0.324 | 0.421 | 0.464 | 0.581 | 0.431 | 0.779 | 0.939 | 0.642 |
| $a_4$ | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| $b_1$ | 0.733 | 0.946 | 0.675 | 0.946 | 1.474 | 0.746 | 1.153 | 1.153 | 0.634 |
| $b_2$ | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| $b_3$ | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| $c_1$ | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| $c_2$ | 2.110 | 3.332 | 1.303 | 1.217 | 1.974 | 1.518 | 2.737 | 1.494 | 1.518 |
| $c_3$ | 1.093 | 1.178 | 0.507 | 0.507 | 0.899 | 0.609 | 1.020 | 0.663 | 0.744 |
| $c_4$ | 0.457 | 0.597 | 0.284 | 0.350 | 0.472 | 0.370 | 0.428 | 0.489 | 0.457 |
| $c_5$ | 1.955 | 1.569 | 0.876 | 1.125 | 1.955 | 1.180 | 1.807 | 1.622 | 1.275 |

# DISCUSSION

In order to explore how to improve knowledge diffusion in the higher-education system, this study has established a knowledge diffusion analytic framework by considering such critical criteria as instruction ($a_1$), experience sharing ($a_3$), R&D activities ($b_1$), publication ($b_2$), network of academic exchange ($b_3$), patent application ($c_2$), start-ups ($c_5$), etc. Numerous factors can influence the diffusion of academic knowledge into industries. An empirical analysis based on Taiwanese experts' opinions demonstrated the feasibility of the proposed analytic framework. Following is a discussion of the results for this empirical study. Policy implications are discussed as well as limitations and suggestions for future research.

## The Impact of Factors on Knowledge Diffusion from Higher Education Institutes to Industries

Based on the analytical results by DEMATEL as shown in **Table 5**, the influence of the service aspect on knowledge diffusion is much stronger than the teaching and research aspects (from $d_i$+$r_i$). The total relation matrix $\boldsymbol{T}_{\text{aspect}}$ (**Figure A 4-5** in **Appendix 4**) and the causal diagram for the total relationship of aspects (**Figure 6**) indicates that the service aspect is affected by the teaching and research aspects.

The finding of knowledge diffusion key factors derivations using the modified Delphi method indicates that the values of instruction ($a_1$), 4.88; start-ups ($c_5$), 4.63; on-the-job learning ($a_2$), 4.25; R&D activities ($b_1$), 4.25; and technology transfer ($c_3$), 4.13, are greater than 4, and these factors are also much more important than other factors. The results also show the values of internship ($a_4$), 2.63; start-ups ($c_5$), 2.63; consultations ($c_1$), 2.88; and technology transfer ($c_3$), 3.00, are lower than 3, and these factors have low satisfaction among all the factors.

As shown in **Table 6**, the $d_i$+$r_i$ and $d_i$-$r_i$ values were calculated from the total relation matrix $\boldsymbol{T}_{\text{factors}}$ by DEMATEL and indicate that instruction ($a_1$), on-the-job training ($a_2$), experience sharing ($a_3$), internships ($a_4$), R&D activities ($b_1$), publication ($b_2$), and consultation ($c_1$) affect other factors (from $d_i$-$r_i$). The network of academic exchange ($b_3$), patent application ($c_2$), technology transfer ($c_3$), strategic alliances ($c_4$), and start-ups ($c_5$) are affected by other factors (from $d_i$-$r_i$).

The results of ANP revealed that instruction ($a_1$), 0.0830, and experience sharing ($a_3$), 0.0823, are the important factors in the teaching aspect; R&D activities ($b_1$), 0.1248; publication ($b_2$), 0.0991; and the network of academic exchange ($b_3$), 0.0944, are the important factors in the research aspect; patent application ($c_2$), 0.0802, and start-ups ($c_5$), 0.0830, are more important factors in the service aspect. R&D activities ($b_1$), publication ($b_2$), and network of academic exchange ($b_3$) are the most important factors of all.

The differences between the survey results based on the modified Delphi questionnaire and the results derived using the ANP are worth further discussion. For the results derived using the modified Delphi results, the importance derived was based on experts' intuitions. The influence relationships between these factors were not considered. However, the ANP results were derived based on the IRM being derived using the DEMATEL. The total influence relationships were also introduced for deriving the weights. So, the more important criteria being derived using the ANP were more reasonable. Criteria that included experience sharing ($a_3$), publication ($b_2$), and network of academic exchange ($b_3$) were not considered as important based on the statistics of the questionnaires. However, these factors were recognized as more important based on the ANP results.

Except for the results derived based on simple statistics and the weights associated with the factors being derived by ANP, the factors belonging to each aspect are also worth further discussion. The more important factors belonging to each aspect and their influence relationships will be discussed in the following sub-sections.

## *Factors involved in the Research Aspect*

The study findings indicate R&D activities ($b_1$), publication ($c_6$), and network of academic exchange ($b_3$) are much more important than others in the Research Aspect. The corresponding weight derived by ANP was comparatively higher than most other factors. From the weights associated with the factors (see **Table 7**), the three most important aspects can be ranked as (1) R&D activities ($b_1$), 0.1248; (2) publication ($c_6$), 0.0991; and (3) network of academic exchange ($b_3$), 0.0944.

### *R&D activities ($b_1$)*

According to the analytic results derived by DEMATEL (**Table 6**) and the causal diagram of R&D Activities ($b_1$) demonstrated in **Figure 11**, the researchers confirmed that R&D activities ($b_1$) is the main factor associated with knowledge diffusion. R&D activities ($c_5$) is very important and very influential for the other factors (from $d_i$+$r_i$). Figure  presents the interactive impact between R&D activities ($b_1$) and instruction ($a_1$), R&D activities ($b_1$) and experience sharing ($a_3$), R&D activities ($b_1$) and publication ($b_2$), R&D activities ($b_1$) and patent application ($c_2$), and R&D activities ($b_1$) and technology transfer ($c_3$). **Figure 11** also shows that R&D activities ($b_1$) affect both strategic alliances ($c_4$) and start-ups ($c_5$).

To keep up with the latest knowledge in their fields, academics conduct research continually. R&D activities of universities and the documentation of those research findings can contribute to the development of knowledge, science, and market (Wong & Goh, 2010). Teaching effectiveness and research productivity are not independent sectors, and academics can benefit from research (Centra, 1983). Academics and industrial experts can not only diffuse the latest theoretical or empirical research findings to students through instruction ($a_1$) and experience sharing ($a_3$), but also conduct R&D activities during the teaching process. With instruction ($a_1$) and experience sharing ($a_3$), academics also can gain new research topics by interacting with students and industrial experts. R&D activities and publication ($b_2$) interact as both cause and effect. Academics can also obtain research concepts and knowledge from reading journal articles, books, etc., and also diffuse their research findings or the latest knowledge in their field through publication.

When the benefits of firms or industries increase, researchers can gain more funding to do more research (Belkhodja & Landry, 2007). Therefore, higher-education institutes can conduct more empirical studies, which fulfills the demand of grant providers to gain more financial support. Many higher-education institutes thus commercialize their research achievements to gain more profits from patent application ($c_2$) and technology transfer ($c_3$).

Intensive UI collaboration may decrease researchers' academic freedom and lead universities to conduct industry-driven, short-term, problem- solving research, rather than long-term original research (Giuliani & Arza, 2009). Higher-education institutes can transform their research approach from curiosity-driven basic research to problem-driven applied research (Tijssen, 2006). To conduct big or interdisciplinary research and achieve more benefits, higher-education institutes build strategic alliances ($c_4$) to share resources with their partners (Ecker & Staples, 1997). With the resources and funding from higher-education institutes, professors and students can apply their research findings, specific knowledge inputs, or latest technology to build start-ups ($c_5$).

### *Publication ($c_6$)*

The analytic results derived by DEMATEL (see **Table 6**) and The causal diagram of Publications ($b_2$)(see **Figure 12**) present the results being derived by DEMATEL: Publication ($b_2$) is an influential factor (from $d_i$+$r_i$). In **Figure 12**, publication ($b_2$) has mutual influences on R&D activities ($b_1$) and affects patent application ($c_2$), technology transfer ($c_3$), and start-ups ($c_5$).

Publication ($b_2$), including journal papers, books, case studies, and other forms of documentation, is one source of R&D activities ($b_1$), patent application ($c_2$), technology transfer ($c_3$) and start-ups ($c_5$) that provide research concepts and background knowledge. Publication also is a way to diffuse the achievement of R&D activities ($b_1$) and can be used to measure knowledge diffusion from different sectors (Chen & Hicks, 2004). To explore technology and production innovation, some companies set up internal leading R&D departments to read the latest research papers and share knowledge with related technology and production development departments. Companies also can create networks or collaboration projects with researchers worldwide. In Taiwan, publication ($b_2$) is regarded as the key performance indicator of excellent academics and innovative capabilities and can be used to evaluate the quantity and quality of research. Publication-oriented faculty promotion motivates academics to publish research results for promotion, tenure, grants, and salaries (Kuo, 2015).

## *Factors involved the Teaching Aspect*

The difference between higher-education institutes and research institutes is the inspiration and cultivation of talent. Thus, academics enhance the role of teaching. **Table 6** shows that instruction ($a_1$), 11.361, and experience sharing ($a_3$), 11.291, are important factors for knowledge diffusion in higher-education institutions (from $d_i$+$r_i$). **Figure 7** and **Figure 9** show that both instruction ($a_1$) and experience sharing ($a_3$) have mutual influences on R&D activities ($b_1$). Instruction ($a_1$) affect patent application ($c_2$) and start-ups ($c_5$); experience sharing ($a_3$) affects patent application ($c_2$), technology transfer ($c_3$) and start-ups ($c_5$). That is, higher-education institutions not only diffuse academic knowledge, but provide industry experience to students.

### *Instruction ($a_1$)*

The activities in higher-education institutions are a knowledge process that includes creation, sharing, transferring, storing, and diffusion (Hussler & Rondé, 2007; Acworth, 2008; Etzkowitz & Zhou, 2008). With instruction, higher education not only provides knowledge but also cultivates well-educated talent to advance the development of industrialization (Just & Huffman, 2009). Graduates from higher education institutes are in a significant channel to diffuse knowledge to industries and fulfill the development of an economy (Carree, Della Malva, & Santarelli, 2014). In recent decades, higher-education institutes have provided interdisciplinary, entrepreneurship courses to empower students to develop their abilities at problem solving, patent application ($c_2$), entrepreneurship and business plan writing, which helps students learn how to set up start-ups (Albulescu & Albulescu, 2014). Moreover, many universities have constructed e-learning platforms or teaching partnerships to improve both teaching and learning.

### *Experience Sharing ($a_3$)*

Most academics lack of industrial or business experiences; they don't know how to manage new start-ups and commercialize academic achievement. More and more industrial experts, however, are delivering lectures and sharing their experiences ($a_3$). When industrial experts, including technicians, managers and masters, share their practice experience with academics, they externalize their working knowledge and communicate both implicit and tacit knowledge from actual practice to higher-education institutes. Academics then will not only have opportunities to apply theories and R&D activities ($b_1$) to real world situations and find new research topics in practice, but also commercialize their academic achievement through patent application ($c_2$), technology transfer ($c_3$) and start-ups (Berbegal-Mirabent et al., 2015).

## *Factors in Service Aspect*

In a knowledge intensive society, higher-education institutions' use and commercialization of research findings can contribute to a region's economic and industry development (Berbegal-Mirabent et al., 2015). Patent application ($c_2$) and new start-ups ($c_5$) are ways to diffuse academic knowledge and researched technology gained from higher-education institutes to companies.

From the result of DEMATEL, as **Figure 14** indicates: (a) patent applications ($c_2$) have an interactive impact relationship with R&D activities ($b_1$) and technology transfer ($c_3$); and (b) patent applications ($c_2$) affect start-ups ($c_5$). According to the results above, all patent applications ($c_2$) and start-ups ($c_5$) play main roles of knowledge diffusion in higher-education institutions.

Skillful performance and knowledge in universities will depend on tacit knowledge, which is unexpressed and experience- based; academics are not cognizant of all the details of their skills or thus able to communicate them (Wright et al., 2008). Higher-education institutions can provide transfer of tacit and codified knowledge to industries in areas of spin-offs, licensing, and patents (Wright et al., 2008). Entrepreneurial universities are able to bridge the traditional UI boundaries to expand the academic enterprises for positive research contracts and knowledge and technology transfer($c_3$) (B. R. Clark, 1998; Etzkowitz, 2003b). Entrepreneurial universities, which are essential to knowledge production and disseminating knowledge and innovation, improve the development of regions (Guerrero & Urbano, 2012). More and more higher-education institutes should commercialize their research achievements to gain more profits from patent applications ($c_2$), technology transfer ($c_3$), consultation ($c_1$), and start-ups ($c_5$).

## The Impact of Policy Instruments on Knowledge Diffusion from Higher Education Institutes to Industries

Knowledge diffusion activities from universities contribute to strong innovations; such innovations have led to regional and industrial developments (Cowan & Zinovyeva, 2013). Universities often diffuse knowledge and technology to industries via technology transfer, patent applications, joint ventures in research, and new start-ups (Perkmann et al., 2013). In many catch-up economies like Korea, Taiwan, and Singapore, it is difficult for SMEs to grasp new technological progress and then innovate accordingly due to very limited resources (Guan & Zhao, 2013; Wright et al., 2008). External sources of knowledge, especially from universities, is important for these firms. Some catch-up economies like South Korea not only enhance the collaboration between higher-education institutions, research institutions, and industries, but also then commercialize their research findings to respond to new developments in science and technology (Wong & Goh, 2010).

Academic knowledge production requires long-term planning and complex multi-level, multidisciplinary mechanisms. Taking that context into account, policy instruments should foster the mechanisms of academic knowledge production, diffusion, and commercialization. According to the results shown in **Table 8**, motivation ($p_7$), investment ($p_8$), and human resources ($p_5$) are the most important policy instruments for improving knowledge diffusion int he higher-education system.

### *Policy Implications of Motivation ($p_7$)*

The Taiwanese government assures the quality of education via performance evaluation mechanisms for university faculty. Based on the revised University Law of the 1990s, the government became an administrator rather than an inspector. Evaluations are the means used to improve the quality of universities and enhance higher-education development. The major performance measures being used for evaluating academic excellence include results from academic publications, international academic exchanges, academic-industry collaborations, etc.

### *Policy Implications of Human Resource ($p_8$)*

Our research findings reveal that human research is the third important policy implication (Grey grade is 0.741 in **Table 8**). Universities not only cultivate a well-educated labor force, but they also have to enhance interdisciplinary teamwork in research and teaching. Since the 1960s, the Taiwanese government has sent many talented people to Western countries like the U.S. and Germany to receive the latest knowledge to upgrade Korean industry and country development. Most academics in Taiwan receive academic training in the United States or in Taiwanese universities, and some graduate students are also educated locally (Bhagwatwar, Hara, & Ynalvez, 2013).

To create a diverse human resource pool and accelerate knowledge diffusion within regions, the government needs to design policy to recruit highly professional people from overseas and draw excellent international students to work in Taiwan after their graduation from these higher-education institutes.

### *Policy Implications of Investment ($p_5$)*

The sources of grants for a university include budget appropriations by the government, incomes from tuition and continuing education, academia-industry cooperation, government subsidies for scientific research, donations, investments, and more. Responding to the global trend, Taiwanese universities are expected to be world class universities and ranked in the world's Top 100 universities. The Taiwanese government has set up various programs and projects to improve teaching and research excellence, accelerate knowledge diffusion, and the competitiveness of higher-education institutes. Additional financial support, such as the Aim for the Top University Project, the program for prompting the teaching and research excellence of universities, were offered to improve the quality and competitiveness of universities. Further, the Taiwanese government initiated a program in 2005 to prompt teaching-oriented universities to enhance the quality of their teaching and develop new academic features. This program offers grants to teaching-oriented higher-education institutions.

Previous studies have considered investment as one of the most significant policy instruments for universities. The Grey grades of Investment was 0.786 (See **Table 8**). In many countries, policy-makers and governments invest in higher education to extend the knowledge process and cultivate well-educated talent (Heitor et al., 2014). Public grants in science and higher-education systems can foster human capital and institutional capacity, which then leads to brain gains. Governments should define its policy and grant long-term funding to academics in higher-education institutions, particularly junior faculty members, so they can upgrade their research capacity and develop their academic careers (Heitor et al., 2014). This finding includes empirical evidence. Investment in R&D activities, start-ups, technology transfer, teaching, and patent application could improve knowledge diffusion in higher-education systems. Therefore, the European Union has increased and strengthened public grants for R&D activities based on academic and basic research so as to promote the development of knowledge infrastructure and the science and technology (S&T) environment for innovation (Heitor & Bravo, 2010).

### *Ownership and Utilization ($p_2$)*

Academics commercialize knowledge and the latest research findings by patents, licensing, selling a product, and more. The patenting and licensing of research findings is a strategy used to improve knowledge transfer from academia to industry and promote higher-education institutes to continue to contribute to social and economic innovation and development (Geuna & Rossi, 2011). Recently, Taiwanese higher-education institutes have set up centers of UI collaboration to manage IP and help academics generate income from patenting and licensing. Academics and their research findings are often regarded as public goods. However, graduate students and professors also conduct R&D activities and produce new knowledge and technology. With UI collaboration projects, academics and firms that offer resources and funds can collaborate on new R&D activities. There is also much negotiation going on over research findings being "public" or "private" goods (Rappert, Webster, & Charles, 1999).

## The Correlations between Policy Instruments and Key Factors for Knowledge Diffusion from Higher Education Institutes to Industries

To enhance knowledge diffusion in Taiwanese higher education institutes, the government should define policy instruments to enhance knowledge diffusion from these higher-education institutes to industries. As shown in **Figures 4** and **5**, the research and teaching aspects affect the service aspect. **Figure 6** shows that the factors of the service aspect are affected by the factors of both research and teaching. Therefore, this study focuses on how policy instruments can advance the important key factors of research and teaching aspects. Based on the results of **Table 9**, the following findings address the correlations between policy instruments and key factors for greater knowledge diffusion from higher education institutes to industries.

### *The Correlations between Policy Instruments and R&D Activities ($b_1$)*

The results of the GRA demonstrate that R&D activities ($b_1$) relates to investment ($p_5$), human resources ($p_8$) and motivation ($p_7$). After the 1990s, many countries were urged to build world class universities and restructure research funding systems to lead in global competitive research, attract high qualified students, and attract more funding (Shin, Lee, & Kim, 2012). As higher-education institutes pay more attention to teaching and research efficiency, policy makers should devote their efforts to improving teachers' teaching skills, renewing research equipment, and enhancing administration activities and operational efficiency (Lu, 2012). In the recent decades, the share of higher-education institute funding from the Taiwanese government has dramatically decreased while the grants from other sources have increased. In many catch-up economies like Taiwan, SMEs have limited resources and R&D funding to try to catch up with new technological progress and innovate continuously. The majority of industries in Taiwan, SMEs, have limited capacity and resources to undertake R&D activities. With UI collaboration, higher-education institutes share resources and diffuse knowledge to let SMEs upgrade technology capabilities (Wright et al., 2008; Guan & Zhao, 2013).

To resolve these problems, first of all, the government should increase investment ($p_5$) and build complete human resource ($p_8$) systems to attract excellent talent that focuses on conducting R&D activities ($b_1$), strengthening research productivity, and improving the quality of research (Borrás & Edquist, 2013; Heitor et al., 2014). Moreover, with an improving motivation ($p_7$) mechanism, the government should provide various graduation and faculty promotion systems, so that academics can promote based on research achievement of technical reports, patents, and other work products.

### *The Correlations between Policy Instruments and Publication ($c_6$)*

Publication ($c_6$) is related to policy instruments, including motivation ($p_7$), human resource ($p_8$) and investment ($p_5$). The quantity of publication in Taiwanese higher-education institutes, especially academic papers, has increased; but the quality and impact of academic research results should be improved. Human resource ($p_8$) and investment ($p_5$) are the main sources for conducting R&D activities ($b_1$), and publication presents the result of R&D activities ($b_1$). With the support of human resources ($p_8$) and investment ($p_5$), higher-education institutes not only can do more advanced and global research, but also obtain more resources to publish higher quality and more influential papers.

### *The Correlations between Policy Instruments and Academic Exchange Networks ($b_3$)*

Networks of academic exchange ($b_3$) are associated with policy instruments including motivation ($p_7$), human resources ($p_8$), and diffusion system ($p_9$). The Taiwanese government should expand its program of scholarships ($p_7$) and create a friendly environment for excellent international students ($p_8$) to study in Taiwan (Roberts, Chou, & Ching, 2010). To create a diverse human resource pool and accelerate knowledge diffusion within regions, the government also needs to design policy to recruit highly-professional people ($p_8$) from overseas and draw excellent international students ($p_8$) to work in Taiwan after they graduate from higher educational institutes. With more improvements in the higher-education system in Taiwan, fewer students are willing to study abroad. The Taiwanese government should build the motivation ($p_7$) mechanism to encourage scholars and students to research and study and go abroad. Moreover, higher-education institutes have to attract more excellent talent flow into the Taiwan higher-education system and enlarge the diversity of its own human resources ($p_8$) pool. The government should also institute new policy to recruit highly professional talent from overseas and draw excellent international students to work in Taiwan after they graduate from higher-education institutes in Taiwan.

### *Correlations between Policy Instruments and Instruction ($a_1$) and Experience Sharing ($a_3$)*

Instruction ($a_1$) are related to policy instruments including human resources ($p_8$), motivation ($p_7$), and investment ($p_5$); experience sharing ($a_3$) is a correlate of human resources ($p_8$), motivation ($p_7$), diffusion system($p_9$), and investment ($p_5$). Theoretically, higher-education institutes gather people who love knowledge, seek to explore unknown questions, and solve problems. With serious competition, evaluation mechanisms, and funding cuts, professors are focusing on research performance and UI collaboration to gain more funding and support rather than inspiring young people in learning, research, self-identity, and life (Lewis, 2006). To improve knowledge diffusion in instruction ($a_1$) and experience sharing ($a_3$), the government should modify the research-intensive environment, increase investment ($p_5$) and provide pluralistic faculty evaluation and promotion mechanisms ($p_7$) to attract talent from different countries to Taiwan. Therefore, Taiwanese higher-education systems will have abundant human resources ($p_8$) who are devoted to teaching activities.

## Limitations and Future Research

In the following section, we present the limitations of the study and what may be of interest for future researchers.

### *Limitations of This Research*

Even though this study has the undeniable merit of offering a valuable analytic framework to drive the key factors and policy instruments to enable and enhance the further diffusion of knowledge embedded in higher-education institutes, the effort has some limitations. First, the questionnaires could not supply a complete picture of the complicated and interacting key factors involved in the knowledge diffusion process and the contexts of higher-education institutes. The second limitation concerns data gathering in this study. The data was gathered through questionnaires, interviews based in Taiwan higher-education institutes, and the opinions of Taiwanese experts. It is thus controversial to generalize these results to apply to other catch-up economics. Moreover, different research fields have different knowledge diffusion processes and mechanisms. The third limitation is that any discussion of different research fields of knowledge diffusion is beyond the focused scope of the study.

### *Recommendations for Future Research*

Among the many issues to be explored in future research, certain important ones can be mentioned. Knowledge can be classified into explicit knowledge and implicit or tacit knowledge (Nonaka, 1988,1991; Nonaka & Takeuchi, 1995). In this study, the researchers regarded knowledge diffusion as a whole entity to investigate key factors and policy instruments of knowledge diffusion in higher-education institutes. Further research could pay more attention to the complexity and diversity of knowledge when discussing knowledge diffusion in higher-education institutes.

The present findings also confirm that previous evidence that UI collaboration, including patent application, technology transfer, instruction, etc., is increasingly important for knowledge diffusion in higher-education systems. Improving the most influential factors will also improve other factors at the same time. Much more still needs to be known about knowledge diffusion at different types of universities. Additionally, this study showed how to improve knowledge diffusion in the Taiwanese higher-education systems, although more extensive research is necessary to present knowledge diffusion in higher-education in the context of different countries.

The study used ANP to explore the weight of the key factors. Future research could analyze the current status of the key factors and the gaps between the aspired levels. Enhancement strategies for closing these gaps and further enhancing the knowledge diffusion capabilities of higher-education institutes could also be proposed.

Policy instruments are interactions and interdependencies. Flanagan, Uyarra, and Laranja (2011) argued for the use of a policy mix to better present the complex, multi-level, multi-actor reality of policy instruments. Future research could use a policy mix to explore the interactions between different policy instruments.

Finally, we proposed a greater knowledge diffusion mechanism for higher-education institutes. However, the performance of knowledge diffusion at higher-education institutes lacks sufficient empirical studies and that issue in higher-education institutes is well worthy of further examination and discussion.

## CONCLUSIONS

The present findings contribute to the understanding of key factors and policy instruments to advance knowledge diffusion in higher education. Core activities in universities are associated with knowledge creation, transfer, and diffusion. Creating higher-education policy to improve knowledge diffusion remains a challenging issue. Higher-education policy should be created by considering key factors related to knowledge diffusion. However, there are no straightforward answers addressing how such policy instruments should be made to fit knowledge diffusion in the higher-education system context. This current research does present a proposal for a policy portfolio to improve knowledge diffusion in higher education.

The recommended portfolio is based on key factors derived using a modified Delphi method, with the relationships between key factors structured by DEMATEL. The weight of each key factor was derived by the IRM between criteria by ANP. The most important policy instruments were derived by GRA. Based on the analytic results, instruction and experience sharing are the most important factors in the teaching aspect. R&D activities, publication, and network of academic exchange are the important factors from the research aspect. Patent application and start-ups are more important factors in the service aspect. R&D activities, publication, and networking of academic exchanges are the most important factors of all. According to the GRA results, motivation, investment, and human resources are the most important policy instruments to use for improving knowledge diffusion in a higher-education system.

For future research possibilities, the influences of complexity and the diversity nature of knowledge on knowledge diffusion in higher-education institutes can be discussed. The current status of the key factors and the corresponding gaps versus the aspired level can also be explored. Enhancement strategies to use for closing the gaps and enhancing knowledge diffusion capabilities of higher-education institutes’ can be proposed. Policy mix can be introduced to explore the interaction between different policy instruments. Further, the performance of knowledge diffusion of higher-education institutes does lack sufficient empirical studies. This issue is worthy of further investigations. Finally, the analytical framework presented in this research can be applied both to individual disciplinary areas or inter-disciplinary areas to evaluate policy instruments for improving knowledge diffusion. The policy instruments once fully defined can then serve as a policy portfolio for action.

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# APPENDICES

## Appendix 1

### *DEMATEL*

The following are explanations of the DEMATEL calculation steps.

**Step 1:** Build an initial direct-relation matrix

Experts are asked to indicate the direct influence degree between factor *i* and factor *j*, as indicated by $a_{ij}$, using a pair-wise comparison scale designated with five levels. The initial direct-relation matrix $\boldsymbol{A}$ is obtained by deriving the influence relationships between criteria through Equation (1).

$$\boldsymbol{A} = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix} \tag{1}$$

$a_{ij}$ is denoted as the degree to which the $i^{th}$ objective affects the $j^{th}$ objective

**Step 2:** Normalize the direct-relation matrix

The normalized direct-relation matrix N is obtained through Equations (2) and (3).

$$\boldsymbol{N} = y\boldsymbol{A} \tag{2}$$

$$y = \min\left\{1/\max_i \sum_{j=1}^{n} a_{ij}, 1/\max_j \sum_{i=1}^{n} a_{ij}\right\}, i, j \in \{1, 2, ..., n\}. \tag{3}$$

**Step 3:** Build the total relation matrix $\boldsymbol{T}$

The total-relation matrix $\boldsymbol{T}$ is acquired by Equation (4):

$$\boldsymbol{T} = N + N^2 + \ldots + N^{\varepsilon} = \boldsymbol{N}\left(\boldsymbol{I} - \boldsymbol{N}\right)^{-1} \tag{4}$$

where $\varepsilon \to \infty$, $I$ is the identity matrix and $N = [x_{ij}]_{nxn}$.

**Step 4:** Compute the influence strength of the factors

Aggregate the values of the rows and columns in matrix $\boldsymbol{T}$ to obtain a value $\boldsymbol{r_i}$ and $\boldsymbol{c_i}$ through the Equations (5) and (6) respectively. The $\boldsymbol{r_i}$ represents the level of direct or indirect impacts on other factor, and $\boldsymbol{c_i}$ represents the level to which it is affected by other factor:

$$r_i = \left[\sum_{j=1}^{n} t_{ij}\right]_{nx1} = [t_i]_{nx1} \tag{5}$$

$$c_i = \left[\sum_{j=1}^{n} t_{ij}\right]_{1xn} = [t_i]_{nx1} \tag{6}$$

**Step 5:** Produce a causal diagram

A causal diagram can be acquired by mapping a data set $(r_i + c_i, r_i - c_i)$. The value of $r_i + c_i$ indicates the strength of influence. The higher the value of $r_i + c_i$ a factor has, the more related it is to the other factors. Similarly, the value of $r_i - c_i$ indicates the causal relationship between factors. If $r_i - c_i$ is positive, then the factor is a "cause factor," dispatching influence to the others. If $r_i - c_i$ is negative, the factor is an "effect factor," receiving influence from others. The higher the value of $r_i - c_i$ a factor has, the more influence it has on the other factors, and hence this factor is presumed to have a higher priority than the others. In other words, the lower the value of $r_i - c_i$ a factor has, the greater its received influence from the other factors, and consequently, the lower the priority it is assumed to have.

## Appendix 2

### *ANP*

Analysis of priorities in a system can be thought of in terms of a control hierarchy with dependence among its bottom-level alternatives arranged as a network as shown in **Figure A 2-1**. Dependence can occur within the components and between them. A control hierarchy at the top may be replaced by a control network with dependence among its components, which are collections of elements whose functions derive from the synergy of their interaction and hence has a higher-order function not found in any single element. The criteria in the control hierarchy that are used for comparing the components are usually the major parent criteria whose subcriteria are used to compare the elements need to be more general than those of the elements because of the greater complexity of the components.

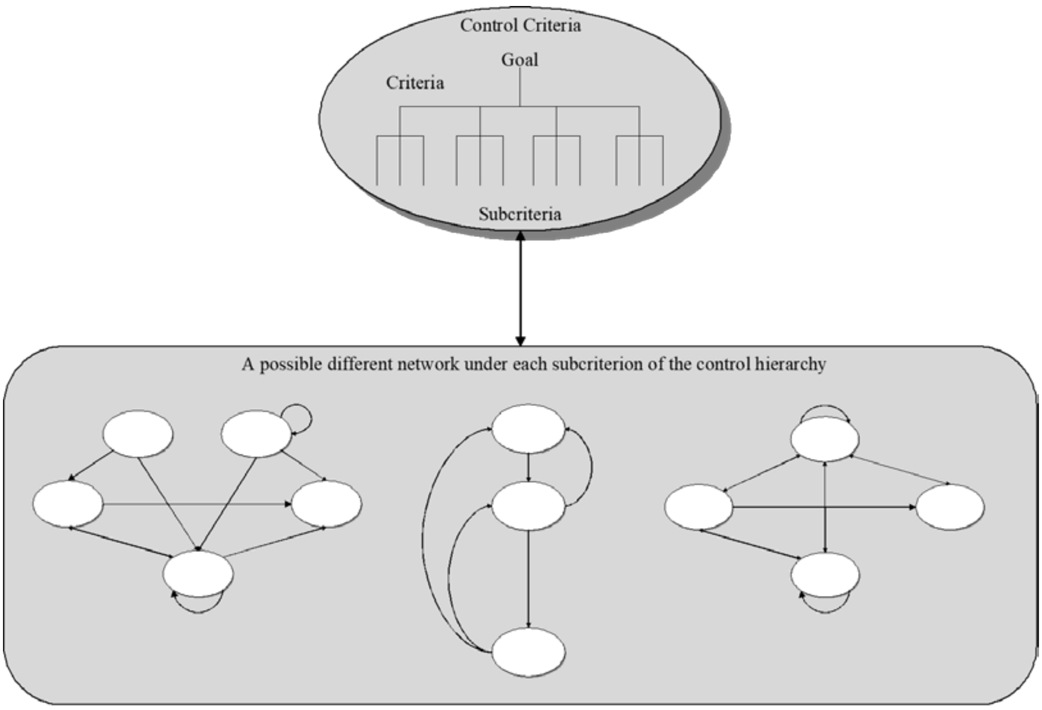


**Figure A 2-1**. The control hierarchy. Source: (Saaty, 1996).

A network connects the components of a decision system. The system is made up of subsystems, with each subsystem made up of components, and each component made up of elements. **Figure A 2-1** demonstrates a typical network. Those components which no arrow enters are known as source components such as $C_1$ and $C_2$. Those from which no arrow leaves are known as sink component such as $C_5$. Those components which arrows both enter and exit leave are known as transient components such as $C_3$ and $C_4$. In addition, $C_3$ and $C_4$ form a cycle of two components because they feed back and forth into each other. $C_2$ and $C_4$ have loops that connect them to themselves and are inner dependent. All other connections represent dependence between components which are thus known to be outer dependent.

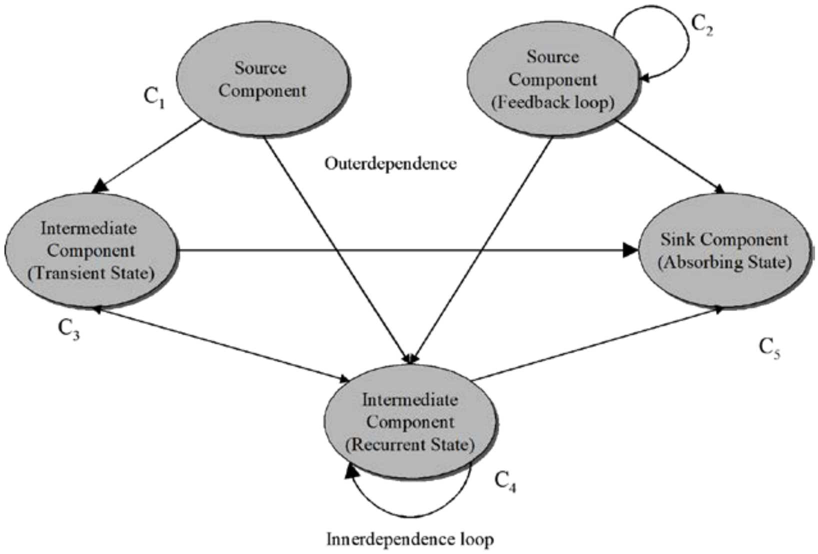


**Figure A 2-2**. Connections in a network. Source: (Saaty, 1996).

A component of a decision network which was derived by the DEMATEL method in Section 3.2. A component will be denoted by $C_k, h = 1, .., m,$ and assume that it has $n_k$ elements, which we denote by $e_{k1}, e_{k2}, .., e_{km}$. The influences of a given set of elements in a component on any element in the decision system are represented by a ratio scale priority vector derived from paired comparisons of the comparative importance of one criterion and another criterion with respect to the interests or preferences of the decision makers. This relative importance value can be determined using a scale of 1–9 to represent equal importance to extreme importance. The influence of elements in the network on other elements in that network can be represented in the following supermatrix:

$$
W = \begin{array}{ll}
 & \begin{array}{ccccccccc} & C_1 & & & C_2 & & \cdots & & C_m \\ e_{11} & \cdots & e_{1n_1} & e_{21} & \cdots & e_{2n_2} & \cdots & e_{m1} \cdots & e_{mn_m} \end{array} \\
\begin{array}{ll} C_1 & \begin{array}{c} e_{11} \\ e_{12} \\ \vdots \\ e_{1n_1} \end{array} \\ C_2 & \begin{array}{c} e_{21} \\ e_{22} \\ \vdots \\ e_{2n_2} \end{array} \\ \vdots & \vdots \\ C_2 & \begin{array}{c} e_{m1} \\ e_{m2} \\ \vdots \\ e_{mn_m} \end{array} \end{array} &
\begin{bmatrix} W_{11} & W_{12} & \cdots & W_{1m} \\ W_{21} & W_{22} & \cdots & W_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ W_{m1} & W_{m2} & \cdots & W_{mm} \end{bmatrix}
\end{array}
$$

A typical entry $W_{ij}$ in the supermatrix is a principal eigenvector of the influence of the elements in the $i^{th}$ component of the network on an element in the $j^{th}$ component. Some of its entries may be zero corresponding to those elements that have no influence.

$$\boldsymbol{W}_{ij}=\begin{bmatrix} w_{i_1 j_1} & w_{i_1 j_2} & \cdots & w_{i_1 j_{n_j}} \\ w_{i_2 j_2} & w_{i_2 j_2} & \cdots & w_{i_2 j_{n_j}} \\ \vdots & \vdots & \ddots & \vdots \\ w_{i_{n_i} j_1} & w_{i_{n_i} j_2} & \cdots & w_{i_{n_i} j_{n_j}} \end{bmatrix}$$

After forming the supermatrix, the weighted supermatrix is derived by transforming all columns sum to unity exactly. The weighted supermatrix is raised to limiting powers, such as Equation (7) to get the global priority vector or called weights.

$$\lim_{\theta\to\infty}\boldsymbol{W}^{\theta} \tag{7}$$

In addition, if the supermatrix has the effect of cyclicity, the limiting supermatrix is not the only one. There are two or more limiting supermatrices in this situation, and the Cesaro sum would need to be calculated to get the priority. The Cesaro sum is formulated as follows.

$$\lim_{\psi\to\infty}\left(\frac{1}{\nu}\right)\sum_{j=1}^{\nu}\boldsymbol{W}_j^{\psi} \tag{8}$$

to calculate the average effect of the limiting supermatrix (*i.e.*, the average priority weights) where $\boldsymbol{W}_j$ denotes the $j^{th}$ limiting supermatrix. Otherwise, the supermatrix would be raised to large powers to get the priority weights (J.-J. Huang, Tzeng, & Ong, 2005).

The weights of the kth criteria being derived by using the above ANP processes, namely, $w_k, k \in \{1,..,n\}$ will be used as the weight for the $k^{th}$ objective in Section 3.4.

## Appendix 3

### *GRA*

**Definition 1:** The relationship scale may also be designated into eleven levels, where the scores of 0, 1, 2, …, 10 represent 'no relationship' to 'very high relationship', respectively, between the specified criterion and the alternative, respectively.

**Definition 2:** The initial relationship matrix G is a $m\times n$ matrix, where there are m alternatives and $n$ criteria, obtained by surveying the relationships where $g_k$ is denoted as the relationship between the $k^{th}$ criterion and the $i^{th}$ alternative.

$$\boldsymbol{G}=\begin{bmatrix} g_{11} & g_{12} & \cdots & g_{1n} \\ g_{21} & g_{22} & \cdots & g_{2n} \\ \vdots & \vdots & g_{ki} & \vdots \\ g_{m1} & g_{m2} & \cdots & g_{mn} \end{bmatrix} \tag{9}$$

$$\boldsymbol{G_i} = [g_{ki}], \quad k \in \{1, 2, \ldots, m\}$$

**Definition 3:** The normalized relationship matrix $\boldsymbol{X}$ can be obtained through the Equations (10) and (11).

$$p_i = 1 \Big/ \max_{1 \le k \le m} g_{ki} \tag{10}$$

$$\boldsymbol{X} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & x_{ki} & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \tag{11}$$

$$\boldsymbol{X_i} = [x_{ki}], \quad k \in \{1, 2, \ldots, m\}$$
$$\boldsymbol{X_i} = p_i \boldsymbol{G_i}$$

**Definition 4:** Let $X_0$ be the reference pattern with $n$ entries (i.e. dependent variable): $X_0 = (X_0(1), X_0(2),\ ..,\ X_0(n))$ and $X_i$ the matrix containing the normalized mapping information of each alternative to the criteria, be one of the $m$ patterns with $n$ entries to be compared with the $X_0$ where $X_i$ is written as: $X_i = \big(X_i(1), X_i(2),\ ..,\ i(n)\big), 1 \le i \le m$. The sequence $X_i$ generally expresses the influencing factor of $X_0$.

**Definition 5:** Let $\boldsymbol{X}$ be a normalized factor set of Grey relation, $X_0 \in X$ the referential sequence, and $X_i \in X$ the comparative sequence; with $X_0(k)$ and $X_i(k)$ representing respectively the numerals at point $k$ for $X_0$ and $X_i$. If $\gamma\big(X_0(k), X_i(k)\big)$ and $\gamma(X_0, X_i)$ are real numbers, and satisfy the following four grey axioms, then call $\gamma\big(X_0(k), X_i(k)\big)$ the grey relation coefficient and the grade of grey relation $\gamma(X_0, X_i)$ is the average value of $\gamma\big(X_0(k), X_i(k)\big)$.

1. Norm Interval

$$0 < \gamma(x_0(k), x_i(k)) \le 1, \ \forall k; \ \gamma(\boldsymbol{X}_0, \boldsymbol{X}_i) = 1 \ iff \ \boldsymbol{X}_0 = \boldsymbol{X}_i;$$
$$\gamma(\boldsymbol{X}_0, \boldsymbol{X}_i) = 0 \ iff \ \boldsymbol{X_0}, \boldsymbol{X}_i \in \phi;$$

where $\varphi$ is an empty set.

2. Duality Symmetric

$$\boldsymbol{Y}, \boldsymbol{Z} \in \boldsymbol{X} \ \Rightarrow \ \gamma(\boldsymbol{Y}, \boldsymbol{Z}) = \gamma(\boldsymbol{Z}, \boldsymbol{Y}) \ iff \ \boldsymbol{X} = \{\boldsymbol{Y}, \boldsymbol{Z}\}.$$

3. Wholeness

$$\gamma(\boldsymbol{X_i}, \boldsymbol{X_j}) \overset{often}{\neq} \gamma(\boldsymbol{X_j}, \boldsymbol{X_i}) \ \ iff \ \ \boldsymbol{X} = \{\boldsymbol{X}_i \,|\, i = 0, 1, \ldots, n\}, \ \ n > 2.$$

4. Approachability

$\gamma\big(X_0(k), X_i(k)\big)$ decreases when $|X_0(k), X_i(k)|$ is increasing.

Deng also proposed a mathematical equation for the grey relation coefficient as follows:

$$\gamma(x_0(k), x_i(k)) = \frac{\min\limits_{\forall j, j \in i} \min\limits_{\forall k} \left|(x_0(k) - x_j(k))\right| + \zeta \max\limits_{\forall j, j \in i} \max\limits_{\forall k} \left|(x_0(k) - x_j(k))\right|}{\left|(x_0(k) - x_i(k))\right| + \zeta \max\limits_{\forall j, j \in i} \max\limits_{\forall k} \left|(x_0(k) - x_j(k))\right|} \tag{12}$$

where $\zeta$ is the distinguished coefficient ($\zeta$ *in* $[0, 1]$). Generally, we pick $\zeta = 0.5$.

**Definition 6:** If $\gamma(X_0, X_i)$ satisfies the four grey relation axioms, then $\gamma$ is called the Grey Relational Map.

**Definition 7:** If $\Gamma$ is the entirety of the Grey Relational Map, $\gamma \in \Gamma$ satisfies the four axioms of grey relation, and $\boldsymbol{X}$ is the factor set of grey relation, then $(X, \Gamma)$ will be called as the grey relational space, while $\gamma$ is the specific map for $\Gamma$ .

**Definition 8:** Let $(X, \Gamma)$be the grey relational space, and if $\gamma(X_0, X_j), \gamma(X_0, X_p), \ldots, \gamma(X_0, X_q)$ satisfy $\gamma(X_0, X_j) > \gamma(X_0, X_p) > .. > \gamma(X_0, X_q)$, then we have the grey relational order as $\boldsymbol{X}_j \succ \boldsymbol{X}_p \succ \ldots \succ \boldsymbol{X}_q$.

When the grey relational coefficient is conducted, we can then derive the grade of grey relation $\gamma(X_0, X_i)$ between the reference and alternative imagination stimulation courses.

$$\gamma(\boldsymbol{x}_0, \boldsymbol{x}_i) = \sum_{k=1}^{n} \omega_k \times \gamma(x_0(k), x_i(k)). \tag{13}$$

where $k$ is the number of criteria, $\omega_k$ expresses the weight of the k$^{th}$ criteria, and $\gamma(X_0, X_i)$ represents the grade of grey relation in $X_i$ (the k$^{th}$ policy instrument) correspondence to $X_0$ . In this study, we rank the policy instruments based on the Grey grades.

## Appendix 4

### *The detailed calculation procedures of the DEMATEL*

At first, the direct relation/influence matrices of aspects ($\boldsymbol{A}_{\text{aspect}}$) and factors ($\boldsymbol{A}_{\text{factors}}$) are introduced as demonstrated in **Figure A 4-1** and **Figure A 4-2**. Afterwards, the direct relation/influence matrices are normalized based on Equation (1). The normalized direct relation/influence matrices of aspects aspects ($\boldsymbol{N}_{\text{aspect}}$) and factors ($\boldsymbol{N}_{\text{factors}}$) are then demonstrated in **Figure A 4-3** and **Figure A 4-4**.

$$\boldsymbol{T}_{\text{aspect}} = \begin{array}{c} \\ A \\ B \\ C \end{array} \begin{array}{c} \begin{array}{ccc} A & B & C \end{array} \\ \begin{bmatrix} 2.022 & 2.348 & 2.814 \\ 2.615 & 2.397 & 3.224 \\ 2.318 & 2.433 & 2.524 \end{bmatrix} \end{array}$$

**Figure A 4-1**. The total relation matrix $\boldsymbol{T}$ aspect

$$\boldsymbol{T}_{\text{factors}}= \begin{array}{cc} & \begin{array}{cccccccccccc} a_1 & a_2 & a_3 & a_4 & b_1 & b_2 & b_3 & c_1 & c_2 & c_3 & c_4 & c_5 \end{array} \\ \begin{array}{c} a_1 \\ a_2 \\ a_3 \\ a_4 \\ b_1 \\ b_2 \\ b_3 \\ c_1 \\ c_2 \\ c_3 \\ c_4 \\ c_5 \end{array} & \begin{bmatrix} 0.430 & 0.489 & 0.517 & 0.426 & 0.568 & 0.468 & 0.448 & 0.428 & 0.549 & 0.504 & 0.462 & 0.563 \\ 0.516 & 0.382 & 0.542 & 0.442 & 0.512 & 0.423 & 0.417 & 0.427 & 0.524 & 0.512 & 0.497 & 0.561 \\ 0.518 & 0.483 & 0.425 & 0.448 & 0.543 & 0.427 & 0.402 & 0.425 & 0.534 & 0.531 & 0.497 & 0.566 \\ 0.445 & 0.417 & 0.468 & 0.300 & 0.447 & 0.348 & 0.339 & 0.371 & 0.442 & 0.445 & 0.426 & 0.519 \\ 0.554 & 0.484 & 0.531 & 0.417 & 0.515 & 0.521 & 0.500 & 0.411 & 0.618 & 0.609 & 0.547 & 0.612 \\ 0.508 & 0.432 & 0.470 & 0.372 & 0.580 & 0.379 & 0.470 & 0.377 & 0.593 & 0.577 & 0.512 & 0.563 \\ 0.404 & 0.351 & 0.380 & 0.299 & 0.458 & 0.395 & 0.281 & 0.285 & 0.416 & 0.404 & 0.368 & 0.416 \\ 0.468 & 0.431 & 0.474 & 0.387 & 0.524 & 0.386 & 0.366 & 0.334 & 0.527 & 0.529 & 0.502 & 0.552 \\ 0.439 & 0.405 & 0.439 & 0.353 & 0.517 & 0.394 & 0.374 & 0.397 & 0.437 & 0.542 & 0.508 & 0.565 \\ 0.439 & 0.382 & 0.429 & 0.344 & 0.532 & 0.396 & 0.362 & 0.395 & 0.528 & 0.429 & 0.511 & 0.565 \\ 0.366 & 0.337 & 0.384 & 0.326 & 0.459 & 0.336 & 0.322 & 0.346 & 0.448 & 0.459 & 0.346 & 0.469 \\ 0.422 & 0.378 & 0.436 & 0.359 & 0.476 & 0.368 & 0.354 & 0.376 & 0.501 & 0.490 & 0.459 & 0.428 \end{bmatrix} \end{array}$$

**Figure A 4-2**. The total relation matrix $\boldsymbol{T}_{\text{factors}}$

$$\boldsymbol{N}_{\text{aspect}} = \begin{array}{cc} & \begin{array}{ccc} A & B & C \end{array} \\ \begin{array}{c} A \\ B \\ C \end{array} & \begin{bmatrix} 3.022 & 2.348 & 2.814 \\ 2.615 & 3.397 & 3.224 \\ 2.318 & 2.433 & 3.524 \end{bmatrix} \end{array}$$

**Figure A 4-3**. The normalized direct relation/influence matrix N of aspects

$$\boldsymbol{N}_{\text{factors}}= \begin{array}{cc} & \begin{array}{cccccccccccc} a_1 & a_2 & a_3 & a_4 & b_1 & b_2 & b_3 & c_1 & c_2 & c_3 & c_4 & c_5 \end{array} \\ \begin{array}{c} a_1 \\ a_2 \\ a_3 \\ a_4 \\ b_1 \\ b_2 \\ b_3 \\ c_1 \\ c_2 \\ c_3 \\ c_4 \\ c_5 \end{array} & \begin{bmatrix} 1.430 & 0.489 & 0.517 & 0.426 & 0.568 & 0.468 & 0.448 & 0.428 & 0.549 & 0.504 & 0.462 & 0.563 \\ 0.516 & 1.382 & 0.542 & 0.442 & 0.512 & 0.423 & 0.417 & 0.427 & 0.524 & 0.512 & 0.497 & 0.561 \\ 0.518 & 0.483 & 1.425 & 0.448 & 0.543 & 0.427 & 0.402 & 0.425 & 0.534 & 0.531 & 0.497 & 0.566 \\ 0.445 & 0.417 & 0.468 & 1.300 & 0.447 & 0.348 & 0.339 & 0.371 & 0.442 & 0.445 & 0.426 & 0.519 \\ 0.554 & 0.484 & 0.531 & 0.417 & 1.515 & 0.521 & 0.500 & 0.411 & 0.618 & 0.609 & 0.547 & 0.612 \\ 0.508 & 0.432 & 0.470 & 0.372 & 0.580 & 1.379 & 0.470 & 0.377 & 0.593 & 0.577 & 0.512 & 0.563 \\ 0.404 & 0.351 & 0.380 & 0.299 & 0.458 & 0.395 & 1.281 & 0.285 & 0.416 & 0.404 & 0.368 & 0.416 \\ 0.468 & 0.431 & 0.474 & 0.387 & 0.524 & 0.386 & 0.366 & 1.334 & 0.527 & 0.529 & 0.502 & 0.552 \\ 0.439 & 0.405 & 0.439 & 0.353 & 0.517 & 0.394 & 0.374 & 0.397 & 1.437 & 0.542 & 0.508 & 0.565 \\ 0.439 & 0.382 & 0.429 & 0.344 & 0.532 & 0.396 & 0.362 & 0.395 & 0.528 & 1.429 & 0.511 & 0.565 \\ 0.366 & 0.337 & 0.384 & 0.326 & 0.459 & 0.336 & 0.322 & 0.346 & 0.448 & 0.459 & 1.346 & 0.469 \\ 0.422 & 0.378 & 0.436 & 0.359 & 0.476 & 0.368 & 0.354 & 0.376 & 0.501 & 0.490 & 0.459 & 1.428 \end{bmatrix} \end{array}$$

**Figure A 4-4**. The normalized direct relation/influence matrix $\boldsymbol{N}$ of factors in aspects

Finally, the total relationship matrices of aspects ($\boldsymbol{T}_{\text{aspect}}$) and factors ($\boldsymbol{T}_{\text{factors}}$) are derived based on Equation (4) and demonstrated in **Figures A 4-5** and **Figure A 4-6**, where major relationships were derived by setting the threshold value at 2.433 for aspects and 0.513 for key factors in the aspects. If the threshold values are lower than 2.433 and 0.513, respectively, the total relationships being derived from total matrix (refer Eqation (4) in Section 3.2) will be too many to be analyzed. On the other hand, if the threshold values are higher than 2.433 and 0.513, respectively, the total relationships being derived can be too few to demonstrate the proper number of relationships.

$$
\boldsymbol{T}_{\text{aspect}} = \begin{array}{c} \\ A \\ B \\ C \end{array}
\begin{array}{c}
\begin{array}{ccc} A & B & C \end{array} \\
\begin{bmatrix}
2.022 & 2.348 & 2.814 \\
2.615 & 2.397 & 3.224 \\
2.318 & 2.433 & 2.524
\end{bmatrix}
\end{array}
$$

**Figure A 4-5.** The total relation matrix $\boldsymbol{T}_{\text{aspect}}$

$$
\boldsymbol{T}_{\text{factors}} = \begin{array}{c|cccccccccccc}
 & a_1 & a_2 & a_3 & a_4 & b_1 & b_2 & b_3 & c_1 & c_2 & c_3 & c_4 & c_5 \\
\hline
a_1 & 0.430 & 0.489 & 0.517 & 0.426 & 0.568 & 0.468 & 0.448 & 0.428 & 0.549 & 0.504 & 0.462 & 0.563 \\
a_2 & 0.516 & 0.382 & 0.542 & 0.442 & 0.512 & 0.423 & 0.417 & 0.427 & 0.524 & 0.512 & 0.497 & 0.561 \\
a_3 & 0.518 & 0.483 & 0.425 & 0.448 & 0.543 & 0.427 & 0.402 & 0.425 & 0.534 & 0.531 & 0.497 & 0.566 \\
a_4 & 0.445 & 0.417 & 0.468 & 0.300 & 0.447 & 0.348 & 0.339 & 0.371 & 0.442 & 0.445 & 0.426 & 0.519 \\
b_1 & 0.554 & 0.484 & 0.531 & 0.417 & 0.515 & 0.521 & 0.500 & 0.411 & 0.618 & 0.609 & 0.547 & 0.612 \\
b_2 & 0.508 & 0.432 & 0.470 & 0.372 & 0.580 & 0.379 & 0.470 & 0.377 & 0.593 & 0.577 & 0.512 & 0.563 \\
b_3 & 0.404 & 0.351 & 0.380 & 0.299 & 0.458 & 0.395 & 0.281 & 0.285 & 0.416 & 0.404 & 0.368 & 0.416 \\
c_1 & 0.468 & 0.431 & 0.474 & 0.387 & 0.524 & 0.386 & 0.366 & 0.334 & 0.527 & 0.529 & 0.502 & 0.552 \\
c_2 & 0.439 & 0.405 & 0.439 & 0.353 & 0.517 & 0.394 & 0.374 & 0.397 & 0.437 & 0.542 & 0.508 & 0.565 \\
c_3 & 0.439 & 0.382 & 0.429 & 0.344 & 0.532 & 0.396 & 0.362 & 0.395 & 0.528 & 0.429 & 0.511 & 0.565 \\
c_4 & 0.366 & 0.337 & 0.384 & 0.326 & 0.459 & 0.336 & 0.322 & 0.346 & 0.448 & 0.459 & 0.346 & 0.469 \\
c_5 & 0.422 & 0.378 & 0.436 & 0.359 & 0.476 & 0.368 & 0.354 & 0.376 & 0.501 & 0.490 & 0.459 & 0.428
\end{array}
$$

**Figure A 4-6.** The total relation matrix $\boldsymbol{T}_{\text{factors}}$.

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