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# EVALUATING KNOWLEDGE DIFFUSION CAPABILITIES OF HIGHER EDUCATION INSTITUTES BY USING THE DEA


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## ABSTRACT

The knowledge diffusion mechanisms embedded in higher education institutes (HEIs) can enable and enrich knowledge diffusion activities, upgrade industries, and enhance region development. The performance evaluation of knowledge diffusion mechanisms in HEIs is a multi-disciplinary research problem. However, few studies have tried to evaluate the performance of knowledge diffusion mechanisms embedded in HEIs. Thus, this study aims to define a Multiple Criteria Decision Making (MCDM) method-based approach to evaluate the efficiency of knowledge diffusion mechanisms embedded in HEIs. The modified Delphi method was first introduced to summarize the possible evaluation criteria. Then, the Decision Making Trial and Evaluation Laboratory (DEMATEL) was applied to derive the influence relationship map (IRM) between criteria. The Analytic Network Process (ANP) was then used to derive the weights associated with the criteria based on the IRM. The most important criteria were selected based on those weights. Finally, both the Charnes-Cooper-Rhodes (CCR) and Banker-Charnes-Cooper (BCC) Data Envelopment Analysis (DEA) models were introduced to evaluate the knowledge diffusion performance of the HEIs based on the most important criteria derived by using the ANP. An empirical study based on a performance evaluation of knowledge diffusion mechanisms embedded in four leading Taiwanese HEIs was used to demonstrate the feasibility of the proposed analytic framework. Based on the empirical study results, the leading Taiwanese HEIs have achieved similar knowledge diffusion performance while considering the variable returns to the scale of these institutes by using the BCC DEA model. In the future, the proposed analytic framework can be used to analyze the knowledge diffusion performance of other HEIs. Meanwhile, the well-verified framework can further be applied when evaluating the knowledge diffusion performance of research institutes, firms, and economies.


**KEYWORDS** : knowledge diffusion, Multiple Criteria Decision Making (MCDM), Data Envelopment Analysis (DEA), higher education institutes (HEIs).

## INTRODUCTION

Higher education institutes (HEIs) provide knowledge and a well-educated labor force and contribute to innovation, industry and country development, and technology evolution [1-3]. The performance evaluation of knowledge diffusion mechanisms in HEIs is a multi-disciplinary research problem that includes the evaluations of teaching and research activities, commercialization of academic performance, and university-industry (UI) collaborat ions. The knowledge diffusion mechanism in HEIs has increasingly been the object of study during recent years [4, 5]. Previous studies apply numerous methods to evaluate the efficiency of knowledge diffusion mechanisms and knowledge activities in HEIs [6-8]. Although the issue is very important for major catch-up economies, very few scholars have attempted to evaluate the performance of knowledge diffusion mechanisms associated with HEIs. Researchers paid less attention to the performance evaluation of knowledge diffusion mechanisms in HEIs. More profound research is needed to explore these issues and further enhance the knowledge diffusion mechanism and capabilities embedded in HEIs.

In order to evaluate the performance of knowledge diffusion mechanisms embedded in HEIs, the research aims to perform the following: (a) identify the key factors that enable and enhance knowledge diffusion in HEIs, (b) derive the weights associated with the key factors, and (c) evaluate the performance of knowledge diffusion mechanisms embedded in HEIs. The analytic results can be used to enhance the knowledge diffusion mechanisms and capabilities of the HEIs.

Thus, this study aims to define a Multiple Criteria Decision Making (MCDM) method-based approach to evaluate the efficiency of knowledge diffusion mechanisms in HEIs. The modified Delphi method was first introduced to summarize the evaluation criteria. After that, the Decision Making Trial and Evaluation Laboratory (DEMATEL) was used to derive the influence relationship map (IRM) between the criteria. The Analytic Network Process (ANP) was then used to derive the weights associated with the criteria based on the influence relationship map (IRM). The most important criteria were selected based on the weights. Finally, both the Charnes-Cooper-Rhodes (CCR) and the Banker-Charnes-Cooper (BCC) Data Envelopment Analysis (DEA) models were introduced to evaluate the knowledge diffusion performance of the HEIs based on the most important criteria derived from the use of the ANP. An empirical study based on a performance evaluation of knowledge diffusion mechanisms embedded in four leading Taiwanese HEIs was used to demonstrate the feasibility of the proposed analytic model.

This paper is structured as follows. Section 2 reviews the roles of HEIs in knowledge diffusion. The research methods and the empirical study framework are introduced in Section 3. Section 4 presents the empirical study process. In this section, the key factors for evaluating the knowledge diffusion mechanism and capabilities embedded in HEIs will be derived by using the modify Delphi method, the DEMATEL, and the ANP. The empirical study results will be demonstrated in Section 5. Advances in the practice of analyzing knowledge diffusion capabilities of HEIs are discussed in Section 6. Finally, Section 7 summarizes the work and suggests future research.

## LITERATURE REVIEW

HEIs embrace the knowledge process, which includes knowledge creation, sharing, transferring, storing, and diffusion via teaching activities, academic publication, joint ventures in research, technology transfer, licensing, consultation services, patent applications, and new startups, etc. [1-3]. Various key factors enable knowledge diffusion capabilities in HEIs. University-industry (UI) collaborations are among the methods applied to reduce the cost of R&D, share resources, and diffuse knowledge to help small- and medium-sized enterprises (SMEs) to upgrade technology capabilities [9, 10]. To advance the contribution of knowledge diffusion and knowledge production at the top level, governments enhance collaboration within higher-education institutions, research organizations, and corporations through education programs, research projects, strategic alliances, and partnerships [11, 12]. Developing economies like Taiwan and Singapore have achieved technological catch-up through a well-developed higher education system [13]. An international joint research network could lead to knowledge diffusion. Researchers and scientists who learn, train, and employ abroad and return to their home countries could benefit from international knowledge diffusion [14]. Many countries make policies and provide supports to improve the development of HEIs and enhance the knowledge diffusion mechanism, especially within the leading research universities.

## RESEARCH METHODS

The authors proposed an analytic framework to evaluate the performance of knowledge diffusion mechanisms embedded in HEIs. First, the modify Delphi method was introduced to summarize the possible factors which can enable and enhance knowledge diffusion in HEIs. The DEMATEL technique was then used to investigate the IRM within the key factors. After that, the ANP was performed to derive the weights associated with the key factors based on the IRM derived by using the DEMATEL. The DEA is a measurement technique to evaluate the performance and efficiency of the decision-making units (DMU) that use resources to create outputs. Without prior assumptions about the inputs or outputs, the DEA has widely been used in non-profit institutions such as HEIs, in which the evaluation of market prices or values of outputs is difficult [15-17]. Various DEA models are available. Among the DEA models, the CCR and the BCC are the most widely adopted. Both CCR and BCC models are input oriented. The difference between the CCR models and BCC models is that the CCR models focus on constant returns to scale, while the BCC models emphasize variable returns to scale [15]. In this work of research, both the CCR and BCC DEA models were introduced to analyze the efficiency of the knowledge diffusion mechanisms embedded in HEIs.

Within the empirical study based on evaluating the performance of knowledge diffusion mechanisms embedded in leading Taiwanese HEIs, 17 experts were invited to provide opinions regarding the evaluation criteria. All of the experts have more than ten years of work experience in one or more than one of these four universities or have long-term collaboration experience with these universities. The experts selected include five professors and three managers from the R&D divisions of these four universities, four Chief Executive Officers (CEOs) and managers from spin-offs of the universities, and five managers and researchers from research institutes that collaborate closely with these four institutes. All of them are familiar with the Taiwanese higher education system in all aspects, which include teaching, R&D activities, UI collaboration, higher education policy, and regulations. The results derived using both CCR and BCC DEA models were compared.

## THE KEY FACTORS FOR ENABLING THE KNOWLEDGE DIFFUSION OF HEIs

Based on the literature review results and experts' opinions, the study revealed twelve key factors for enabling and diffusing knowledge. The factors can further be grouped into three aspects: (1) teaching, (2) research, and (3) service. The factors within the teaching aspect include lectures ($a_1$), on-the-job training ($a_2$), experience sharing ($a_3$), internship ($a_4$). The factors within the research aspect include R&D activities ($b_1$), publication ($b_2$), and a network of academic exchange ($b_3$). Finally, the factors related to the service aspect include consultation ($c_1$), patent application ($c_2$), technology transfer ($c_3$), strategic alliances ($c_4$), and startups ($c_5$). The definitions and the corresponding symbols are demonstrated in Table 1. Figure 1 demonstrates the IRM derived by using the DEMATEL; the IRM consists of the influence relationships between aspects and criteria. Based on the IRM, the weights associated with each key factor were derived by using the ANP and are demonstrated in Table 2.

The IRM indicates that (1) lectures ($a_1$), on-the-job training ($a_2$), experience sharing ($a_3$), internship ($a_4$), R&D activities ($b_1$), publication ($b_2$), and consultation ($c_1$) influence other factors, and (2) network of academic exchange ($b_3$), patent application ($c_2$), technology transfer ($c_3$), strategic alliances ($c_4$), and startups ($c_5$) are affected by other factors. Based on the results derived by using the ANP, the key factors for enabling and diffusing knowledge include lectures ($a_1$), experience sharing ($a_3$), R&D activities ($b_1$), publication ($b_2$), network of academic exchange ($b_3$), patent application ($c_2$), and startups ($c_5$).

## PERFORMANCE EVALUATION OF THE KNOWLEDGE DIFFUSION MECHANISMS EMBEDDED IN TAIWANESE HEIS

In this section, a performance evaluation of the knowledge diffusion mechanisms embedded in the top four research universities of Taiwan was used to demonstrate the feasibility of the proposed analytic framework. The analysis will proceed as follows, based on the work by Gökşen et al. [15]: (1) a selection of input and output variables will take place and (2) the performance of DMUs by the CCR and BCC models will be evaluated.

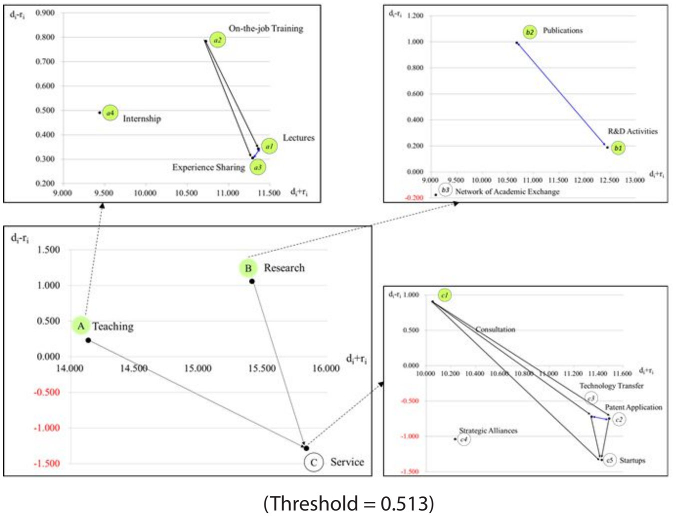
Based on 17 experts' opinions summarized by using the modified Delphi method, the input data which includes annual budgets, the number of master and Ph.D. students, and the number of full-time faculty were derived based on the annual reports for years 2007 to 2014 for these four universities. The possible criteria for evaluating the performance of knowledge diffusion in HEIs were derived based on the ANP results demonstrated in Table 2. Seven criteria, which include lectures ($a_1$), experience sharing ($a_3$), R&D activities ($b_1$), publication ($b_2$), network of academic exchange ($b_3$), patent application ($c_2$), and startups ($c_5$), were summarized based on the experts' opinions. The input and output criteria are demonstrated in Table 3. Then, the bivariate correlations of the input and output variables were derived. Based on the results of correlation analysis, experience sharing ($a_3$) was omitted due to the very low correlation coefficients with the budgets of 2008, 2013, 2014, etc. The correlation coefficients are even lower than the level, -0.2 to 0.4, suggested by Banker and Natarajan [18]. Except for experience sharing ($a_3$ ), which experts from industries play a dominant role and does not have positive correlations with other factors, the remaining input and output variables were maintained. According to Jenkins and Anderson [19], omitting even highly correlated variables could have a major influence on the computed efficiency scores, as argued by Dyson et al. [20]. Therefore, the authors kept the remaining input variables, though such variables are highly correlated. The performance evaluation results derived by both the CCR and the BCC DEA models are presented in Table 5.

The performance evaluation results present three major findings. Based on the evaluation results derived by using the CCR models, universities U2 and U3 have achieved the best performance in knowledge diffusion. Furthermore, based on the results derived by the BCC DEA model, research universities of different scales have the same knowledge diffusion performance.

**TABLE - 1**
**DEFINITION OF KEY FACTORS OF KNOWLEDGE DIFFUSION**

| Aspect | Key factor | Definition |
|---|---|---|
| Teaching | Lectures ($a_1$) | Both theoretical and practical curriculums and activities to diffuse knowledge from teachers to students and foster innovation –[2] |
| | On-the-job training ($a_2$) | Employees receive training from higher-education institutes to empower individual productivity, capabilities, and improve job performance on the job .[2,21] |
| | Experience sharing ($a_3$) | Industrial experts who have specialist professional knowledge and practical experience share their practice experience and advise with academics to commercialize academic achievement . [22] |
| | Internship ($a_4$) | During semester or vacations, students work at a firm or institute to transit theoretical knowledge to practice, find their interests and position in an industry, and to accumulate practical experience .[23] |
| Research | R&D activities ($b_1$) | Academics conduct R&D activities to acquire new knowledge, broaden and explore understanding of the fundamental aspects .[24] |
| | Publications ($b_2$) | Academics present research accomplishments by journal papers, books, and other forms of documentation — .[25] |
| | Network of Academic Exchange ($b_3$) | Research skills, latest information, knowledge, and technology are transferred and diffused to academic and industries via professional associations, meetings, conferences and seminars ' .[26] |
| Service | Consultation ($C_1$) | Academic consultation by faculty in higher-education institutes is used to transfer knowledge and technology between the academy and industry .[27] |
| | Patent Application ($C_2$) | The patenting process is the major channel to diffuse commercialization of academic knowledge to industries or users '–– and protect their intellectual property rights in application to new and useful processes, machines, and technologies.[28] |
| | Technology Transfer ($C_3$) | Technology transfer is organized work to achieve the goal and to make the necessary technical information move reasonably .[29] |
| | Strategic Alliances ($C_4$) | Strategic alliances share resources with partners in flexible ways to achieve more benefits [30] |
| | Startups ($C_5$) | University-related spin-off/start-up firms, which have university funding and commercialize research accomplishment to build high-tech either knowledge extensive firms .[31] |

Resource :[32]




(Threshold = 0.513)

Resource: [32]

| 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 |

**TABLE - 3 INPUT AND OUTPUT DATASETS OF THE HEIS**

| | INPUT 1: ANNUAL BUDGET (UNIT: NT$1000) (A) | | | | | | | | INPUT 2: MASTER AND PHD. STUDENTS (B)(CONTINUE) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| HEIs | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 |
| U1 | 14193479 | 12405499 | 14301931 | 16574949 | 16389706 | 16821921 | 15986754 | 14336423 | 14018 | 14548 | 14573 | 14117 | 14698 | 14630 | 14397 | 14117 |
| U2 | 4924325 | 5023739 | 4927761 | 5198046 | 5592157 | 5269741 | 5596143 | 5510549 | 5670 | 5869 | 5967 | 5858 | 5891 | 5832 | 5782 | 5706 |
| U3 | 4890737 | 4045310 | 4763611 | 5278161 | 5582052 | 5646150 | 5334277 | 4857070 | 6952 | 6877 | 7102 | 7363 | 7302 | 7280 | 7312 | 7207 |
| U4 | 6664799 | 7024009 | 7577593 | 7868598 | 8344301 | 8062304 | 8383219 | 8339331 | 9326 | 9563 | 9603 | 9583 | 9587 | 9424 | 9208 | 8995 |

| | INPUT 3: FULL-TIME FACULTY (C) | | | | | | | | OUTPUT: PERFORMANCE OF HEIS (D) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| HEIs | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | $a_1$ | $a_3$ | $b_1$ | $b_2$ | $b_3$ | $C_2$ | $C_5$ |
| U1 | 1912 | 1937 | 1986 | 2011 | 2018 | 2020 | 2043 | 2057 | 8.001 | 7.504 | 8.218 | 8.332 | 8.364 | 7.891 | 8.001 |
| U2 | 599 | 604 | 600 | 615 | 635 | 651 | 660 | 662 | 7.820 | 7.360 | 8.200 | 8.153 | 8.167 | 7.283 | 7.820 |
| U3 | 659 | 698 | 706 | 693 | 699 | 710 | 720 | 714 | 7.867 | 7.873 | 8.226 | 8.153 | 8.055 | 7.495 | 7.867 |
| U4 | 1202 | 1207 | 1241 | 1284 | 1298 | 1315 | 1338 | 1353 | 7.696 | 7.451 | 7.884 | 7.906 | 7.744 | 7.677 | 7.696 |

**TABLE - 4 CORRELATION MATRIX**

| | B2007 | B2008 | B2009 | B2010 | B2011 | B2012 | B2013 | B2014 | S2007 | S2008 | S2009 | S2010 | S2011 | S2012 | S2013 | S2014 | F2007 | F2008 | F2009 | F2010 | F2011 | F2012 | F2013 | F2014 | $a_1$ | $a_3$ | $b_1$ | $b_2$ | $b_3$ | $c_2$ | $c_5$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **B2007** | 1.000 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **B2008** | 0.986 | 1.000 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **B2009** | 0.994 | 0.995 | 1.000 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **B2010** | 0.999 | 0.990 | 0.998 | 1.000 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **B2011** | 0.998 | 0.992 | 0.999 | 1.000 | 1.000 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **B2012** | 0.999 | 0.987 | 0.997 | 1.000 | 0.999 | 1.000 | | | | | | | | | | | | | | | | | | | | | | | | | |
| **B2013** | 0.996 | 0.995 | 1.000 | 0.998 | 1.000 | 0.997 | 1.000 | | | | | | | | | | | | | | | | | | | | | | | | |
| **B2014** | 0.985 | 0.999 | 0.997 | 0.991 | 0.994 | 0.988 | 0.997 | 1.000 | | | | | | | | | | | | | | | | | | | | | | | |
| **S2007** | 0.967 | 0.966 | 0.982 | 0.977 | 0.979 | 0.979 | 0.979 | 0.978 | 1.000 | | | | | | | | | | | | | | | | | | | | | | |
| **S2008** | 0.972 | 0.974 | 0.987 | 0.981 | 0.984 | 0.983 | 0.985 | 0.985 | 0.999 | 1.000 | | | | | | | | | | | | | | | | | | | | | |
| **S2009** | 0.972 | 0.972 | 0.986 | 0.981 | 0.984 | 0.983 | 0.984 | 0.982 | 1.000 | 1.000 | 1.000 | | | | | | | | | | | | | | | | | | | | |
| **S2010** | 0.961 | 0.958 | 0.976 | 0.972 | 0.974 | 0.975 | 0.974 | 0.971 | 1.000 | 0.998 | 0.999 | 1.000 | | | | | | | | | | | | | | | | | | | |
| **S2011** | 0.971 | 0.966 | 0.983 | 0.979 | 0.982 | 0.982 | 0.981 | 0.977 | 1.000 | 0.999 | 1.000 | 0.999 | 1.000 | | | | | | | | | | | | | | | | | | |
| **S2012** | 0.973 | 0.965 | 0.983 | 0.981 | 0.983 | 0.983 | 0.981 | 0.977 | 0.999 | 0.998 | 0.999 | 0.999 | 1.000 | 1.000 | | | | | | | | | | | | | | | | | |
| **S2013** | 0.973 | 0.962 | 0.982 | 0.981 | 0.982 | 0.984 | 0.980 | 0.974 | 0.998 | 0.997 | 0.998 | 0.998 | 0.999 | 1.000 | 1.000 | | | | | | | | | | | | | | | | |
| **S2014** | 0.974 | 0.962 | 0.982 | 0.981 | 0.983 | 0.985 | 0.980 | 0.974 | 0.998 | 0.996 | 0.998 | 0.998 | 0.999 | 1.000 | 1.000 | 1.000 | | | | | | | | | | | | | | | |
| **F2007** | 0.963 | 0.980 | 0.985 | 0.974 | 0.979 | 0.974 | 0.982 | 0.989 | 0.993 | 0.996 | 0.994 | 0.990 | 0.991 | 0.989 | 0.986 | 0.985 | 1.000 | | | | | | | | | | | | | | |
| **F2008** | 0.965 | 0.978 | 0.986 | 0.976 | 0.981 | 0.977 | 0.983 | 0.988 | 0.996 | 0.998 | 0.997 | 0.993 | 0.994 | 0.993 | 0.990 | 0.989 | 1.000 | 1.000 | | | | | | | | | | | | | |
| **F2009** | 0.962 | 0.976 | 0.984 | 0.974 | 0.978 | 0.974 | 0.981 | 0.986 | 0.996 | 0.998 | 0.997 | 0.994 | 0.994 | 0.992 | 0.989 | 0.988 | 1.000 | 1.000 | 1.000 | | | | | | | | | | | | |
| **F2010** | 0.957 | 0.976 | 0.981 | 0.969 | 0.975 | 0.969 | 0.978 | 0.986 | 0.993 | 0.995 | 0.994 | 0.990 | 0.990 | 0.988 | 0.984 | 0.983 | 1.000 | 0.999 | 1.000 | 1.000 | | | | | | | | | | | |
| **F2011** | 0.957 | 0.977 | 0.981 | 0.969 | 0.974 | 0.969 | 0.978 | 0.987 | 0.992 | 0.995 | 0.993 | 0.989 | 0.989 | 0.987 | 0.983 | 0.982 | 1.000 | 0.999 | 0.999 | 1.000 | 1.000 | | | | | | | | | | |
| **F2012** | 0.955 | 0.976 | 0.980 | 0.967 | 0.973 | 0.967 | 0.977 | 0.986 | 0.991 | 0.994 | 0.992 | 0.988 | 0.988 | 0.986 | 0.982 | 0.980 | 1.000 | 0.999 | 0.999 | 1.000 | 1.000 | 1.000 | | | | | | | | | |
| **F2013** | 0.953 | 0.975 | 0.979 | 0.966 | 0.972 | 0.966 | 0.976 | 0.985 | 0.990 | 0.993 | 0.991 | 0.987 | 0.987 | 0.985 | 0.981 | 0.980 | 0.999 | 0.999 | 0.999 | 1.000 | 1.000 | 1.000 | 1.000 | | | | | | | | |
| **F2014** | 0.951 | 0.974 | 0.977 | 0.964 | 0.970 | 0.964 | 0.975 | 0.985 | 0.989 | 0.992 | 0.990 | 0.986 | 0.986 | 0.983 | 0.979 | 0.978 | 0.999 | 0.998 | 0.998 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | | | | | | | |
| **$a_1$** | 0.702 | 0.584 | 0.624 | 0.672 | 0.653 | 0.677 | 0.632 | 0.569 | 0.556 | 0.554 | 0.562 | 0.554 | 0.575 | 0.587 | 0.602 | 0.608 | 0.496 | 0.512 | 0.505 | 0.482 | 0.478 | 0.472 | 0.467 | 0.460 | 1.000 | | | | | | |
| **$a_3$** | -0.192 | -0.328 | -0.235 | -0.198 | -0.212 | -0.176 | -0.238 | -0.296 | -0.117 | -0.152 | -0.135 | -0.091 | -0.105 | -0.096 | -0.079 | -0.076 | -0.230 | -0.205 | -0.202 | -0.226 | -0.235 | -0.239 | -0.241 | -0.247 | 0.229 | 1.000 | | | | | |
| **$b_1$** | 0.164 | 0.024 | 0.059 | 0.120 | 0.096 | 0.125 | 0.071 | -0.003 | -0.038 | -0.040 | -0.030 | -0.041 | -0.015 | 0.000 | 0.018 | 0.026 | -0.103 | -0.087 | -0.096 | -0.121 | -0.124 | -0.131 | -0.137 | -0.144 | 0.809 | 0.340 | 1.000 | | | | |
| **$b_2$** | 0.609 | 0.495 | 0.523 | 0.573 | 0.553 | 0.575 | 0.533 | 0.470 | 0.423 | 0.426 | 0.433 | 0.417 | 0.443 | 0.456 | 0.470 | 0.477 | 0.374 | 0.387 | 0.378 | 0.356 | 0.354 | 0.347 | 0.342 | 0.336 | 0.979 | 0.136 | 0.881 | 1.000 | | | |
| **$b_3$** | 0.587 | 0.492 | 0.503 | 0.549 | 0.531 | 0.548 | 0.515 | 0.460 | 0.377 | 0.386 | 0.390 | 0.365 | 0.396 | 0.408 | 0.419 | 0.426 | 0.346 | 0.355 | 0.345 | 0.327 | 0.326 | 0.320 | 0.315 | 0.310 | 0.935 | -0.024 | 0.863 | 0.984 | 1.000 | | |
| **$c_2$** | 0.867 | 0.868 | 0.896 | 0.885 | 0.891 | 0.892 | 0.891 | 0.894 | 0.964 | 0.956 | 0.958 | 0.970 | 0.961 | 0.959 | 0.958 | 0.956 | 0.947 | 0.952 | 0.955 | 0.952 | 0.950 | 0.950 | 0.950 | 0.949 | 0.404 | 0.029 | -0.199 | 0.236 | 0.159 | 1.000 | |
| **$c_5$** | 0.680 | 0.561 | 0.637 | 0.672 | 0.659 | 0.687 | 0.637 | 0.581 | 0.692 | 0.671 | 0.684 | 0.706 | 0.705 | 0.714 | 0.728 | 0.732 | 0.603 | 0.624 | 0.623 | 0.600 | 0.593 | 0.587 | 0.585 | 0.578 | 0.790 | 0.586 | 0.450 | 0.654 | 0.520 | 0.703 | 1.000 |

**TABLE - 5 EFFICIENCY SCORES FOR DEA MODELS**

| DEA MODEL DMU / DMU | EFFICIENCY | |
|---|---|---|
| | CCR | BCC |
| U1 | 0.450 | 1.000 |
| U2 | 1.000 | 1.000 |
| U3 | 1.000 | 1.000 |
| U4 | 0.762 | 1.000 |

## DISCUSSIONS

Governments provide resources for HEIs to enhance knowledge diffusion to industries [11, 12]. In developed countries, top universities which gain the most recourses should achieve the best performance. Knowledge diffusion are contributed by knowledge integration and implementation users [33]. Experience sharing suggests the professional experiences and advices given by the experts from industries. By collaborating with senior expert from industries, researchers in academia could successfully commercialize their studies. As the senior experts from industries function as external resource, instead of internal and direct assistance. That is, the statistical correlation between expert's experience sharing and input is limited. Based on the analytic results, the leading Taiwanese universities achieved similar performance while relaxing the constant returns-to-scale assumption by using the BCC DEA model. Compared to other leading universities (U1 and U4), U2 and U3 have little resources and fewer academic disciplines. Thus, these two institutes are comparatively lower in scale. To resolve the resource shortage problem, these two smaller institutes established strategic alliances with other leading Taiwanese educational and research institutions from the aspects of teacher exchange and equipment sharing, inter-institution research collaborations, etc., so as to resolve the resource shortage problem and enhance the performance of knowledge diffusion. Thus, the four HEIs achieved similar performance in knowledge diffusion.

## CONCLUSION

The research defined an analytic framework for evaluating the knowledge diffusion performance of HEIs. Based on the empirical study results, the leading Taiwanese HEIs have achieved similar knowledge diffusion performance while considering the variable returns to scale of these institutes by using the BCC DEA model. In the future, the proposed analytic framework can be used to analyze the knowledge diffusion performance of other HEIs. Meanwhile, the well-verified framework can further be applied when evaluating the knowledge diffusion performance of research institutes, firms, and economies.

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