Technological Forecasting & Social Change 92 (2015) 25–39

Contents lists available at ScienceDirect

Technological Forecasting & Social Change

Toward successful commercialization of university technology: Performance drivers of university technology transfer in Taiwan

David W.L. Hsu [a,1], Yung-Chi Shen [b,*], Benjamin J.C. Yuan [c,1], Chiyan James Chou [d,1]

[a] Office of Research and Development, National Chiao Tung University, 1001 University Road, Hsinchu, Taiwan, ROC
[b] Department of Biobusiness Management, National Chiayi University, 580 Shinmin Road, Chiayi, Taiwan, ROC
[c] Institute of Industrial Economics, Jinan University, Guangzhou, China
[d] Graduate Institute of Technology Management, National Chiao Tung University, 1001 University Road, Hsinchu, Taiwan, ROC

ARTICLE INFO

Article history:
Received 16 September 2013
Received in revised form 27 September 2014
Accepted 5 November 2014
Available online xxxx

Keywords:
University technology transfer
Performance drivers
Fuzzy Delphi method
Interpretive structural modeling
Analytic network process

ABSTRACT

The transfer of university technology[2] to industry involves a multitude of mechanisms which can be broken down into an even larger number of activities. These mechanisms and activities include launching technology-oriented start-ups, and providing the following: collaborative research, contract research, consulting services, technology licensing, graduate education, advanced training for enterprise staff, exchange of research staff, and other forms of formal or informal information transfer. Taking Taiwan's universities as a research base, this study intends to identify the critical drivers affecting the performance of university technology transfer. The Fuzzy Delphi method, interpretive structural modeling (ISM), and the analytic network process (ANP) are employed sequentially to derive the relative importance of the various performance drivers. Human capital and institutional/cultural resources are the two most emphasized resources for the improvement of university technology transfer in Taiwan. Some policy implications are derived on the basis of these results.

© 2014 Elsevier Inc. All rights reserved.

1. Introduction

Knowledge spillovers are regarded as one of the important sources of a country's economic growth (Romer, 1986, 1990). Gibbons et al. (1994) indicated that there are two modes of knowledge generation. In the first mode, knowledge production is motivated by autonomous universities, with self-defined and self-sustaining disciplines and specialties. And in this mode, there is nearly no interaction between academia and industry. This is the so-called “Mode 1” of knowledge production. The “Mode 2” paradigm describes knowledge production which relies on interdisciplinary teams collaborating together for short periods to work on specific problems in the real world (Gibbons et al., 1994). “Mode 2” knowledge production is conceptualized in terms of university–industry–government relations, i.e. the Triple Helix model (Etzkowitz and Leydesdorff, 1995, 2000). The Triple Helix system illustrates the interaction among university, industry, and government for cross-sector knowledge generation.

From the perspective of the Triple Helix model, the interactions between these institutions for boundary-spanning knowledge production and dissemination are the catalytic regime that stimulates knowledge-based economic development for newly industrializing, deindustrializing or reindustrializing nations (Leydesdorff and Etzkowitz, 1996). The institutions generating knowledge play an important role in the networks woven by university, industry, and government. The interactions among the three actors are increasingly overlapping (Etzkowitz and Leydesdorff, 1995). In the Triple Helix model, universities increasingly take part in the business functions and the incubation of small technology-based

* Corresponding author. Tel.: +886 52732877; fax: +886 52732874.
E-mail addresses: davidhsu@mail.nctu.edu.tw (D.W.L. Hsu), syc@mail.ncyu.edu.tw (Y.-C. Shen), benjamin@faculty.nctu.edu.tw (B.J.C. Yuan), c.james.chou@gmail.com (C.J. Chou).
[1] Tel.: +886 35712121.
[2] This study adopts the definition of university technology transfer suggested by Siegel et al. (2003).

http://dx.doi.org/10.1016/j.techfore.2014.11.002
0040-1625/© 2014 Elsevier Inc. All rights reserved.

companies. This is in addition to their primary missions of creating human capital and conducting basic research. Industrial corporations increasingly use universities' infrastructure to engage their R&D activities, and transfer part of their R&D expenditures to universities in the form of funding for academia. Governments deploy policy measures to encourage the development of small innovative companies both through the funding of universities and through the enactment of legislative regulations designed to stimulate the development and implementation of new technologies in industry. Universities and industry can partially substitute for the state in the creation of an innovation infrastructure (Leydesdorff and Etzkowitz, 1996). Therefore, both the university–industry relationship and the university–government relationship lead to activities which bring innovations to the market.

The objective of the Triple Helix approach is to realize an innovative environment for knowledge-based economic development through trilateral coordination (Etzkowitz and Leydesdorff, 2000). While the university–industry and university–government relations may require corresponding catalysts, many regulations tend to shape the university into a constituent part of the corresponding innovation system. Regarding the experience of United States, in the 1980s, the U.S. government sequentially passed the Bayh–Dole Act, the Stevenson–Wydler Technology Innovation Act, the National Cooperative Research Act, the Federal Technology Transfer Act, and the Technology Transfer Improvement and Advancement Act. These acts collectively built an environment conducive to university–industry collaboration and technology transfer thereby improving the contribution of the system of higher education to industrial technology innovation (Ken et al., 2009). For developing countries such as Taiwan, an important strategy for catching up is enhancing the role of universities in building a nation's innovative capacity, since universities are, in general, seen as a source of knowledge flow (Mathews and Hu, 2007). Inspired by the U.S. experience, Taiwan has sought to enhance its national innovation capacity by encouraging domestic universities and public research institutes to diffuse their inventions to public use. Taiwan's Fundamental Science and Technology Act, passed in 1999, defines the intellectual property rights of government-funded academic research studies at universities or research institutes, removing them from regulation under the National Property Act. With the enactment of the Fundamental Science and Technology Act, researchers are motivated to commercialize their academic research to take advantage of royalties, licensing income, and equity participation for their institutes (Chang et al., 2009). Many Taiwan universities have begun to establish technology transfer offices to facilitate their technology licensing and transfer.

Owing to diversified forms of industry–science linkage (Debackere and Veugelers, 2005), a university might find it difficult to manage outcomes per se owing to the multitudinous outputs of university technology transfer, unless it finds the influencing factors and then allows administrators to contribute ideas for their improvement. Organizational scholars suggest that the key performance drivers provide an opportunity to enhance an organization's outcomes through improving its internal processes (Kaplan and Norton, 1992; Walsh, 1996). Using Taiwan as a test case, this study aims to define the performance drivers of university technology transfer.

There are plenty of quantitative studies which attempt to identify the critical factors on the outcome of university knowledge transfer by applying econometric regression models (Landry et al., 2007; González-Pernía et al., 2013; Rizzo and Ramaciotti, 2014) or data envelopment analysis (DEA) (Chapple et al., 2005; Anderson et al., 2007; Ho et al., 2014). A few qualitative studies use case studies to clarify the factors which effect technology transfer in the case of a specific institution (O'Shea et al., 2007; Swamidass, 2013; Guerrero et al., 2014). Nevertheless, one may need several econometric models to reflect the myriad outputs of the university technology transfer process, since one regression model estimates the influence of independent variables on only a single dependent variable. While data envelopment analysis (DEA) can measure the efficiency of university technology transfer through multiple input and output indicators, it may none-the-less miss some factors that are difficult to quantify. These might include the history and culture of a university (O'Shea et al., 2007) and the value of its informal networks, for example (Geuna and Muscio, 2009). Whereas multi-criteria decision-making (MCDM) techniques are able to quantify the elements for which it is difficult to obtain quantitative data or numeric proxies (Antonio Cortés-Aldana et al., 2009), this study by contrast intends to pioneeringly bridge the gap between qualitative and quantitative methodologies in the field of university technology transfer with MCDM approaches. Hence, this study attempts to construct a comprehensive framework to not only identify the performance drivers but also determine the relative weighting to attribute to each of these drivers, based on the clarification of each driver's contribution to the improvement of university technology transfer. To accomplish this end, this study intends to employ a series of three techniques. First, the fuzzy Delphi method is used to verify the appropriateness of each performance driver in the context of Taiwan's university research. Second of all, Interpretive Structural Modeling (ISM) is used to detect the interdependence among the performance drivers. Finally, Analytic Network Process (ANP) methodology is adopted to determine the proper weighting to assign to each performance driver.

The organization of the text, for the remainder of this paper, is as follows: Section 2 presents the various forms of university technology transfer. Section 3 briefly covers some theoretical background and extracts the performance drivers of university technology transfer from existing literature. Section 4 describes the ISM and ANP methods employed in this study. Section 5 presents the empirical analysis. Finally, Section 6 provides the conclusions and policy implications derived from the results in Section 5.

2. The diversified forms of university technology transfer

University scientists are regarded as the suppliers of innovation, in the sense that the new knowledge and technology created in the university are expected to be transferable to industrial use. The transfer of knowledge and technology from university to industry appears in diverse forms, such as technology startups, collaborative research, contract research and know-how-based consulting, the development of intellectual property rights serving as a base for licensing technologies to enterprises, cooperation in graduate education, advanced training for enterprise staff, and the systematic exchange of research staff between companies and research institutes (Debackere and Veugelers, 2005). Allen (1977) and Matkin (1990) indicate that there are a myriad of informal contacts, gatekeeping processes, and industry–science networks on the individual level. These informal contacts and human capital flows are channels of knowledge exchange between university research centers and private enterprises, which are difficult to quantify (Debackere and Veugelers, 2005).

Despite the difficulty in quantifying this technology transfer, many scholars attempt to employ quantitative indicators to reflect the nature of university technology transfer, such as university spin-offs (Di Gregorio and Shane, 2003; Lockett et al., 2005; O'Shea et al., 2005), technology licensing income (Thursby and Kemp, 2002; Siegel et al., 2003; Link and Siegel, 2005), citations to academic patents (Henderson et al., 1998; Mowery, 1998), and university–industry collaborative research (Caldera and Debande, 2010). Siegel et al. (2003) investigate entrepreneurs, technology transfer directors, and university scientists who are experienced in university technology transfer and indicate that university/industry technology transfer outputs comprise licenses, royalties, patents, sponsored research agreements, start-up companies, invention disclosures, students, informal transfer of know-how, product development, and economic development. Moreover, informal knowledge transfer is regarded as a highly significant way to inspire or facilitate technology development in enterprises, although such informal information transfer could not be adopted immediately into a product (Siegel et al., 2003). Thus, in numerous studies, the number of references to scientific publications in patents is adopted as a proxy to reflect the nature of knowledge transfer (Narin et al., 1997; Henderson et al., 1998; Mowery, 1998; Verbeek et al., 2002). As university technology transfer has many aspects, it is difficult to use a set of quantitative proxies to reveal the overall picture of knowledge and information transfer from university to industry.

3. Framework development

To understand the critical performance drivers of university technology transfer, it is necessary to depict the process of technology transfer from a university to a firm or entrepreneur through a licensing agreement or a spin-off activity. Extracting from the process of university technology transfer, Siegel et al. (2003) indicate that a set of internal, environmental, and organizational factors affect the effectiveness of university technology transfer. Based on the well-known resource-based view (Wernerfelt, 1984), O'Shea et al. (2005) categorize factors into four types: institutional, human, financial, and commercial. As mentioned in the previous section, the critical performance drivers facilitate internal process improvement toward successful output enhancement. Therefore, this study synthesizes the factors related to a university's internal resources which spur technology transfer, and then attempts to derive their relative importance. The performance drivers extracted from literature are presented in Table 1.

3.1. Human resources

The process of university technology transfer begins with scientific discovery (Siegel et al., 2003). The faculty members and researchers of a university dedicate themselves to discovering cutting-edge technologies. Once such technologies are developed, the researchers then file their inventions with the university technology transfer office. As the suppliers of innovations, several empirical studies demonstrate that higher-quality scientists create spin-off firms to capture the rents generated by their intellectual capital (Zucker et al., 1998; O'Shea et al., 2005). Their motivation for developing leading-edge innovations may be to earn economic rents on valuable asymmetric information (Di Gregorio and Shane, 2003; O'Shea et al., 2005). Additionally, *faculty quality* has been shown to be one of the key factors in other studies related to the performance of university technology licensing (Thursby and Kemp, 2002; Friedman and Silberman, 2003; Lach and Schankerman, 2004; O'Shea et al., 2007).

Since faculty quality is critical for the performance of university technology transfer, a large number of faculty members and researchers may make it easier to generate the "star" scientists who facilitate academic technology transfers (Foltz et al., 2000). In addition, the availability of researchers and engineers with higher skills and R&D know-how is positive for the realization of technology transfer activity in a university (Powers, 2003; O'Shea et al., 2005). Therefore, *faculty size*, *size of scientific and technological departments*, and *size of postdoc staff and number of full-time researchers* are regarded as inputs to university technology transfer in several works (Foltz et al., 2000; Friedman and Silberman, 2003; Lach and Schankerman, 2004).

Once a given invention is formally disclosed, the university technology transfer office then evaluates the commercial potential of the technology and decides whether to patent the invention. Furthermore, the university technology transfer office has to design the patent portfolio to maximize the value of the invention by seeking domestic or global patent protection. If the patent is granted, the university technology transfer office will attempt to commercialize this technology by licensing it or launching a start-up (Siegel et al., 2003). Therefore, the university technology transfer offices play an important role within the facilitation of technology commercialization. These transfer offices need to weave the networks between academics, venture capitalists, advisors, and managers who collectively provide the necessary human and financial resources to start a company. Moreover, they have to be equipped with company formation knowledge, such as evaluating markets, writing business plans, raising venture capital, assembling venture teams, and obtaining space and equipment (Chugh, 2004; O'Shea et al., 2005). Several studies consider the *size of technology transfer offices* as a determinant for the performance of university technology transfer (Rogers et al., 2000; Thursby and Kemp, 2002; Lach and Schankerman, 2004; Link and Siegel, 2005; Chapple et al., 2005; O'Shea et al., 2005; Chang et al., 2006).

3.2. Institutional/culture resources

University technology transfer may depend on distinctive institutional factors that create an atmosphere which encourages entrepreneurial activity at a particular university. Such an atmosphere, grounded in the particular history of the university, forms a unique *culture and tradition*, which serves as a rare resource to help fertilize university technology transfer or

Table 1
Performance drivers of university technology transfer.

Dimensions	Performance drivers	Descriptions	Sources
Human resources	Faculty quality	The quality of faculty members.	Thursby and Kemp (2002), Friedman and Silberman (2003), Di Gregorio and Shane (2003), Lach and Schankerman (2004), O'Shea et al. (2005), O'Shea et al. (2007)
	Faculty size	The number of faculty members.	Foltz et al. (2000), Lach and Schankerman (2004)
	Size of scientific and technological departments	The number of faculty members of scientific and technological departments.	Foltz et al. (2000), Friedman and Silberman (2003)
	Size of postdoc staff and full-time researchers	The number of postdoc fellows and full-time researchers.	O'Shea et al. (2005)
	Size of technology transfer offices	The number of full-time equivalent employees in university technology transfer offices.	Rogers et al. (2000), Thursby and Kemp (2002), Lach and Schankerman (2004), Link and Siegel (2005), Chapple et al. (2005), O'Shea et al. (2005), Chang et al. (2006)
Institutional/culture resources	Culture and tradition	The entrepreneurial-oriented culture and tradition of university.	Clarke (1998), O'Shea et al. (2007)
	Experience of technology transfer offices	The age and the experience of university technology transfer offices.	Rogers et al. (2000), Carlsson and Fridh (2002), Friedman and Silberman (2003), Lach and Schankerman (2004), Link and Siegel (2005), Chapple et al. (2005), Lockett and Wright (2005)
	University's location	Universities in locations characterized by a relative high concentration of technology firms, industry research, and an entrepreneurial climate.	Anselin et al. (1997), Friedman and Silberman (2003), Chapple et al. (2005), O'Shea et al. (2007)
	Incentive policy	University-wide incentive program for faculty members to become involved in activities related to technology transfer.	Friedman and Silberman (2003), Di Gregorio and Shane (2003), Lockett et al. (2005), Link and Siegel (2005), Chang et al. (2006)
	Interdisciplinary research	Interdisciplinary research centers or interdisciplinary research projects of universities.	O'Shea et al. (2007)
	Entrepreneurship development programs	Entrepreneurship development programs to deliver entrepreneurship education.	O'Shea et al. (2007), Rasmussen and Sørheim (2012)
Financial resources	Industry funding	Industry funding to support university research.	Rogers et al. (2000), Foltz et al. (2000), Friedman and Silberman (2003), Lach and Schankerman (2004), O'Shea et al. (2005), Link and Siegel (2005), O'Shea et al. (2007)
	Government funding	Government funding to support university research.	Henderson et al. (1998), Rogers et al. (2000), Foltz et al. (2000), Thursby and Kemp (2002), Friedman and Silberman (2003), Lach and Schankerman (2004), O'Shea et al. (2005), Chang et al. (2006)
	Expenditure on associated intellectual property protection	A university's expenditure on associated intellectual property protection.	Siegel et al. (2003), Chapple et al. (2005), Lockett and Wright (2005), Chang et al. (2006)
	Funding on intellectual property commercialization	Funding on the commercialization of intellectual property.	Rasmussen and Sørheim (2012)
Commercial resources	Incubators	University incubators.	Smilor and Gill (1986), Mian (1996), O'Shea et al. (2005), Mathews and Hu (2007)
	Invention disclosures	The number of university invention disclosures.	Carlsson and Fridh (2002), Siegel et al. (2003), Link and Siegel (2005), Chapple et al. (2005)
	Entrepreneurial capability	The faculty members' entrepreneurial capability.	Clarysse et al. (2011)
	Entrepreneurial experience	The faculty members' entrepreneurial experience.	Clarysse et al. (2011)
	Social network	The university's connection between industry, venture capitalists, academia, and government.	Siegel et al. (2003), Lockett et al. (2005), O'Shea et al. (2007)
	Patent portfolios	The international and domestic patent protections.	Lichtenthaler and Ernst (2010)
	Proofs and prototypes	University inventions with proofs of concept or prototypes.	Jensen and Thursby (2001), Rasmussen and Sørheim (2012)

spin-off activities. For instance, Clarke (1998) indicates that entrepreneurial culture is a key element for successful university–industry technology transfer in a cross-national study of five highly successful European universities. O'Shea et al. (2007) report a number of historical events and choices made by the Massachusetts Institute of Technology (MIT)—a university that is highly prolific in its spin-off activity.

To foster a climate for entrepreneurship in their academic institutions, university administrators should deploy university-wide mechanisms. Many universities and technology transfer offices have found that they need to offer proper motivation schemes, such as an adequate share for the inventors in royalties or equity to stimulate these academics to file their innovations. Several studies show the importance of proper incentives in drawing academics' cooperation in technology licensing (Macho-Stadler et al., 1996; Jensen and Thursby, 2001; Lach and Schankerman, 2004; Link and Siegel, 2005; Siegel et al., 2007). In addition, some studies indicate that the royalty regime provided by a university has a positive effect on university spin-off rates (Di Gregorio and Shane, 2003; O'Shea et al., 2005; Siegel et al., 2007). According to these empirical analyses, an effective *incentive policy* is positive for the realization of technology transfer activities.

In addition, Siegel et al. (2004) indicate that recruiting experienced employees for university technology transfer offices can more effectively promote the commercialization of technology from university to industry. Several empirical studies report that the age of a university technology transfer office is a positive indicator for its performance (Rogers et al., 2000; Carlsson and Fridh, 2002). In other words, the established technology transfer offices that have more experience will generate more licenses and income from technology transfer. The *experience of university technology transfer offices*, thus, is regarded as a determinant in several studies (Friedman and Silberman, 2003; Lach and Schankerman, 2004; Link and Siegel, 2005; Chapple et al., 2005; Lockett and Wright, 2005).

The *university's location* is another factor significantly affecting the performance of academic technology transfer. Most empirical studies examining the contribution of university research to regional economic development suggest that contributions of university-based research tend to be geographically concentrated (Anselin et al., 1997; Friedman and Silberman, 2003; Chapple et al., 2005; Mathews and Hu, 2007). Taking MIT as a case, O'Shea et al. (2007) indicate that the university supports and acts as a virtual incubator for entrepreneurial activity and new technology-based spin-offs. The cutting-edge knowledge and innovation created by universities may spill over and benefit the regional technology industry and the private research sector. The industry clusters surrounding the universities generate feedback through increasing demand for university technology transfer. The university's ability to generate licenses and royalty income may also depend on the access to lawyers, venture capitalists, consultants, entrepreneurs, and industry-based researchers spilled over from the regional industrial sector (Friedman and Silberman, 2003; O'Shea et al., 2007).

Additionally, O'Shea et al. (2007) report that *interdisciplinary research* and *entrepreneurship development programs* are two important institutional factors that constitute MIT's entrepreneurial culture. MIT has a long history of securing funding for interdisciplinary research. Many of MIT's interdisciplinary research centers incubate highly successful spin-offs, such as Momenta and Alnyalm, both originating from Broad Institute, which was jointly founded by MIT and Harvard University and is regarded as the leading laboratory in the Human Genome Project consortium (O'Shea et al., 2007). Lee et al. (2010b) also suggest that an interdisciplinary research team can generate multiple perspectives and expertise to accomplish research goals more effectively and thus facilitate university technology transfer.

MIT supplements rigorous engineering curriculums with formal and experiential programs in entrepreneurship, which form another pillar establishing the entrepreneurial climate of MIT. MIT fosters its academic entrepreneurial activities in several ways, including through the Deshpande Center for Technological Innovation, which funds promising research and coaches grantees in commercializing their innovations or launching start-ups, and the Martin Trust Center for MIT Entrepreneurship, which provides educational courses and executive programs to develop leaders of successful high-tech ventures (O'Shea et al., 2007). Rasmussen and Sørheim (2012) also suggest that entrepreneurship education could serve as an initiative to facilitate university entrepreneurship activity.

3.3. Financial resources

Universities are expected to be increasingly efficient in their use of public resources. Empirical studies show that *government funding* is important for cutting-edge research, particularly in the fields of biotechnology and the life sciences, (Foltz et al., 2000; O'Shea et al., 2007) because such basic research has more uncertainty as to when it will lead to commercial products. Other studies related to university technology transfer consider government funding as a facilitator due to the fact that it enables university academics to develop a wealth of technology for commercialization (Henderson et al., 1998; Rogers et al., 2000; Thursby and Kemp, 2002; Friedman and Silberman, 2003; Lach and Schankerman, 2004; O'Shea et al., 2005).

According to Siegel et al. (2003), one of the primary motives of university scientists is the desire to secure funding for graduate students, postdoctoral fellows, and laboratory equipment or facilities. Therefore, university scientists are motivated to secure additional research funding for continuing research through royalties, licensing fees, and sponsored research agreements, particularly with the federal government's relinquishment of intellectual property for accelerating the commercialization of university innovations. In addition, numerous studies have shown that adequate *industry funding* contributes to university spin-off and technology licensing activities (Rogers et al., 2000; Foltz et al., 2000; Thursby and Kemp, 2002; Friedman and Silberman, 2003; Lach and Schankerman, 2004; O'Shea et al., 2005; Link & Siegel, 20 05; O'Shea et al., 2007). Powers and McDougall (2005) report a positive and significant relationship between university R&D expenditure and spin-off activity. Wright et al. (2004) suggest that the involvement of industry, such as venture capitalists, may facilitate the launch of university spin-offs as these venture capitalists have the necessary financial resources and business expertise to successfully commercialize technologies (O'Shea et al., 2005). O'Shea et al. (2007) indicate that industry-funded research plays a strong role in the commercialization of MIT's research output.

Once the university scientists file their inventions at their technology transfer offices, the offices need to employ attorneys to support the protection of intellectual property, through patenting, licensing, maintenance, and litigation. In several studies on university technology transfer, *expenditures on intellectual property protection* are regarded as one of the factors for success (Siegel et al., 2003; Chapple et al., 2005; Lockett and Wright, 2005). After the university obtains the intellectual property it may find it difficult to seek financial support from private financiers for the commercialization of early stage technologies developed by academics. To bridge this financing gap, Rasmussen and Sørheim (2012) suggest seed funding to commercialize the early stage technologies thus reducing technological and organizational uncertainty. With the support of seed funding programs, the early stage technologies have a greater chance of emerging in the marketplace through university spin-offs. This study therefore considers the *funding of intellectual property commercialization* as a factor in successful university technology transfer.

3.4. Commercial resources

Human resources, institutional resources, and financial resources directly impact the generation of university innovations. In addition, commercial resources serve as complementary resources to these for facilitating the emergence of university innovations in the marketplace. Several elements play a key role with respect to engendering academic entrepreneurship. The *incubator* in a university is regarded as an effective measure to accelerate the spin-offs (Mian, 1996). Smilor and Gill (1986) indicate that start-up companies located in university incubators can access the library and state-of-the-art facilities, and enjoy a creative environment and well-trained student laborers. Encouraged by the Fundamental Science and Technology Act in Taiwan, many universities have been upgraded to accelerate the commercialization of academic research results, including National Taiwan University, National Tsing Hua University, and National Chiao Tung University (Mathews and Hu, 2007).

As mentioned before, academics, dedicated to basic research, serve as suppliers of innovations for economic growth. Adequate *invention disclosures* become a key to establishing an intellectual property inventory for university technology transfer or licensing. Several empirical analyses have demonstrated the significance of invention disclosures for university technology transfer activity (Carlsson and Fridh, 2002; Siegel et al., 2003; Link and Siegel, 2005; Chapple et al., 2005).

There is still demand for other types of catalysts for successful university technology transfer, in addition to the university administrations' encouragement of university scientists to disclose their inventions. Clarysse et al. (2011) investigate UK universities and reveal that academics who have a high degree of *entrepreneurial capability* and *entrepreneurial experience* will be more involved in entrepreneurial initiatives created by others or in founding entrepreneurial ventures themselves than academics without these capabilities and experiences. Such academic entrepreneurship may facilitate the commercialization of university inventions, especially when the inventors are involved in entrepreneurial activity themselves. Take MIT, for instance, where many faculty members expect to see their inventions realized in the marketplace. In addition, MIT has developed informal internal and external networks between government, industry, and academia (O'Shea et al., 2007). Such *social networks* enable university scientists to access research funding and entrepreneurial expertise and can serve as another catalyst for successful technology transfer (Siegel et al., 2003; Lockett et al., 2005).

To enhance the value of a given invention disclosure, university technology transfer offices will decide whether to apply for a patent. As mentioned in the previous section, university technology transfer offices may need to maximize the market value of the invention by seeking appropriate global patent protection to construct a patent portfolio. Lichtenthaler and Ernst (2010) found that firms with strong *patent portfolios* have better licensing performance. Universities could improve their licensing performance through stronger patent portfolios as well. Moreover, university inventions from academic research are highly variable in terms of commercial potential. *Proofs and prototypes* beyond lab-scale inventions are effective in reducing the technological uncertainty for university scientists in applying for licensing or spinning-off a company successfully (Rasmussen and Sørheim, 2012). Jensen and Thursby (2001) surveyed 62 U.S. universities and found that over 75% of the inventions have proof of concept or lab-scale prototype at the time of licensing. Therefore, university inventions with proofs and prototypes, which require less commercializing development, are better able to draw entrepreneurs and venture capitalists' attentions.

4. Methodology

To determine the key factors driving Taiwan's commercialization of university technology, it is necessary to verify the appropriateness of the factors extracted from related literature in accordance with Taiwan's university research context. Thus, this study attempts to evaluate the appropriateness of the extracted factors before determining their relative importance. The fuzzy Delphi method is employed to survey experts' opinions to ensure the appropriateness of the factors extracted from the literature. Many studies have adopted the fuzzy Delphi method to verify the appropriateness of elements for subsequent multi-criteria decision-making techniques, such as analytic hierarchy process (AHP) (Shen et al., 2010; Horng et al., 2011) and ANP (Lee et al., 2010a; Wang et al., 2013).

ANP is a generalization of AHP (Saaty, 1996) designed to reflect the interdependence and feedback between elements (Lee et al., 2009). However, the difficulty of using ANP lies in determining the dependencies and feedback loops between factors. To address this challenging decision-making issue, scholars suggest adopting ISM for determining the interrelationship through expert survey (Yang et al., 2008; Kannan et al., 2009; Lee et al., 2010a). Several studies have combined ISM with ANP to derive the relative importance of interdependent elements in a complex environment (Singh et al., 2003; Thakkar et al., 2007; Lee et al., 2010a). The three methods mentioned earlier are elaborated upon as follows.

4.1. Fuzzy Delphi method

The process of the fuzzy Delphi method is briefly explained as follows. The experts' opinions on the performance drivers of university technology transfer are collected by questionnaire and are converted into triangular fuzzy numbers by Eq. (1):

$$\widetilde{W}_k = (a_k, b_k, c_k) \quad (1)$$

where $\widetilde{W}_k$ is the fuzzy number of performance driver k, a_k is the minimum of the experts' evaluation, b_k denotes the geometric mean of the experts' evaluation, and c_k presents the maximum of the experts' evaluation.

The center-of-gravity method is commonly used (Klir and Folger, 1988), where S_k denotes the clear value in Eq. (2):

$$S_k = \frac{a_k + b_k + c_k{}^k}{3} \quad (2)$$

Finally, researchers select the appropriate factors according to the needs of the study. The principles are as follows:

(1) If $S_k \geq \lambda$ then accept factor k.
(2) If $S_k < \lambda$ then omit factor k.

4.2. Interpretive structural modeling

The procedure of ISM is elaborated as follows (Warfield, 1973a,b; Yang et al., 2008; Lee et al., 2010a). The first step of ISM is to identify the interrelation among elements. With an expert panel survey, an adjacency matrix is constructed to present the interrelation between any two elements in both directions between element e_i and e_j. If element e_j is reachable from e_i, then $\pi_{ij} = 1$; otherwise, $\pi_{ij} = 0$. There could be four types of relationship between any two elements x_i and x_j in the adjacency matrix **D**, i.e. from x_i to x_j, from x_j to x_i, in both directions between x_i and x_j, or no relationship between x_i and x_j (Lee et al., 2010a). Hence, π_{ij} is not necessarily equal to π_{ji}, and the adjacency matrix **D** is not necessarily symmetric. The adjacency matrix **D** can be shown as follows:

$$\mathbf{D} = \begin{array}{c} \\ e_1 \\ e_2 \\ \vdots \\ e_n \end{array} \begin{array}{c} \begin{array}{cccc} e_1 & e_2 & \cdots & e_n \end{array} \\ \begin{bmatrix} 0 & \pi_{12} & \cdots & \pi_{1n} \\ \pi_{21} & 0 & \cdots & \pi_{2n} \\ \vdots & \vdots & 0 & \vdots \\ \pi_{n1} & \pi_{n2} & \cdots & 0 \end{bmatrix} \end{array}, i = 1, 2, \ldots, n; j = 1, 2, \ldots, n \quad (3)$$

where π_{ij} denotes the interrelation between the ith row and the jth column elements.The adjacency matrix **D** is a structural self-interactive matrix. A basic assumption of ISM is the transitivity of contextual relation, which means that if an element e_i is related to e_j and e_j is related to e_k, then e_i is necessarily related to e_k. After the construction of adjacency matrix, the matrix **D** needs to be converted into a reachability matrix. The initial reachability matrix **M** is then calculated using Eq. (4):

$$\mathbf{M} = \mathbf{D} + \mathbf{I} \quad (4)$$

where **I** denotes the identity matrix. Finally, the reachability matrix $\mathbf{M^*}$ can be obtained through the operation of the Boolean multiplication and addition, and a convergence can be met with Eq. (5):

$$\mathbf{M}^* = \mathbf{M}^b = \mathbf{M}^{b+1}, b > 1 \quad (5)$$

Note that this study focuses on the network relationship among the performance drivers and then weighs their relative importance, rather than the hierarchical structure of these drivers. Therefore, Huang et al. (2005) and Lee et al. (2010a) who adopted similar methods suggest that the procedure of ISM to determine the levels among factors could be ignored.

4.3. Analytic network process

The ANP is the general form of the analytic hierarchy process (AHP) (Saaty, 1996). The AHP desires to find the weights of the elements, w_1, …, w_n, the hierarchical structure constructed by researchers. A nine-point scale recommended by Saaty (1980) is adopted to obtain experts' opinions—with preferences between alternatives given as equally, moderately, strongly, very strongly, or extremely preferred (with pairwise weights of 1, 3, 5, 7, and 9, respectively)—and values of 2, 4, 6, and 8 as the intermediate values for the preference scale. A pairwise comparison can be represented by a reciprocal matrix **A** as Eq. (6):

$$\mathbf{A} = \left[a_{ij}\right] = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ a_{21} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & 1 \end{bmatrix} = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ 1/a_{12} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/a_{1n} & 1/a_{2n} & \cdots & 1 \end{bmatrix} \quad (6)$$

where a_{ij} denotes the number indicating the strength of element i when compared with element j. To ensure that the priority of elements is consistent, the eigenvalues and eigenvectors are calculated using Eq. (7):

$$\mathbf{A} \cdot \mathbf{w} = \lambda_{\max} \cdot \mathbf{w} \quad (7)$$

where $\boldsymbol{w}$ is the eigenvector of the matrix **A**, and $\lambda_{\max}$ is the largest eigenvalue of the matrix **A**. The eigenvector **w** can be obtained by Eq. (8):

$$\mathbf{w} = \left(\prod_{j=1}^{n} a_{ij}\right)^{1/n} \Bigg/ \sum_{i=1}^{n} \left(\prod_{j=1}^{n} a_{ij}\right)^{1/n} \quad (8)$$

where n is the number of elements being compared in this matrix. The largest eigenvalue $\lambda_{\max}$ of **A** can be estimated by using Eq. (9):

$$\lambda_{\max} = \frac{1}{n} \sum_{i=1}^{n} \frac{(\mathbf{Aw})_i}{w_i} \quad (9)$$

As to the ANP, the pairwise comparisons of elements in the entire system form a supermatrix. The general form of the supermatrix is shown as Eq. (10):

$$\mathbf{A} = \begin{array}{cc} & \\ C_1 & \begin{array}{c} e_{11} \\ e_{12} \\ \vdots \\ e_{1t_1} \end{array} \\ C_2 & \begin{array}{c} e_{21} \\ \vdots \\ e_{2t_2} \end{array} \\ C_s & \begin{array}{c} e_{s1} \\ \vdots \\ e_{st_s} \end{array} \end{array} \begin{array}{c} \begin{array}{ccc} C_1 & C_2 & C_s \\ e_{11} \cdots e_{1t_1} & e_{21} \cdots e_{2t_2} & e_{s1} \cdots e_{st_s} \end{array} \\ \begin{bmatrix} \mathbf{A}_{11} & \mathbf{A}_{12} & \cdots & \mathbf{A}_{1m} \\ \mathbf{A}_{21} & \mathbf{A}_{22} & \cdots & \mathbf{A}_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{A}_{s1} & \mathbf{A}_{s2} & \cdots & \mathbf{A}_{ss} \end{bmatrix} \end{array} \quad (10)$$

where C_s denotes the sth cluster, e_{st} denotes the tth element in the sth cluster, and matrix $\mathbf{A}_{ss'}$ is the principal eigenvector of the influence of the elements compared in the sth cluster to the s' th cluster. In ANP, the interaction and feedback present within clusters, C_s, which is defined as inner dependence, and between clusters, which is defined as outer dependence. The supermatrix represents the impact of all model elements relative to the complete element set. The elements consisting of the columns ($\mathbf{A}_{ss'}$) of the supermatrix are the eigenvector solutions within the components. Since there usually is interdependence among clusters, the columns of a supermatrix usually sum to more than one. The supermatrix must be normalized to make it stochastic, that is, each column of the matrix sums to unity. The final priority weights of decision elements, which account for element interactions, can be obtained by multiplying the supermatrix by itself until the columns stabilize (Niemira and Saaty, 2004).

5. Empirical analysis

In this study, the relative importance of each performance driver is acquired through three procedures. First, the fuzzy Delphi method is applied to evaluate the appropriateness of performance drivers extracted from related literature. In the second step, the ISM is utilized to identify the interdependent relationship among the appropriate performance drivers for the subsequent ANP. Finally, the ANP is used in this study to identify relative importance of each performance driver, based on the network relationship established by the ISM. The process is elaborated as follows.

5.1. Verify the appropriateness of performance drivers

As the existing studies indicate that numerous factors could affect the performance of university technology transfer, it is necessary to evaluate the appropriateness of these factors for subsequent analysis to fit Taiwan's university context. As mentioned before, the fuzzy Delphi method effectively converges the diversified experts' opinions without costly and time-consuming repetitive surveys. The expert panel this study surveys consists of 12 senior specialists with an average of 7-years' experience in the activities of university technology transfer and 12 directors of university technology units who are served by the full-time professors with at least 10-year experience involving university technology transfer. These respondents' evaluations on the appropriateness of performance drivers are converted using the linguistic variables shown in Table 2.

The fuzzy numbers of respondents' opinions are calculated using Eq. (1) to obtain the fuzzy number of each performance driver as presented in Table 3. The center-of-gravity method is employed to convert the fuzzy number into a crisp value with Eq. (2), as shown in Table 3. To eliminate the inappropriate performance drivers, a threshold value needs to be determined for the fuzzy Delphi method. The threshold value will affect the number of selected performance drivers for the subsequent analysis. If the threshold value is higher, there will be fewer remaining factors so that the following analysis might be affected. Therefore, the surveyed experts suggest the quartile of crisp value, i.e., 5.25, as the threshold value. Six performance drivers—faculty size, size of scientific and technological departments, size of postdoc staff and full-time researchers, university's location, entrepreneurship development programs, and entrepreneurial experience—are eliminated, based on the suggested threshold value. The evaluation of appropriate performance drivers is presented in Table 3.

Table 2
Linguistic scales.

Linguistic variables	Corresponding triangular fuzzy number
Very poor	(1,1,3)
Poor	(1,3,5)
Fair	(3,5,7)
Good	(5,7,9)
Very good	(7,9,9)

5.2. Construct the network relationship among performance drivers

As mentioned in the previous section, application of the ANP aims to reflect the interdependent relationships found in the real world. Several studies suggest that the ISM facilitates network building for the subsequent ANP (Singh et al., 2003; Huang et al., 2005; Thakkar et al., 2007; Lee et al., 2010a). Thus, the ISM is applied to detect the interrelationship among different dimensions for establishing the network of performance drivers in the second step. The same expert panel surveyed in the previous step is employed to determine the interrelationship among the different dimensions. Then, the geometric mean of experts' opinions on the relationship between a pair of performance drivers is calculated to synthesize their diverse judgments. The mean of experts' opinions, i.e., 0.74, is suggested by the expert panel to be the threshold value for synthesizing their responses. That is, an adjacency matrix is prepared for each expert first, and a mean adjacency matrix is calculated using the arithmetic mean to integrate adjacency matrices from all experts. If the arithmetic mean between two drivers (π_{ij}) in the mean adjacency matrix is higher than the threshold value, x_j is deemed reachable from x_i, and π_{ij} equals to 1 (Lee et al., 2010a). The integrated adjacency matrix is obtained and is shown as Table 4.

5.3. Identify the relative importance of performance drivers

According to the analysis of ISM presented in Table 4, a network structure can be derived to illustrate the interdependent relationships between the four dimensions, as shown in Fig. 1. This network structure shown in Fig. 1 serves as the control hierarchy that describes the interactions between performance drivers in this study. Based on this network structure, the pairwise comparison matrices can be established. In this step, 24 respondents of the same expert panel are surveyed to determine the relative importance of performance drivers. Before calculating the unweighted supermatrix of ANP, the consistency index (C.I.) and consistency ratio (C.R.) suggested by Saaty (1980) are used to check the consistency of pairwise comparison matrices in this study. The values of C.I. and C.R. are less than 0.1, which conforms to the consistency threshold defined by Saaty (1980).

To take into account the interdependent relationships between performance drivers, the ANP method is employed in this study to derive the relative importance of the various

Table 3
The appropriateness of performance drivers.

Dimensions	Performance drivers	Fuzzy numbers	Crisp value	Result
Human resources	Faculty quality (i_1)	(3.00, 8.05, 9.00)	6.68	
	Faculty size	(1.00, 5.07, 9.00)	5.02	Canceled
	Size of scientific and technological departments	(1.00, 5.73, 9.00)	5.24	Canceled
	Size of postdoc staff and full-time researchers	(1.00, 5.55, 9.00)	5.18	Canceled
	Size of technology transfer offices (i_2)	(3.00, 7.27, 9.00)	6.42	
Institutional/culture resources	Culture and tradition (i_3)	(5.00, 7.94, 9.00)	7.31	
	Experience of technology transfer offices (i_4)	(5.00, 7.77, 9.00)	7.26	
	University's location	(1.00, 5.40, 9.00)	5.13	Canceled
	Incentive policy (i_5)	(1.00, 7.74, 9.00)	6.58	
	Interdisciplinary research (i_6)	(1.00, 5.85, 9.00)	5.28	
	Entrepreneurship development programs	(1.00, 4.83, 9.00)	4.94	Canceled
Financial resources	Industry funding (i_7)	(3.00, 7.43, 9.00)	6.48	
	Government funding (i_8)	(3.00, 7.10, 9.00)	6.37	
	Expenditure on associated intellectual property protection (i_9)	(3.00, 7.48, 9.00)	6.49	
	Funding on intellectual property commercialization (i_{10})	(3.00, 7.56, 9.00)	6.52	
Commercial resources	Incubators (i_{11})	(1.00, 6.27, 9.00)	5.42	
	Invention disclosures (i_{12})	(1.00, 5.91, 9.00)	5.30	
	Entrepreneurial capability (i_{13})	(1.00, 5.93, 9.00)	5.31	
	Entrepreneurial experience	(1.00, 5.41, 9.00)	5.14	Canceled
	Social network (i_{14})	(1.00, 6.21, 9.00)	5.40	
	Patent portfolios (i_{15})	(3.00, 7.94, 9.00)	6.65	
	Proofs and prototypes (i_{16})	(3.00, 7.88, 9.00)	6.63	

performance drivers. As we see, the dimension of institution/culture resources has no interaction with the other dimensions, based on the network structure shown as Fig. 1. To elaborate upon the detailed derivation of priority weights of performance drivers, the calculation on weights of performance drivers is divided into three sequential steps. The first step computes the weights of four dimensions in the control hierarchy. The second step establishes the pairwise comparisons for performance drivers and then calculates the local weights of performance drivers within the interdependent dimensions of human capital, financial resources, and commercial resources. The final priority weights of performance drivers within the three interdependent dimensions are then obtained from the limited supermatrix of ANP. Finally, the third step is intended to obtain the weights of performance drivers within the independent dimension of institutional/culture resources by the standard application of AHP. The following is the process to solve the ANP for identifying the performance drivers.

5.3.1. Determine the weights of dimensions

The first step establishes the pairwise comparison matrices to derive the weights of the four main dimensions using Eq. (6) through Eq. (9). The pairwise comparisons are used to derive the priority weights if there is feedback in the cluster, i.e. dimension; if not, the matrix entry is zero. Based on the control hierarchy illustrated in Fig. 1, the institutional/culture resources do not receive feedback from other three dimensions. Accordingly, the entries for this dimension in the control matrix presented in the last panel of Table 5 are zero. On the other hand, the feedback relationship exists in the human capital, financial resources, and commercial resources. The same nine-point scale mentioned in the Section 4.3 is used to express the pairwise comparisons made by the 24 respondents. The C.I. and C.R. are employed to check consistency of respondents' pairwise comparisons. If the C.I. and C.R. exceed 0.1 which is the consistency threshold suggested by Saaty (1980), the respondents will be asked to repeat their judgments until both C.I. and C.R. are less than 0.1. This study then adopts the weighted geometric mean method, suggested by Xu (2000), to aggregate the surveyed respondents' judgments. The first through the fourth panel in Table 5 presents the pairwise comparison matrices and relative importance weights of four main dimensions toward these dimensions, respectively. The last panel in Table 5 reveals the control matrix in this study.

5.3.2. Determine the pairwise comparisons for performance drivers and construct the supermatrix

The second step determines the element weights within each cluster, i.e. the four dimensions, by applying AHP. Likewise, the pairwise comparisons are established by using Eq. (6) to represent the relationships among performance drivers within each dimension. The priority weights of performance drivers within a given dimension, which will be used in the unweighted supermatrix, then can be obtained by using Eq. (7) through Eq. (9). To demonstrate this process, consider an evaluation of pairwise comparison within the

Table 4
Adjacency matrix between dimensions.

$\mathbf{M}^*$	Human resources	Institutional/culture resources	Financial resources	Commercial resources
Human resources	1	0	1	1
Institutional/culture resources	1	1	1	1
Financial resources	1	0	1	1
Commercial resources	1	0	1	1

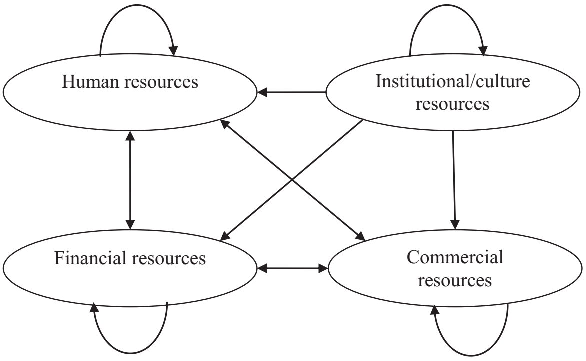

Fig. 1. Network structure of dimensions.

commercial resources block of the ANP model. Again, the same 15 experts are surveyed to pairwisely compare the relative importance of performance drivers within commercial resources under the objective of faculty quality. The C.I. and C.R. are used to check the consistency of respondents' judgments. They will be asked to repeat their evaluations until the C.I. and C.R. are less than 0.1, if the values of C.I. and C.R. exceed the threshold value. The importance weights of performance drivers within commercial resources with respect to faculty quality are then derived by using Eq. (7) through Eq. (9). The pairwise comparison matrix in this example and the priority weights are shown as Table 6. The weights of performance drivers of commercial resources with respect to faculty quality are input into the commercial resources block at the bottom of unweighted supermatrix, as shown in Table 7. The unweighted supermatrix of ANP is composed of sub-matrices derived by the process demonstrated in this example. If there is no dependent relation between two elements, the pairwise comparison value equals zero. Huang et al. (2005) suggest simply placing 1 in diagonal elements to create a feedback effect. The unweighted supermatrix is then multiplied by the priority weights of the four dimensions that are determined in the step 1 and presented in the last panel of Table 5. The weighted supermatrix is then yielded and shown in Table 8. Finally, the solution is derived by multiplying the weighted supermatrix by itself until the system's row values converge to the same value

Table 6
Pairwise comparison matrix for commercial resources with respect to faculty quality.

	i_{11}	i_{12}	i_{13}	i_{14}	i_{15}	i_{16}	Weights
i_{11}	1.00000	0.62329	0.60095	0.74292	0.36935	0.34070	0.08743
i_{12}	1.60438	1.00000	0.91697	1.35277	0.51904	0.45903	0.13498
i_{13}	1.66402	1.09054	1.00000	0.96206	0.66817	0.35957	0.13225
i_{14}	1.34605	0.73923	1.03944	1.00000	0.43357	0.45959	0.11748
i_{15}	2.70743	1.92665	1.49662	2.30643	1.00000	1.17346	0.25415
i_{16}	2.93514	2.17848	2.78108	2.17585	0.85218	1.00000	0.27372

Table 5
Construct the control matrix.

With respect to human capital

	Human capital	Financial capital	Commercial resources	Weights
Human capital	1.00000	1.86837	1.92969	0.48699
Financial capital	0.53523	1.00000	1.03282	0.26065
Commercial resources	0.51822	0.96822	1.00000	0.25237

With respect to institutional/culture resources

	Human capital	Institutional/culture resources	Financial resources	Commercial resources	Weights
Human capital	1.00000	1.45066	2.37800	1.69124	0.37433
Institutional/culture resources	0.68934	1.00000	1.09704	1.12509	0.23133
Financial resources	0.42052	0.91155	1.00000	1.24899	0.20035
Commercial resources	0.59128	0.88882	0.80065	1.00000	0.19399

With respect to financial resources

	Human capital	Financial capital	Commercial resources	Weights
Human capital	1.00000	1.86045	1.93029	0.48649
Financial capital	0.53750	1.00000	1.03754	0.26149
Commercial resources	0.51806	0.96382	1.00000	0.25203

With respect to commercial resources

	Human capital	Financial capital	Commercial resources	Weights
Human capital	1.00000	1.87391	1.94060	0.48806
Financial capital	0.53364	1.00000	1.03559	0.26045
Commercial resources	0.51531	0.96564	1.00000	0.25150

Control matrix

	Human capital	Institutional/culture resources	Financial resources	Commercial resources
Human capital	0.48699	0.37433	0.48649	0.48806
Institutional/culture resources	0.00000	0.23133	0.00000	0.00000
Financial resources	0.26065	0.20035	0.26149	0.26045
Commercial resources	0.25237	0.19399	0.25203	0.25150

Table 7
Unweighted supermatrix.

	i_1	i_2	i_3	i_4	i_5	i_6	i_7	i_8	i_9	i_{10}	i_{11}	i_{12}	i_{13}	i_{14}	i_{15}	i_{16}
i_1	1.000	0.000	0.500	0.167	0.167	0.875	0.660	0.632	0.539	0.531	0.523	0.586	0.662	0.545	0.448	0.685
i_2	0.000	1.000	0.500	0.833	0.833	0.125	0.340	0.368	0.461	0.469	0.477	0.414	0.338	0.455	0.552	0.315
i_3	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
i_4	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
i_5	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
i_6	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
i_7	0.261	0.327	0.207	0.051	0.138	0.158	1.000	0.000	0.000	0.000	0.279	0.257	0.262	0.334	0.266	0.284
i_8	0.291	0.219	0.293	0.232	0.525	0.195	0.000	1.000	0.000	0.000	0.244	0.224	0.205	0.208	0.205	0.208
i_9	0.210	0.212	0.293	0.184	0.053	0.047	0.000	0.000	1.000	0.000	0.209	0.237	0.232	0.201	0.267	0.198
i_{10}	0.238	0.241	0.207	0.533	0.284	0.599	0.000	0.000	0.000	1.000	0.269	0.282	0.302	0.256	0.262	0.310
i_{11}	0.087	0.107	0.145	0.111	0.096	0.056	0.097	0.087	0.113	0.113	1.000	0.000	0.000	0.000	0.000	0.000
i_{12}	0.135	0.139	0.112	0.092	0.181	0.182	0.131	0.116	0.134	0.115	0.000	1.000	0.000	0.000	0.000	0.000
i_{13}	0.132	0.131	0.093	0.080	0.088	0.051	0.151	0.131	0.106	0.121	0.000	0.000	1.000	0.000	0.000	0.000
i_{14}	0.117	0.120	0.031	0.038	0.056	0.100	0.141	0.130	0.152	0.183	0.000	0.000	0.000	1.000	0.000	0.000
i_{15}	0.254	0.284	0.146	0.206	0.239	0.182	0.259	0.277	0.242	0.230	0.000	0.000	0.000	0.000	1.000	0.000
i_{16}	0.274	0.219	0.472	0.473	0.341	0.428	0.222	0.259	0.251	0.238	0.000	0.000	0.000	0.000	0.000	1.000

for each column of the matrix. This process generates the limiting supermatrix and indicates the relative importance weights for every performance driver within the dimensions of human capital, financial resources, and commercial resources.

5.3.3. Determine the weights of performance drivers within independent dimension

The third step is intended to obtain the weights of performance drivers within the independent dimension of institutional/culture resources by pairwise comparison, as in the process from Eq. (6) through Eq. (9) mentioned in the previous section. Table 9 presents the final priority weights which are composed of performance drivers within interdependent human capital, financial resources, and commercial resources and the independent dimension of institutional/culture resources.

5.4. Discussions

As presented in Table 9, human capital (0.374) is the most emphasized dimension, with institutional/culture resources (0.231), financial resources (0.200), and commercial resources (0.194) rank second, third, and fourth, respectively. Within the dimension of human capital, faculty quality is the most important performance driver to improve the performance of university technology transfer. In many empirical studies, faculty quality is identified as the key factor driving the performance of university technology transfer (Thursby and Kemp, 2002; O'Shea et al., 2005, 2007). This result is consistent with the work of Chang et al. (2006) as well. In Taiwan, public universities are traditionally endowed with adequate research resources and government funding. Hence, they have the higher social legitimacy necessary to attract the eminent scientists who then go on to incubate innovative knowledge (Chang et al., 2006). These findings reinforce the empirical work by Mathews and Hu (2007) and Hsu and Yuan (2013) that Taiwan's public research-oriented universities are ideal for producing patents and incubating the innovative capacity for industry.

The size of technology transfer offices (0.203) ranks second within the dimension of human capital. This finding reinforces the importance of the professional competence of the staff of technology transfer offices, as highlighted by the empirical studies of Rogers et al. (2000), Foltz et al. (2000), Thursby and Kemp (2002), Lach and Schankerman (2004), and O'Shea et al. (2005). Technology transfer in the university is a complex and

Table 8
Weighted supermatrix.

	i_1	i_2	i_3	i_4	i_5	i_6	i_7	i_8	i_9	i_{10}	i_{11}	i_{12}	i_{13}	i_{14}	i_{15}	i_{16}
i_1	0.487	0.000	0.187	0.062	0.062	0.328	0.321	0.308	0.263	0.259	0.255	0.285	0.322	0.265	0.218	0.334
i_2	0.000	0.487	0.187	0.312	0.312	0.047	0.166	0.179	0.224	0.228	0.232	0.202	0.165	0.222	0.269	0.153
i_3	0.000	0.000	0.231	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
i_4	0.000	0.000	0.000	0.231	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
i_5	0.000	0.000	0.000	0.000	0.231	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
i_6	0.000	0.000	0.000	0.000	0.000	0.231	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
i_7	0.068	0.085	0.059	0.010	0.028	0.032	0.261	0.000	0.000	0.000	0.073	0.067	0.068	0.087	0.069	0.074
i_8	0.076	0.057	0.041	0.046	0.105	0.039	0.000	0.261	0.000	0.000	0.064	0.058	0.053	0.054	0.053	0.054
i_9	0.055	0.055	0.055	0.037	0.011	0.009	0.000	0.000	0.261	0.000	0.054	0.062	0.066	0.052	0.070	0.051
i_{10}	0.062	0.063	0.041	0.107	0.057	0.120	0.000	0.000	0.000	0.261	0.070	0.073	0.079	0.067	0.068	0.081
i_{11}	0.022	0.027	0.028	0.021	0.019	0.011	0.024	0.022	0.029	0.029	0.252	0.000	0.000	0.000	0.000	0.000
i_{12}	0.035	0.035	0.022	0.018	0.035	0.035	0.033	0.029	0.034	0.029	0.000	0.252	0.000	0.000	0.000	0.000
i_{13}	0.033	0.033	0.018	0.016	0.017	0.010	0.038	0.033	0.027	0.031	0.000	0.000	0.252	0.000	0.000	0.000
i_{14}	0.030	0.030	0.006	0.007	0.011	0.019	0.036	0.033	0.038	0.046	0.000	0.000	0.000	0.252	0.000	0.000
i_{15}	0.064	0.072	0.028	0.040	0.046	0.035	0.065	0.070	0.061	0.058	0.000	0.000	0.000	0.000	0.252	0.000
i_{16}	0.069	0.055	0.092	0.092	0.067	0.083	0.056	0.065	0.063	0.060	0.000	0.000	0.000	0.000	0.000	0.252

Table 9
Weights of performance drivers.

Performance drivers	Weights	Ranking within dimension
Human capital	0.374	
Faculty quality	0.284	1
Size of technology transfer offices	0.203	2
Financial resources	0.200	
Industry funding	0.074	1
Government funding	0.064	3
Expenditure on associated intellectual property protection	0.056	4
Funding on intellectual property commercialization	0.066	2
Commercial resources	0.194	
Incubators	0.025	6
Invention disclosures	0.033	4
Entrepreneurial capability	0.033	5
Social network	0.045	3
Patent portfolios	0.066	1
Proofs and prototypes	0.062	2
Institutional/culture resources	0.231	
Culture and tradition	0.208	3
Experience of technology transfer offices	0.288	2
Incentive policy	0.367	1
Interdisciplinary research	0.137	4

time-consuming job, which includes identifying, sourcing, and exploiting university technologies for commercial exploitation (O'Shea et al., 2005). Nevertheless, investigation by Chang et al. (2008) reveals that 64.7% of the employees in Taiwan's university technology transfer offices are contract workers. The turnover rate of contract workers is higher, and their expertise is insufficient to deal with the complexity of technology transfer for universities. Therefore, expanding the number of full-time employees should be critical for Taiwan's university technology transfer.

Industry funding (0.074) is identified as the most critical performance driver within the dimension of financial resources. The importance of industry funding is supported by the findings of Chang et al. (2006), which highlight the positive influence of contract research and collaborative research upon technology licensing creation in Taiwan's universities. Funding on intellectual property commercialization (0.066) ranks second within the same dimension. This result implies that industrial support contributes more substantial incomes for universities. Furthermore, university inventions supported by industry funding need sufficient financial resources allocated to their commercialization.

Incentive policies (0.367) and the experience of technology transfer offices (0.288) are the two most critical drivers within the dimension of institutional/culture resources. The importance of incentive policy in this study is consistent with the works of Friedman and Silberman (2003) and Lach and Schankerman (2004) that emphasize the positive effect of university incentive policy for enhancing the scientists' willingness to involve themselves in technology transfer. Since the effort of technology transfer competes in time against university researchers' major mission of basic research and publishing papers, a greater incentive policy would encourage scientists to dedicate greater efforts to technology transfer.

The technology transfer offices of Taiwan's universities need to organize patenting, technology licensing, creating spin-offs, incubation, etc. to exploit university inventions. Experienced technology transfer staff members are best able to engage in this complex work. Therefore, the experience of technology transfer offices is identified as one of the key performance drivers in this study, which echoes the empirical work by Rogers et al. (2000), Carlsson and Fridh (2002), and Friedman and Silberman (2003).

Patent portfolios (0.066) and proofs and prototypes (0.062) are the two most emphasized drivers within the dimension of commercial resources. Knowledge developed in universities is too general to address the specific knowledge needs in industry (Gilsing et al., 2011). This is due to the fact that the knowledge generated by university scientists originates from basic research. A strong patent portfolio facilitates product development based on the given technology (Lichtenthaler and Ernst, 2010). In addition, proof-of-concept projects and prototypes tend to reduce technological uncertainty (Rasmussen and Sørheim, 2012). These mechanisms for reducing technological uncertainty can enhance the willingness of enterprises to exploit the technologies developed by universities.

Nevertheless, some performance drivers are distributed with lower importance weightings that are somewhat inconsistent with past findings in the literature. Expenditures on intellectual property protection (0.056), incubators (0.025), and interdisciplinary research (0.137) are the least emphasized drivers in financial resources, commercial resources, and institutional/culture resources, respectively. By contrast, Chapple et al. (2005) report that the expenditure of intellectual property protection positively influences licensing income. In the work of Lockett et al. (2005), intellectual property protection expenditures raise the number of spin-out companies derived from public research institutions. Markman et al. (2005) indicate that the incubator is an effective mechanism to transfer technological innovations from academia to startup firms. Moreover, O'Shea et al. (2007) and Nelson (2012) report that interdisciplinary research facilitates technology innovation and entrepreneurship. These phenomenon might result from Taiwan's universities being dedicated to basic research in pursuit of academic publications rather than being dedicated to applied research. The respondents perceive that universities should strive for industry funding to increase innovations for industrial use in the current circumstance of Taiwanese universities, instead of seeking legal protections for universities' innovation inventory. After the passage of Taiwan's Fundamental Science and Technology Act, over 56% of universities have established incubators (90 incubators). Thus, the importance of incubators is less than that of other measures in the transfer of university innovations. Moreover, Taiwanese universities have tended to establish interdisciplinary research centers to facilitate cooperation and secure research funding. Interdisciplinary research, hence, is not the primary driver in institutional/culture resources under current circumstances.

6. Conclusions and limitations

University technology transfer attempts to disseminate innovative knowledge and technologies to enterprises through various mechanisms, such as high-tech spin-offs, collaborative research, contract research, know-how based consulting, technology licensing, education, training for enterprise staff, and exchange of research staff between enterprises and research institutes. As mentioned in Section 2, many empirical studies use a set of quantitative proxies to reflect the overall picture of activities in university technology transfer. This study is intended to identify the relative importance of performance drivers in enhancing the outcome of university technology transfer by improving internal administration processes and procedures. This study integrates the fuzzy Delphi method, ISM, and the ANP to identify the weights of each performance driver.

6.1. Policy implications

Based on the previous analysis, some policy implications can be derived as follows.

(1) The human capital of a university is the key to the performance of university technology transfer. Public universities in Taiwan possess sufficient research resources provided by the government to employ eminent scientists. Funding programs supported by the government, such as the Aim for the Top University Project (Study in Taiwan, 2013), should be continued. Private universities in Taiwan can concentrate their resources on strengthening their faculty quality in some specific technology fields and on establishing joint technology transfer organizations through collaborations.

(2) With regard to financial resources, research projects funded by enterprises tend to exploit the output for industrial applications. Technology transfer can be enhanced by increased expenditures on contract research and collaboration research. Expenditures on intellectual property commercialization facilitate the exploitation of university inventions by industry. Similar inferences can be drawn based on the analysis demonstrating the importance of patent portfolios and proofs and prototypes in the dimension of commercial resources. University administrators, therefore, should consider encouraging faculty to involve themselves in activities related to technology transfer. Strengthening the university network with industry and the government might be a feasible approach for university administrators to directly or indirectly draw industry and government funding. For example, National Taiwan University raised 20 million US dollars from its alumni as the seed fund to commercialize innovations generated on campus. Similarly, other universities could increase their budgets for university scientists to strengthen their patent portfolios and convert their research outcomes into proof-of-concept prototypes.

(3) As demonstrated in this analysis, university-wide incentive policies providing attractive rewards encourages faculty members to get involved in technology development for industrial exploitation. Nevertheless, the criteria of university faculty promotion in Taiwan tend to emphasize academic publications. It is necessary to revise promotion and tenure guidelines to encourage and reward knowledge and technology dissemination, and thus enhance technology spillover. In addition, professional training for the staffs of university technology transfer offices is crucial. Experienced staff can better conduct the complex work of technology transfer, such as identifying, sourcing, and utilizing university technologies for commercial exploitation.

6.2. Research limitations and future research suggestions

Despite the interdependent structure among performance drivers being determined by ISM, there is still the concern that these relationships may vary if the expert panel is changed, due to the fact that the fuzzy Delphi method relies heavily on the experts' evaluations. The studies exploring the reliability of fuzzy Delphi method are extremely deficient. Therefore, one may need to recognize this limitation when applying the results obtained in this study. In future works, it will be necessary to survey additional panels of experts to compare the results with the outcomes of this study. This will allow for the further refinement of our understanding of the key performance drivers necessary for successful university technology transfer in Taiwan.

This study only identifies the relative importance of each performance driver, and afterward raises some questions for future works. A primary concern for future works might be to explore what it costs to increase each performance driver incrementally in order to improve the cost effectiveness and the ROI of expenditures meant to improve university technology transfer. Second, it is suggested to clarify the roles of university administrators and of the government in the activities of university technology transfer in the context of Taiwan. As a result of such clarity, the university administrators and the Taiwanese government could deploy cost-effective measures to influence the crucial drivers on university technology transfer. Third, it is suggested to further clarify the effects of the various critical performance drivers. Additionally, the barriers to the process of university technology transfer are worth investigating as well. Knowledge of such barriers might help in the construction of effective procedures to facilitate the dissemination of knowledge and technologies developed by Taiwan's universities.

Acknowledgment

This research is supported by the National Science Council Taiwan, under grant NSC 102-2410-H-415-001-MY2. The insightful comments from reviewers are gratefully acknowledged.

References

Allen, T.J., 1977. Managing the Flow of Technology. The MIT Press, Cambridge.
Anderson, T.R., Daim, T.U., Lavoie, F.F., 2007. Measuring the efficiency of university technology transfer. Technovation 27 (5), 306–318.
Anselin, L., Varga, A., Acs, Z., 1997. Local geographic spillovers between university research and high technology innovations. J. Urban Econ. 42 (3), 422–448.
Antonio Cortés-Aldana, F., García-Melón, M., Fernández-de-Lucio, I., Aragonés-Beltrán, P., Poveda-Bautista, R., 2009. University objectives and socioeconomic results: a multicriteria measuring of alignment. Eur. J. Oper. Res. 199 (3), 811–822.
Caldera, A., Debande, O., 2010. Performance of Spanish universities in technology transfer: an empirical analysis. Res. Policy 39 (9), 1160–1173.
Carlsson, B., Fridh, A., 2002. Technology transfer in United States universities: a survey and statistical analysis. J. Evol. Econ. 12 (1–2), 199–232.
Chang, Y.C., Chen, M.H., Hua, M., Yang, P.Y., 2006. Managing academic innovation in Taiwan: towards a "scientific–economic" framework. Technol. Forecast. Soc. Chang. 73 (2), 199–213.
Chang, Y.H., Lin, P.F., Weng, S.Y., 2008. Exploring the development of the organizations and staffs of technology transfer in the universities and R&D institutions of Taiwan. Commer. Manag. Q. 9 (4), 525–545.
Chang, Y.C., Yang, P.Y., Chen, M.H., 2009. The determinants of academic research commercial performance: towards an organizational ambidexterity perspective. Res. Policy 38 (6), 936–946.

Chapple, W., Lockett, A., Siegel, D., Wright, M., 2005. Assessing the relative performance of U.K. university technology transfer offices: parametric and non-parametric evidence, Res. Policy 34 (3), 369–384.
Chugh, H., 2004. New academic venture development: exploring the influence of the technology transfer office on university spinouts. Working Paper. Tanaka Business School, Imperial College, London.
Clarke, B.R., 1998. Creating Entrepreneurial Universities: Organizational Pathways of Transformation Emerald, Bingley.
Clarysse, B., Tartari, V., Salter, A., 2011. The impact of entrepreneurial capacity, experience and organizational support on academic entrepreneurship. Res. Policy 40 (8), 1084–1093.
Debackere, K., Veugelers, R., 2005. The role of academic technology transfer organizations in improving industry science links. Res. Policy 34 (3), 321–342.
Di Gregorio, D., Shane, S., 2003. Why do some universities generate more start-ups than others? Res. Policy 32 (2), 209–227.
Etzkowitz, H., Leydesdorff, L., 1995. The triple helix—university–industry–government relations: a laboratory for knowledge-based economic development. EASST Rev. 14 (1), 14–19.
Etzkowitz, H., Leydesdorff, L., 2000. The dynamics of innovation: from national systems and "Mode 2" to a triple helix of university–industry–government relations. Res. Policy 29 (2), 109–123.
Foltz, J., Barham, B., Kim, K., 2000. Universities and agricultural biotechnology patent production. Agribusiness 16 (1), 82–95.
Friedman, J., Silberman, J., 2003. University technology transfer: do incentives, management, and location matter? J. Technol. Transf. 28 (1), 17–30.
Geuna, A., Muscio, A., 2009. The governance of university knowledge transfer: a critical review of the literature. Minerva 47 (1), 93–114.
Gibbons, M., Limoges, C., Nowotny, H., Schwartzman, S., Scott, P., Trow, M., 1994. The New Production of Knowledge: The Dynamics of Science and Research in Contemporary Societies. Sage, London.
Gilsing, V., Bekkers, R., Bodas Freitas, I.M., van der Steen, M., 2011. Differences in technology transfer between science-based and development-based industries: transfer mechanisms and barriers. Technovation 31 (12), 638–647.
González-Pernía, J.L., Kuechle, G., Peña-Legazkue, I., 2013. An assessment of the determinants of university technology transfer. Econ. Dev. Q. 27 (1), 6–17.
Guerrero, M., Urbano, D., Cunningham, J., Organ, D., 2014. Entrepreneurial universities in two European regions: a case study comparison. J. Technol. Transf. 39 (3), 415–434.
Henderson, R., Jaffe, A., Trajtenberg, M., 1998. Universities as a source of commercial technology: a detailed analysis of university patenting, 1965–1988. Rev. Econ. Stat. 80 (1), 119–127.
Ho, M.H.C., Liu, J.S., Lu, W.M., Huang, C.C., 2014. A new perspective to explore the technology transfer efficiencies in US universities. J. Technol. Transf. 39 (2), 247–275.
Horng, J.S., Hsu, H., Liu, C.H., Lin, L., Tsai, C.Y., 2011. Competency analysis of top managers in the Taiwanese hotel industry. Int. J. Hosp. Manag. 30 (4), 1044–1054.
Hsu, D.W.L., Yuan, B.J.C., 2013. Knowledge creation and diffusion of Taiwan's universities: knowledge trajectory from patent data. Technol. Soc. 35 (3), 172–181.
Huang, J.J., Tzeng, G.H., Ong, C.S., 2005. Multidimensional data in multidimensional scaling using the analytic network process. Pattern Recogn. Lett. 26 (6), 755–767.
Study in Taiwan, The aim for the top university project. Retrieved August, 15, 2013, from http://www.studyintaiwan.org/top_universities.html.
Jensen, R., Thursby, M., 2001. Proofs and prototypes for sale: the licensing of university inventions. Am. Econ. Rev. 91 (1), 240–259.
Kannan, G., Pokharel, S., Kumar, P.S., 2009. A hybrid approach using ISM and fuzzy TOPSIS for the selection of reverse logistics provider. Resour. Conserv. Recycl. 54 (1), 28–36.
Kaplan, R., Norton, D., 1992. The balance scorecard—measures that drive performance. Harv. Bus. Rev. (January–February), 71–79.
Ken, Y., Chang, Y.H., Chen, Y.S., Weng, S.Y., 2009. The overall investigation of the development of academic institutions' technology transfers in Taiwan. Commer. Manag. Q. 10 (4), 625–646.
Klir, G.J., Folger, T.A., 1988. Fuzzy Sets Uncertainty and Information. Prentice-Hall, New Jersey.
Lach, S., Schankerman, M., 2004. Royalty sharing and technology licensing in universities. J. Eur. Econ. Assoc. 2 (2/3), 252–264.
Landry, R., Amara, N., Ouimet, M., 2007. Determinants of knowledge transfer: evidence from Canadian university researchers in natural sciences and engineering. J. Technol. Transf. 32 (6), 561–592.
Lee, W.S., Tzeng, G.H., Guan, J.L., Chien, K.T., Huang, J.M., 2009. Combined MCDM techniques for exploring stock selection based on Gordon model. Expert Syst. Appl. 36 (3), 6421–6430.
Lee, A.H.I., Wang, W.M., Lin, T.Y., 2010a. An evaluation framework for technology transfer of new equipment in high technology. Technol. Forecast. Soc. Chang. 77 (1), 135–150.
Lee, K.J., Ohta, T., Kakehi, K., 2010b. Formal boundary spanning by industry liaison offices and the changing pattern of university—industry cooperative research: the case of the University of Tokyo. Technol. Anal. Strateg. Manag. 22 (2), 189–206.
Leydesdorff, L., Etzkowitz, H., 1996. Emergence of a Triple Helix of university–industry–government relations. Sci. Public Policy 23 (5), 279–286.
Lichtenthaler, U., Ernst, H., 2010. Integrated knowledge exploitation: the complementarity of product development and technology licensing. Strateg. Manag. J. 33 (5), 513–534.
Link, A.N., Siegel, D.S., 2005. Generating science-based growth: an econometric analysis of the impact of organizational incentives on university–industry technology transfer. Eur. J. Financ. 11 (3), 169–182.
Lockett, A., Wright, M., 2005. Resources capabilities, risk capital and the creation of university spin-out companies. Res. Policy 34 (7), 1043–1057.
Lockett, A., Siegel, D., Wright, M., Ensley, M., 2005. The creation of spin-off firms at public research institutions: managerial and policy implications. Res. Policy 34 (7), 981–993.
Macho-Stadler, I., Martinez-Giralt, X., Pérez-Castrillo, D., 1996. The role of information in licensing contract design. Res. Policy 25 (1), 43–57.
Markman, G.D., Phan, P.H., Balkin, D.B., Gianiodis, P.T., 2005. Entrepreneurship and university-based technology transfer. J. Bus. Ventur. 20 (2), 241–263.
Mathews, J.A., Hu, M.C., 2007. Enhancing the role of universities in building national innovative capacity in Asia: the case of Taiwan. World Dev. 35 (6), 1005–1020.
Matkin, G.W., 1990. Technology Transfer and the University. MacMillan Publishing Company, New York.
Mian, S., 1996. Assessing value-added contributions of university technology business incubators to tenant firms. Res. Policy 25 (3), 325–335.
Mowery, D.C., 1998. The changing structure of the US national innovation system: implications for international conflict and cooperation in R&D policy. Res. Policy 27 (6), 639–654.
Narin, F., Hamilton, K.S., Olivastro, D., 1997. The increasing linkage between U.S. technology and public science. Res. Policy 26 (3), 317–330.
Nelson, A.J., 2012. Putting university research in context: assessing alternative measures of production and diffusion at Stanford. Res. Policy 41 (4), 678–691.
Niemira, M.P., Saaty, T.L., 2004. An analytic network process model for financial-crisis forecasting. Int. J. Forecast. 20 (4), 573–587.
O'Shea, R., Allen, T., Chevalier, A., 2005. Entrepreneurial orientation, technology transfer, and spin-off performance of US universities. Res. Policy 34 (7), 994–1009.
O'Shea, R.P., Allen, T.J., Mores, K.P., O'Gorman, C., Roche, F., 2007. Delineating the anatomy of an entrepreneurial university: the Massachusetts Institute of Technology experience. R D Manag. 37 (1), 1–16.
Powers, J., 2003. Commercializing academic research resource effects on performance of university technology transfer. J. High. Educ. 74 (1), 26–50.
Powers, J., McDougall, P., 2005. University start-up formation and technology licensing with firms that go public: a resource based view of academic entrepreneurship. J. Bus. Ventur. 20 (3), 291–311.
Rasmussen, E., Sørheim, R., 2012. How governments seek to bridge the financing gap for university spin-offs: proof-of-concept, pre-seed, and seed funding. Technol. Anal. Strateg. Manag. 24 (7), 663–678.
Rizzo, U., Ramaciotti, L., 2014. The determinants of academic patenting by Italian universities. Technol. Anal. Strateg. Manag. 26 (4), 469–483.
Rogers, E.M., Yin, Y., Hoffmann, J., 2000. Assessing the effectiveness of technology transfer offices at U.S. research universities. J. Assoc. Univ. Technol. Manag. 12 (47), 80.
Romer, P.M., 1986. Increasing returns and long-run growth. J. Polit. Econ. 94 (5), 1002–1037.
Romer, P.M., 1990. Endogenous technological change. J. Polit. Econ. 98 (5), S71–S102.
Saaty, T.L., 1980. The Analytic Hierarchy Process. McGraw-Hill, New York.
Saaty, T.L., 1996. Decision Making with Dependence and Feedback: The Analytic Network Process. RWS Publications Publishers, Pittsburgh.
Shen, Y.C., Chang, S.H., Lin, G.T.R., Yu, H.C., 2010. A hybrid selection model for emerging technology. Technol. Forecast. Soc. Change 77 (1), 151–166.
Siegel, D.S., Waldman, D., Link, A., 2003. Assessing the impact of organizational practices on the relative productivity of university technology transfer offices: an exploratory study. Res. Policy 32 (1), 27–48.
Siegel, D.S., Waldman, D.A., Atwater, L.E., Link, A.N., 2004. Toward a model of the effective transfer of scientific knowledge from academia to practitioners: qualitative evidence from the commercialization of university technology. J. Eng. Technol. Manag. 21 (1–2), 115–142.
Siegel, D.S., Veugelers, R., Wright, M., 2007. Technology transfer offices and commercialization of university intellectual property: performance and policy implications. Oxf. Rev. Econ. Policy 23 (4), 640–660.
Singh, M.D., Shankar, R., Narain, R., Agarwal, A., 2003. An interpretive structural modeling of knowledge management in engineering industries. J. Adv. Manag. Res. 1 (1), 28–40.
Smilor, R., Gill Jr., M., 1986. The New Business Incubator: Linking Talent, Technology, Capital, and Know-how. Lexington Books, Lexington.

Swamidass, P.M., 2013. University startups as a commercialization alternative: lessons from three contrasting case studies. 38 (6), 788–808.
Thakkar, J., Deshmukh, S., Gupta, A.D., Shankar, R., 2007. Development of a balanced scorecard: an integrated approach of interpretive structural modeling (ISM) and analytic network process (ANP). Int. J. Product. Perform. Manag. 56 (1), 25–59.
Thursby, J.G., Kemp, S., 2002. Growth and productive efficiency of university intellectual property licensing. Res. Policy 31 (1), 109–124.
Verbeek, A., Debackere, K., Luwel, M., Andries, P., Zimmermann, E., Deleus, F., 2002. Linking science to technology: using bibliographic references in patents to build linkage schemes. Scientometrics 54 (3), 399–420.
Walsh, P., 1996. Finding key performance drivers: some new tools. Total Qual. Manag. 7 (5), 509–519.
Wang, W.M., Lee, A.H.I., Peng, L.P., Wu, Z.L., 2013. An integrated decision making model for district revitalization and regeneration project selection. Decis. Support. Syst. 54 (2), 1092–1103.
Warfield, J.N., 1973a. On arranging elements of a hierarchy in graphic form. IEEE Trans. Syst. Man Cybern. 3 (2), 121–132.
Warfield, J.N., 1973b. Binary matrices in system modeling. IEEE Trans. Syst. Man Cybern. 3 (5), 441–449.
Wernerfelt, B., 1984. A resource-based view of the firm. Strateg. Manag. J. 5 (2), 171–180.
Wright, M., Vohora, A., Lockett, A., 2004. The formation of high-tech university spinouts: the role of joint ventures and venture capital investors. J. Technol. Transf. 29 (3–4), 287–310.
Xu, Z., 2000. On consistency of the weighted geometric mean complex judgement matrix in AHP. Eur. J. Oper. Res. 126 (3), 683–687.
Yang, J.L., Chiu, H.N., Tzeng, G.H., Yeh, R.H., 2008. Vendor selection by integrated fuzzy MCDM techniques with independent and interdependent relationships. Inf. Sci. 178 (21), 4166–4183.
Zucker, L.G., Darby, M.R., Armstrong, J., 1998. Geographically localized knowledge: spillovers or markets? Econ. Inq. 36 (1), 65–86.

David W. L. Hsu received his Ph.D degree from the Graduate Institute of Management of Technology at National Chiao Tung University, Taiwan. He received his master degree from the Graduate Institute of Management Science, National Chiao Tung University, Taiwan. He joined in the Industrial Technology Research Institute and managed the activities of technology transfer. He has been the deputy director of Center of Academia and Industry Collaboration at National Chiao Tung University since 2009. His current research focuses on technology transfer, patent analysis, university entrepreneurship, and technology foresight.

Yung-Chi Shen is an assistant professor of the Department of Bio-industry and Agribusiness Administration, National Chiayi University, Taiwan. He received his master degree from the Graduate Institute of Industrial Education and Technology, National Changhua University of Education and the Ph.D degree in management of technology from National Chiao Tung University in Taiwan. His works have appeared in Technological Forecasting & Social Change, Entrepreneurship & Regional Development, and Energy Policy. His current research focuses on university technology transfer, new product development, and technology evaluation.

Benjamin J. C. Yuan is now a visiting professor of Institute of Industrial Economics, Jinan University. He was a professor of the Graduate Institute of Management of Technology, National Chiao Tung University. He received his master degree and Ph.D degree in electrical engineering from University at Buffalo, the State University of New York. He then established the Graduate Institute of Management of Technology for National Chiao Tung University. He was a member of technology policy committee of Taiwan's Executive Yuan. His research interests include innovation management, technology forecasting and assessment, technology foresight and policy, industrial economy and technology development.

Mr. Chiyang James Chou received his PhD degree from the Graduate Institute of Technology Management at National Chiao Tung University, Taiwan. He currently works for Riant Biotech Corporation as the Assistant Vice President. His research areas involve technology management, international business, and industrial analysis.