J Syst Sci Syst Eng (Sep 2015) 24(3):293-315
DOI: 10.1007/s11518-015-5271-3 ISSN: 1004-3756 (Paper) 1861-9576 (Online)
CN11-2983/N

MULTI-CRITERIA UNIVERSITY SELECTION: FORMULATION AND IMPLEMENTATION USING A FUZZY AHP

Negin Salimi Jafar Rezaei

Faculty of Technology, Policy and Management, Delft University of Technology, Jaffalaan 5, 2628 BX, Delft, The Netherlands

n.salimi@tudelft.nl (✉) *j.rezaei@tudelft.nl*

Abstract

Collaboration with universities as 'knowledge factories' is increasingly perceived to be an effective and viable solution for firms to gain competitive advantage. One of the main challenges firms face in this area is how to select the best university for collaboration. This selection undoubtedly affects some other strategic activities of firms, such as managing and governing the relationship with the selected university and, most importantly, firm performance. As such, the selection becomes an important strategic decision that deserves a great deal of attention. Thus far, no systematic attempt has been made to investigate this significant area of research. The main purpose of this study is to formulate a decision-making model for university selection. Reviewing existing literature of university-industry relationship yields a list of relevant criteria for this problem. The problem is then formulated as a multi-criteria decision-making (MCDM) model, and a fuzzy AHP is used to provide the solution. To illustrate the model, three Dutch universities are ranked based on the importance of the selected criteria.

Keywords: University-industry relationship, university selection, multi-criteria decision-making (MCDM), analytic hierarchy process (AHP), fuzzy analytic hierarchy process (FAHP)

1. Introduction

With today's rapid pace of technological changes, it is crucial for firms to have a competitive advantage. Innovation is one of the significant ways for firms to gain such a competitive advantage. To be innovative, firms need to acquire new knowledge. Therefore, with the increasing importance of knowledge and the way it is created and transferred, firms search for more competent knowledge generators. One of the most powerful potential partners for each firm, when it comes to creating knowledge, is university. In recent years, by increasing the importance of knowledge as a source of wealth creation and economic development (Druker 1994, Nanoka and Takeuchi 2005), the role of university as a 'knowledge factory' (David 1997) has received considerable attention. To make university research more relevant to what industry needs, policy-makers try to create more ties to universities (Cohen and Walsh 2002). Furthermore, universities have shown enthusiasm for entering into a closer relationship with firms. The public policy center of Stanford Research International (Thursby and Kemp 2002) indicates that more than 90% of universities are eager to increase interaction with industry. Thus, there has been an increasing mutual tendency to create a deeper relationship between firm and university, which has increased and changed from an arm's length relationship to a closer, more involved and productive partnership (Santoro and Bierly 2006). There are different types of collaboration between university and industry, such as joint research and development (R&D), publishing (Bekkers and Bodas Freitas 2008), spin-offs, patent, licensing, consultancy, graduate and researcher mobility (Wright et al. 2008). Nowadays, there is more attention on the more interactive or collaborative modes, which are labeled as 'academic engagement' (D'Este and Patel 2007, Perkmann et al. 2013). For instance, collaborative Ph.D. project, in which university, industry and Ph.D. candidate are actively involved, is a kind of academic engagement (see, for instance, Salimi et al. 2013, 2014). As initiators of collaboration with universities, firms select one or more of these channels in line with their objectives, which can be, for instance, technical competence building, by which firm tries to build competencies based on the acquired knowledge and explored new technologies; technical competence leveraging, which refers to the adaptation of a firm's existing technical competences and knowledge base to new market opportunities; radical innovation, which mainly refers to a marked improvement in product/service performance compared to existing products/services; and incremental innovation, which mainly refers to the technological adaptation, improvement and enrichment of existing products/services processes (van Gils 2010). Although collaboration has several benefits for both university and firm, not all the benefits can be achieved in practice. Failing the collaboration can be related to ignoring the motivations of the exchange, unsuitable governance structure, and selecting inappropriate partners for collaboration (Morandi 2013). By focusing on the partner selection, firms need to evaluate the characteristics of different universities in order to choose the most qualified one(s) for collaboration. This strategic task is a significant basis for a successful collaboration.

In the existing literature on university-firm relationships, the role of university in economic growth (e.g. Owen-Smith and Powell 2003, Rothaermel and Thursby 2005, Bramwell and Wolfe 2008), different channels of knowledge transfer between firms and universities (Agrawal 2001, Cohen and Walsh 2002, Balconi and Laboranti 2006, Bekkers and Bodas Freitas 2008), the process of knowledge transfer in these relationships (Cortés-Aldana et al. 2009), governance of collaborative Ph.D. project and its effect on the success (Salimi et al. 2013), and the performance of the relationship are the main topics that have attracted many researchers and that have been investigated in several empirical studies. Surprisingly enough, however, what has been neglected is university selection, which is the main topic of this paper.

In literature, universities are mostly evaluated from the students' perspective. These studies include different criteria to select university by students who are seen as the customers of universities. Geographical proximity between university and the student's home (Briggas 2006, Simoesa and Soaresa 2010, Polat 2012), university life style, career (Kembera et al. 2010), social and cultural facilities of university (Polat 2012), the university's reputation, the nature of the course and financial considerations (Donaldson and McNicholas 2004) are among the evaluation criteria. Other than offering education to students, universities have another important role, which is to provide commercial services and transfer knowledge to other organizations, such as manufacturers and service providers. From a firm's perspective, there are two main activities that influence the performance of the relationship: firstly, 'university selection', by which firm selects the most suitable university and secondly, 'university relationship management' (URM) (Salimi and Rezaei 2013), which relates to how (and through which channel) the firm enters into a relationship with the selected universities. The focus of this paper is on university selection. In this paper, we formulate a university selection model for firms, using the characteristics of the universities as the main selection criteria. We then propose an MCDM methodology for the university selection problem, which is one of the most recent fuzzy variants of Analytic Hierarchy Process (AHP).

The remainder of this paper is organized as follows. In section 2, the university selection model is formulated. A methodology to solve the problem is presented in section 3. In section 4, we illustrate how the proposed model can be used in a real situation. In section 5, the conclusion and suggestions for future research are presented.

2. University Selection Problem Formulation

In this section, a systematic process is proposed by which firm can select the most suitable university/universities from a set of alternative universities. The proposed model contains the following steps:

Step 1. Identify a set of available universities;
Step 2. Select a number of qualitative and quantitative criteria;
Step 3. Evaluate the universities based on the selected criteria;
Step 4. Select the most qualified university (or universities).

We discuss the first two steps in this section. Steps 3 and 4 are discussed as methodology in Section 3.

2.1 Identify a Set of Available Universities

In this step, the firm compiles a list of available universities for a possible relationship, and conducts an initial screening, to limit the number of alternative universities by considering some very general criteria. For example, if the firm is interested to be involved in regional collaboration networks, it should make a list of local universities, while if the firm is interested in international collaborations, it should identify a set of available universities in international level. Type of university (public vs. private, universities with a focus on specific subjects) can be considered as another example of general criterion for this pre-selection phase.

2.2 Select a Number of Qualitative and Quantitative Criteria

University selection criteria are a basis for selecting the most suitable universities. These

Table 1 A list of criteria, and sub-criteria for university selection process

Main criteria	Sub-criteria	Description/importance	Supporting references
Networking and knowledge exchanging ability	Ability in interactive exchange of knowledge at local levels	University relationship with other research institutes, universities and firms at local level/ Easier access to local knowledge	Smedlund 2006, Barmwell and Wolfe 2008
	Ability in connecting firm to international academic research networks to access knowledge	University exchange of knowledge via some channels such as sending researchers to international conferences/ Easier access to global knowledge	Bathelt et al. 2004, Lawton Smith 2003, OECD 1999, Barmwell and Wolfe 2008
General attractiveness	Willingness to cooperate	University's enthusiasm to engage in relationship with firm/ Leads to more involvement of university in relationship	
	Geographical proximity	Spatial distance between university and firm/ Facilitates transfer of knowledge from university to firm, labor mobility, and access to laboratories, etc.	Buschma 2005, Barmwell and Wolfe 2008
	International academic reputation	Academic standing of university compared to other universities/ Shows a higher chance of relationship success	Barmwell and Wolfe 2008
	Previous relationship	Prior history between university and firm/ Increases trust and commitment between university and firm	Butcher and Jeffrey 2007, Thune 2009
Research ability	Research capacity	University creates an environment that attracts highly skilled researchers/ Increases quality of transferred knowledge from university to firm	Florida 2002, Betts and Lee 2005, Gertler and Vinodrai 2005, Barmwell and Wolfe 2008
	Research facilities	University research environment, infrastructure and culture/ Facilitates conducting more useful research	
	Research quality	Impact of university research results on the society/ Shows the ability of the university to pursue the relationship objectives with a high quality	
	Alignment of university research with industry needs and interests	Consistency between university research directions and firm needs/ Shows the usefulness and effectiveness of university research directions	Barmwell and Wolfe 2008
Commercialization ability	Conducting more applied research	Considering future potential applications of new discoveries/ Supports the successful commercialization of new products and processes	Stokes 1997, Barmwell and Wolfe 2008
	Entrepreneurial academic spin-off activities	University supports commercialization of ideas, which leads to a large number of start-ups and spin-offs in the region/ Supports the successful commercialization of new products and processes	Barmwell and Wolfe 2008
	University licensing and patenting activities	University supports commercialization of ideas, which leads to licensing agreements and patents/ Shows the ability of university to bring the ideas close to the market, which is very important to a firm	Thursby and Kemp 2002

criteria are used to evaluate different aspects of a university. Here, we discuss a comprehensive set of criteria, extracted from relevant literature, which can be used for university selection. Although the list of criteria presented in this paper is a comprehensive list, firm can decide to use other criteria. The criteria used here are presented in Table 1 in four general categories.

(i) Networking and Knowledge Exchanging Ability

The ability of a university to enter into a relationship with other universities, research institutes, researchers and students at local and global levels are especially important to firms looking to collaborate with a university. Bramwell and Wolfe (2008) argue that the intensity of a university's relationship increases the number of university spin-off firms, the amount of public and private research funding, and patenting and licensing activities provide the firm access to local and global knowledge. Hirai et al. (2013) also realized that such relationships help spin-off firms overcome their financial problem by acquiring social capital. Moreover, at U.S. universities, technology transfer activities, such as patenting activities and university spin-offs, have become the outstanding strategy, because they contribute to the knowledge spill-overs between universities and firms (Link and Scott 2005).

Generally speaking, universities provide firms with access the local and global knowledge via different channels, that can range from project-oriented consulting and joint research project (partnership) to publishing journals, academic conferences and making international formal and informal research network (Geuna and Muscio 2009). For this main criterion, we define two sub-criteria: *ability to provide an interactive exchange of knowledge at a local level* (Smedlund 2006), and *ability to connect the firm to international academic research networks* (OECD 1999, Bathelt et al. 2004).

(ii) General Attractiveness

This main criterion contains the elements of willingness on the part of the university to collaborate, geographical proximity, reputation, and previous relationship between university and firm. We explain these criteria as follows:

- *Willingness on the part of the university to collaborate:* the motivation the university has for entering into a relationship with a firm is a significant selection criterion. When a university shows a high level of willingness, it will be involved in different parts of the relationship more actively and effectively, which in turn influences the performance of the relationship. The importance of willingness for the performance of collaboration becomes more vital when we consider the information and knowledge transferring from the university to the firm. The interest of university, as a source of knowledge, to share knowledge enhances the performance of collaboration. Although knowledge sharing is not easy among organizations with different cultures, goals, and structures (Nonaka and Takeuchi 1995) and requires clear common visions and objectives among organizations (Lee and Kim 1999), firm's decision to be involved in collaboration with university without the willingness of university to share information is waste of time and energy.
- *Geographical proximity*: geographical

proximity between firm and university can reduce uncertainty and solve many potential problems of the relationship, thus facilitates interactive learning and innovation (Boschma 2005). In other words, proximity can influence the success of transferring knowledge from university to firm (Bramwell and Wolfe 2008). In fact, tacit knowledge, which is easier transferred through face-to-face interaction, is easier to organize when collaboration partners (university and firm) are located in close neighborhood. In addition, when the partners are located far from each other, more time and resources are required for meetings, which makes the trust building more difficult (Ponds et al. 2007, Salimi et al. 2014).

- *The university's reputation:* the academic standing of the university compared to other universities can be an important factor for the firm. University reputation, which is measured based on different criteria such as student demand (Dill and Soo 2005), can be used to attract resources and talent, and can be considered as a very strong proxy for the success of university (Shattock 2010).

- *Previous relationship:* the prior history of the relationship between university and firm makes it easier for the firm to select a university (Butcher and Jeffrey 2007, Thune 2009). When previous encounters with a specific university have been successful, that inspires the firm to continue the relationship. In this case, the relationship needs little time investment to obtain information as already some required bases are made in comparison to the relationship without any previous experience of relationship. Therefore having successful previous relationship can increase the efficiency of a new relationship (Levin et al. 2011). However, if the encounters were less than successful, that will discourage the firm from entering into a new relationship with that university.

(iii) Research Ability

Since universities act as engines of development, research is one of their central missions. Firms use the research results of universities to help grow and develop economies. Therefore, we define research ability as a university's accumulated knowledge, skills, institutional development and resources, which enable the university to conduct useful research that firms can put to practical use. Based on this definition, we consider four sub-criteria that show the research ability of a university as follows:

- *Research capacity:* this has to do with the university's ability to attract (good) students, train and generate talents and researchers. Although a university with high skilled teachers provides an effective learning, which consequently results in more qualified researchers (Gibbs and Coffey 2004), quality of incoming students has significant role in producing high-quality outputs (i.e. publications, patents) (Dill and Soo 2005).

- *Research facilities*: this refers to the university's research infrastructure such as data-bases, laboratories and libraries, and its ability to create and maintain an atmosphere for conducting high-quality research. In many instances, in-house construction of these facilities are very expensive for firms (Ponds et al. 2007), therefore being involved in collaboration with other organizations such as universities can be considered as a good alternative.

- *Research quality*: this refers to the university's productivity and the impact of its research on society in the short or long term (Carlsson et al. 2011). Nicholls (2007) argues that university research quality is related to the three main areas of research activity and output: quantity and quality of publications, quantity and quality of research grants, and higher degree by research activity. The quantity of grant is related to the total funding value or the number of grants obtained while the quality of research grant is characterized by the act of having won the grants competitively. The latest area is related to the Ph.D. programs of universities that contain the number of Ph.D. candidates (full and part time) who are defended and graduated, duration of candidature (Ph.D. completion time) and the completion rate (Nicholls 2007).

- *Level of consistency of research with firm needs*: this means that, although research and development (R&D) is necessary, it is not sufficient for growth. Knowledge that is provided by the university must be aligned with the needs and interests of firms (Perkmann and Walsh 2007).

(iv) Commercialization Ability

Today, by moving the role of university from conducting basic (fundamental) research towards more applied research (Geiger 2004), firms can focus more on the potential applications of knowledge. By having an Intellectual Property (IP) policy, universities support the commercialization of ideas, which leads university research parks (URP), large number of start-ups, spin-offs, licensing agreements and patents in the region (Siegel et al. 2003, Phan et al. 2005). In other words, patents, licenses, research joint ventures and spin-offs firms are the essential ways of commercialization. Thursby and Kemp (2002), and Lockett et al. (2005) argue that private universities tend to be more efficient in commercialization than public universities, which focus more on their teaching duties. Consequently, we propose three sub-criteria for commercialization ability as follows:

- *Conducting more applied research:* a university is applied research-oriented when it mainly focuses on the type of research that aims to gain the "knowledge or understanding necessary for determining the means by which a recognized and specific need may be met" (National Science Foundation 1998).

- *Entrepreneurial academic spin-off activities:* an academic spin-off is a company that is established by a university to commercialize the scientific ideas of university researchers, staff and students (Carayannis et al. 1998, Druilhe and Garnsey 2004).

- *The university's licensing and patenting activities*: are seen as potential ways to commercialize university inventions (Mowery et al. 2001). In fact, as there has been increasing pressure on university to transfer the results of its research into privately appropriable knowledge, university licensing and patenting are considered as important drivers of economic growth (Henderson et al. 1988).

3. Methodology

In general, selecting a partner for collaboration is a multi-criteria problem and, as mentioned before, university selection can also be viewed as a multi-criteria decision-making

(MCDM) problem. One of the main goals of MCDM methods is to help decision-makers select the best alternative from a number of choice-alternatives based on multiple criteria. These methods improve the quality of decisions in complex situations with many criteria, by making decision more obvious, rational and efficient. To put it more precisely, university selection is a perception-based problem with multiple criteria, which means universities should be evaluated by experts based on multiple criteria.

Of the existing MCDM methodologies, the Analytic Hierarchy Process (AHP), which was introduced by Saaty (1977, 1980), is one of the most commonly used (Rotter et al. 2012, Vinodh et al. 2013). In the AHP, we begin by constructing a hierarchy of the problem, containing a goal (the main purpose of the problem), some criteria (elements used to evaluate the alternatives) and, finally, some alternatives. The ultimate goal is to evaluate the alternatives and select the best one(s). To this end, criteria are compared pairwise against the goal, and the alternatives are also compared pairwise against each criterion. Finally, through some simple calculations, the best alternative(s) is identified. In traditional AHP, the decision-makers are asked to compare criteria *i* and *j* using integer numbers between 1 (*i* has the same importance as *j*) and 9 (*i* has extreme priority over *j*).

Although AHP has been shown to be very useful in real-world problems, it has a very important shortcoming, in that using discrete numbers 1 to 9 is not easy for the decision-makers making the comparisons. They prefer using linguistic variables like 'important', 'very important' etc. when comparing two criteria. Fortunately, this issue was resolved by introducing fuzzy variants of AHP, where for the comparisons, associated fuzzy numbers of linguistic variables are used. There are several variants of fuzzy AHP in literature (for example van Laarhoven and Pedrycz 1983, Buckley 1985, Chang 1996, Zhu et al. 1999, Mikhailov 2003, Wang et al. 2006), each of which has its advantages and disadvantages. However, as was pointed out by Leung and Cao (2000), one main common shortcoming of fuzzy AHP methods is their weakness to handle consistency. Mikhailov (2003), using fuzzy preference programming (FPP), proposed a fuzzy AHP that provides a robust foundation for tackling inconsistency. This methodology, which was further improved by Rezaei et al. (2013), is used in this study[1].

Fuzzy AHP

In this section, we explain the AHP method using fuzzy preference programming as follows:

Step 1. Structure the hierarchy

In this step, the aim is to structure a hierarchy, including the goal, criteria, sub-criteria and alternatives. The elements of each level (criteria, sub-criteria, and alternatives) should be homogeneous. It is not, however, necessary that the hierarchy be complete. That is to say, it is not necessary for an element in a given level to function as a criterion for all the elements in the level below (Saaty and Vargas

[1]We refer interested readers to Saaty (1977, 1980), Saaty and Vargas (2012) for more discussion on AHP, and to van Laarhoven and Pedrycz (1983), Mikhailov (2003), Rezaei et al. (2013) for more discussion on the fuzzy AHP applied in this paper.

2012, p. 2).

Step 2. Establish the pairwise comparison matrices

This step uses the experts' knowledge to construct the comparison matrices for the criteria, sub-criteria and alternatives. In this step, the elements of each level are compared to each other. For instance, for the main criteria level, all the main criteria are compared to each other. The following matrix shows the pairwise comparison of *n* elements.

$$\tilde{A} = \begin{bmatrix} \tilde{a}_{11} & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & \tilde{a}_{22} & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & \tilde{a}_{nn} \end{bmatrix} \quad (1)$$

where $\tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij})$ is a triangular fuzzy number (TFN) showing the expert's preference of *i* over *j*, and $\tilde{a}_{ji} = 1/\tilde{a}_{ij}$. The definition of TFN, the TFNs used for the applied fuzzy AHP, and the operational laws, are presented in the Appendix.

Step 3. Using fuzzy preference programming (FPP) to obtain a crisp priority vector $w = (w_1, w_2, \cdots, w_n)^T$

In this step, we determine the relative weight of the criteria, such that the ratios w_i / w_j are approximately within the scopes of the pairwise judgment $\tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij})$, or equivalently:

$$l_{ij} \tilde{\le} w_i / w_j \tilde{\le} u_{ij} . \quad (2)$$

For each *i* and *j*, there may be many w_i and w_j that satisfy the inequality (2). However, different ratios w_i / w_j are associated with different levels of expert satisfaction that can be measured by a membership function as follows:

$$\mu_{ij}\left(\frac{w_i}{w_j}\right) = \begin{cases} \dfrac{\frac{w_i}{w_j} - l_{ij}}{m_{ij} - l_{ij}}, & \dfrac{w_i}{w_j} \le m_{ij}, \\ \dfrac{u_{ij} - \frac{w_i}{w_j}}{u_{ij} - m_{ij}}, & \dfrac{w_i}{w_j} \ge m_{ij}. \end{cases} \quad (3)$$

As the judgments a_{ij} are uncertain, $l_{ij} < m_{ij} < u_{ij}$ and therefore dividing by zero does not take place. The membership function (3) may take the following values:

$$\mu_{ij}\left(\frac{w_i}{w_j}\right) \in (-\infty, 0), \text{ if } \frac{w_i}{w_j} < l_{ij} \ or \ \frac{w_i}{w_j} > u_{ij} , \quad (4)$$

$$\mu_{ij}\left(\frac{w_i}{w_j}\right) \in [0,1], \text{if } l_{ij} \le \frac{w_i}{w_j} \le u_{ij} . \quad (5)$$

It takes the maximum value of 1 when $\frac{w_i}{w_j} = m_{ij}$.

The FPP is aimed at finding the optimal crisp priority vector w^* of the fuzzy feasible area *P* on the ($n-1$)-dimensional simplex

$$Q^{n-1} = \{w_i \big| \textstyle\sum_{i=1}^{n} w_i = 1, w_i > 0\} , \quad (6)$$

with the following membership function:

$$\mu_P(w) = \min_{ij} \{\mu_{ij}(w) \,|\, i = 1, \ldots, n-1, j = 2, \ldots, n, j > i\}. \quad (7)$$

According to Mikhailov (2003), there is always an optimal crisp priority vector that has a maximum degree of membership as follows:

$$\lambda^* = \mu_P(w^*) = \max_{w \in Q^{n-1}} \min_{ij} \{\mu_{ij}(w)\} . \quad (8)$$

Using the maximin rule of Bellman and Zadeh (1970), and in order to fully take the skewness and non-linearity of the reciprocal fuzzy numbers into account, the problem (8) can be transformed to the following problem, which results in the optimal priority vector w^* and λ^* (Rezaei et al. 2013).

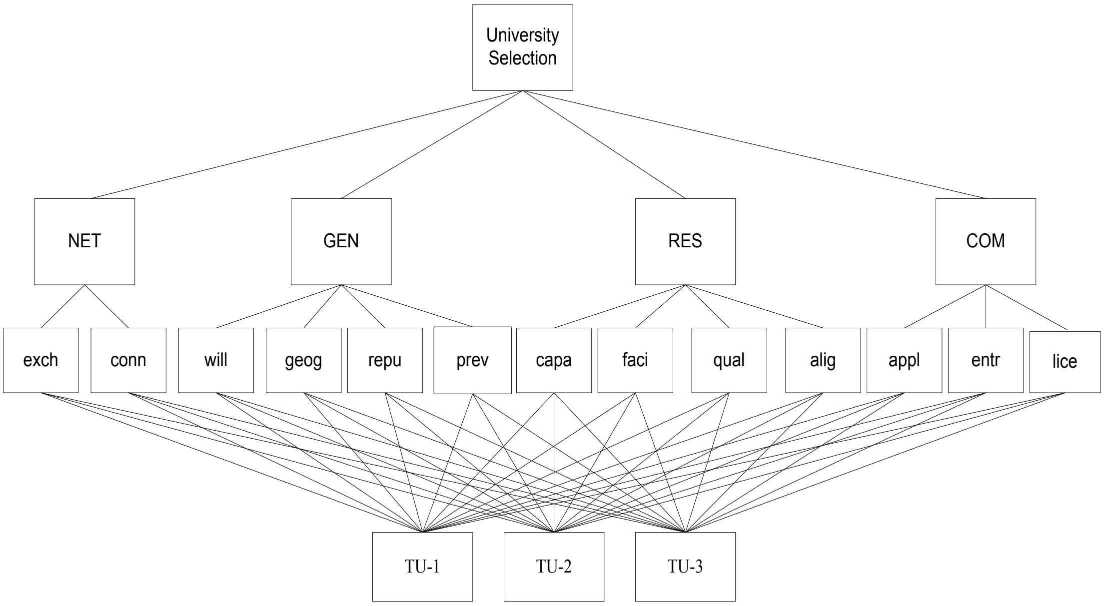
$$\begin{aligned}
&\max \lambda \\
&\text{s.t.} \\
&\left.\begin{aligned}(m_{ij}-l_{ij})\lambda w_j - w_i + l_{ij} w_j \le 0,\\ (u_{ij}-m_{ij})\lambda w_j + w_i - u_{ij} w_j \le 0\end{aligned}\right\}\text{for FN of Type I,} \\
&\left.\begin{aligned}(m_{ji}-l_{ji})\lambda w_i - w_j + l_{ji} w_i \le 0,\\ (u_{ji}-m_{ji})\lambda w_i + w_j - u_{ji} w_i \le 0\end{aligned}\right\}\text{for FN of Type II,} \qquad (9)\\
&\textstyle\sum_{k=1}^{n} w_k = 1, \\
&w_k > 0, \\
&i = 1,\dots,n-1,\ j = 2,\dots,n,\ j > i,\ k = 1,\dots,n.
\end{aligned}$$

where FN (fuzzy number)s of Type I are $\tilde{1},...,\tilde{9}$ (see the Appendix), and FNs of Type II are, $\frac{\tilde{1}}{9},\frac{\tilde{1}}{8},\dots,\frac{\tilde{1}}{2},\tilde{1}$ which are in fact the corresponding reciprocals of the FNs of Type I.

Solving the non-linear programming problem (9) results in the optimal priority vector w^* and λ^*. The vector w^* shows the optimal weights of the criteria, and λ^* is a consistency index. That is to say, the negative values of λ^* show existing inconsistent pairwise comparisons in a matrix, while the positive values of λ^* shows being a matrix of pairwise comparisons consistent, with $\lambda^* = 1$ showing full consistency. If λ^* is negative, the decision-maker should revise the comparisons such that it becomes consistent.

4. Application

In this section, the proposed model using the fuzzy AHP is illustrated in selecting the best university among three Dutch technical universities (in this paper we call them TU-1, TU-2, TU-3). First, the problem is converted into a hierarchy (the first step of the proposed methodology), as shown in Figure 1. This figure consists of the goal (university selection), alternatives (three universities), main criteria that relate the alternatives to the goal (*networking and knowledge exchanging ability, general attractiveness, research ability, and commercialization ability*). Finally, each criterion has been broken down into sub-criteria. For example, in this study, the first criterion is *networking and knowledge exchanging ability*, which contains two sub-criteria: *ability in interactive exchange of knowledge at local levels* and *ability to connect firms to international academic research networks to access knowledge*. The second criterion, *general attractiveness,* includes four sub-criteria. *Research ability* and *commercialization ability* (third and fourth criteria) consist of four and three sub-criteria respectively.



NET: networking and knowledge exchanging ability; GEN: general attractiveness; RES: research ability; COM: commercialization ability; exch: exchange of knowledge at local levels; conn: connecting firm to international academic research networks; will: willingness to cooperate; geog: geographical proximity; repu: international academic reputation; prev: previous relationship; capa: research capacity; faci: research facilitator; qual; research quality; alig: alignment of university research with industry needs; appl: conducting applied research; entr: entrepreneurial academic spin-off activities; lice: university licensing and patenting activities.

Figure 1 A hierarchy of the university selection problem

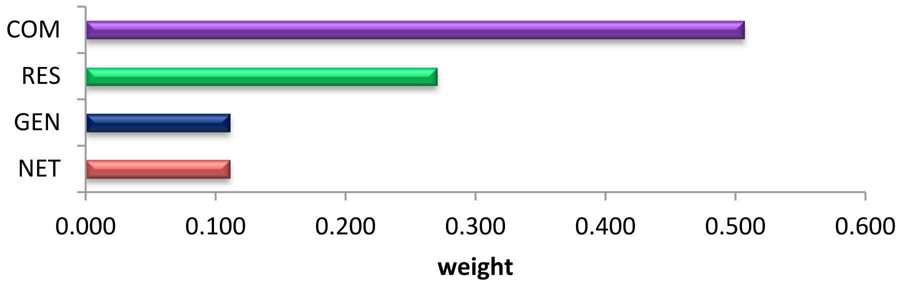
In the second step, based on equation (1), two experts who have extensive information on the situation in which a firm chooses a university as a partner for collaboration, are asked to pairwise compare the main criteria against the goal, the sub-criteria against the main criteria, and the alternatives (the three universities) against the sub-criteria[2]. One may argue that having the opinions of two experts may only provide a rough picture. However, AHP does not necessarily need a large sample (Lam and Zhao 1998), because it is an expert-based rather than a data-based method, which means that using the opinions of a limited number of experts is enough (Rezaei et al., 2012).

Here, the results of solving the improved non-linear programming model (9) are reported as follows. Table 2 shows the relative importance (weights) of the main criteria and sub-criteria (see also Figures 2 and 3).

[2] The pair-wise comparison matrices are available upon the reader's request.

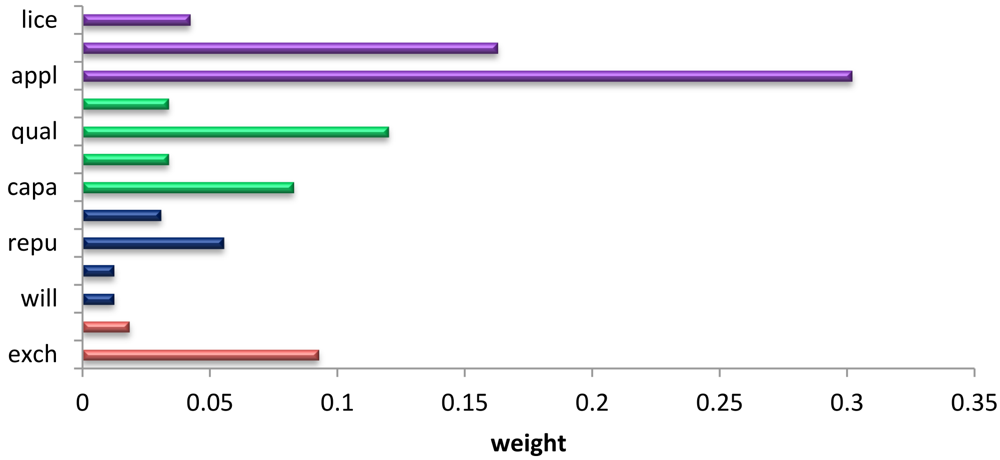
Table 2 Relative weights of the criteria and sub-criteria (fuzzy AHP)

Criteria	Criteria weights	Sub-criteria	Local weights of sub-criteria	Global weight of sub-criteria
Networking and knowledge exchanging ability (NET)	0.111	Ability to engage in the interactive exchange of knowledge at a local level	0.833	0.093
		Ability to connect firms to international academic research networks to access knowledge	0.167	0.019
General attractiveness (GEN)	0.111	Willingness	0.111	0.012
		Geographical proximity	0.111	0.012
		International academic reputation	0.500	0.056
		Previous relationship	0.278	0.031
Research ability (RES)	0.271	Research capacity	0.306	0.083
		Research facilities	0.125	0.034
		Research quality	0.444	0.120
		Alignment of university research with industry needs and interests	0.125	0.034
Commercialization ability (COM)	0.507	Conducting more applied research	0.595	0.302
		Entrepreneurial academic spin-off activities	0.321	0.163
		University licensing and patenting activity	0.083	0.042



COM: commercialization ability; *RES*: research ability; *GEN*: general attractiveness; *NET*: networking and knowledge exchanging ability

Figure 2 The relative importance of the main criteria



lice: university licensing and patenting activities; *entr*: entrepreneurial academic spin-off activities; *appl*: conducting applied research; *alig*: alignment of university research with industry needs; *qual*; research quality; *faci*: research facilitator; *capa*: research capacity; *prev*: previous relationship; *repu*: international academic reputation; *geog*: geographical proximity; *will*: willingness to cooperate; *conn*: connecting firm to international academic research networks; *exch*: exchange of knowledge at local levels

Figure 3 The relative importance of the sub-criteria

As can be seen from Table 2, according to the judgment of our two experts as decision-makers, *commercialization ability* is the most important criterion with respect to achieving the goal, followed by *research ability*. *Networking and knowledge exchanging ability* and *general attractiveness* are the least important criteria, all with the same weight. Our results are supported by literature, e.g. Goldfarb and Henrekson (2003) mentioned that there are some national policies for example in the US to create (economic) incentives and motivations for universities to commercialize their works. More precisely, they found that, for the commercialization of knowledge generated by university, involving university researchers is crucial. As shown in the survey conducted by Thursby et al. (2001), most successful commercialization of inventions involves academic researchers. Therefore, for a firm, an active role on the part of the university in terms of commercialization is the main criterion.

The global weights of the sub-criteria (the multiplication of the weights of the sub-criterion by the weights of the main criterion to which it belongs) are reported in Table 2 and Figure 3. Based on these results, for the *networking and knowledge exchanging ability* dimensions, the most important item is *ability to engage in interactive exchange of knowledge at local levels*. It would appear that a university with the ability to exchange knowledge at a local level allows firm to know more about the needs in the local area and how to satisfy customers better. In recent years, identifying and satisfying customer needs are among the most challenging issues facing firms (Herrmann et al. 2000). Moreover, from this channel, firms are informed about the research that is carried out at other universities or research institutes. As such, duplicated research can be avoided, which saves time and money. With regard to the *general attractiveness* dimension, *international academic reputation* is the most important item, while *willingness on the part of the university to engage in collaboration* and *geographical proximity* are the least important items, with the same weight. Having an international academic reputation can be considered an indication that the university has high-quality students, which are key elements when it comes to transferring knowledge to firms (Bramwell and Wolfe 2008). Furthermore, of the four sub-criteria of *research ability* dimension, *research quality* has the highest weight, while *research facilitators* and *alignment of university research with industry needs* are of least importance. Finally, *conducting more applied research* is the most important item of *commercialization ability* dimension, and *university licensing and patenting activity* is the least important item. When universities focus more on applied knowledge, they contribute to the diffusion of knowledge and provide technical support to firms. That is to say, by conducting applied research, universities consider potential future applications of discoveries, which increases the likelihood of successful commercialization (Mok 2005).

As mentioned before, the goal is to choose the most suitable university based on four specific criteria. Based on the results, the second university (TU-2) is the preferred university, with a priority of 0.53, more than twice as much as TU-1 (0.26), followed by TU-3 (0.22) (see Figure 4).

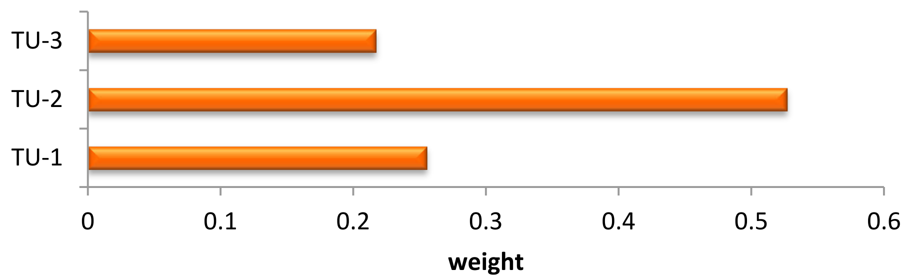


Figure 4 The relative importance of the alternatives (universities)

5. Model Validation

To assess the validity of fuzzy AHP methodology, two approaches are used (Rezaei and Ortt 2013). The first approach is based on the consistency index. As mentioned in section 3, the value of λ^* shows the degree of consistency of the corresponding initial judgments. In other words, it is a measure designed to determine the level of consistency of pairwise comparison matrices by experts. The minimum acceptable value of λ^* is 0 and the maximum is 1. For this study, the value of λ^* for the goal is 0.436 and in the level of main criteria we have the following values: 1, 0.5, 0.449 and 0.854 for *networking and knowledge exchanging ability*, *general attractiveness*, *research ability* and *commercialization ability* respectively. At the level of sub-criteria, our results show that the average value of λ^* for two items of *networking and knowledge exchanging ability* is 0.851. Regarding the second and the third main criteria, *general attractiveness and research ability*, each of which with four items, the average values of λ^* are: 0.797 and 0.622 respectively. Our last main criterion is *commercialization ability* (containing three items) with the average λ^* of 0.557. As all the values are positive, most of them very close or equal to 1, we conclude that the pairwise comparison matrices are filled in consistently, thus the final weights are almost consistent, and the model is valid. The second approach involves comparing the results found by the fuzzy AHP to the results of the conventional AHP. The closer the results are, the higher the degree of model validity. For the purpose of this study, we considered the equivalent crisp values of comparison matrices, conducting a conventional AHP (Saaty 1977, 1980). Table 3 shows the weights of criteria and sub-criteria using the conventional AHP.

Table 3 Relative weights of the criteria and sub-criteria (conventional AHP)[1]

Criteria	Criteria weights	Sub-criteria	Local weights of sub-criteria	Global weight of sub-criteria
Networking and knowledge exchanging ability (NET)	0.083	Ability to engage in the interactive exchange of knowledge at a local level	0.833	0.069
		Ability to connect firms to international academic research networks to access knowledge	0.167	0.014
General attractiveness (GEN)	0.128	Willingness	0.104	0.013
		Geographical proximity	0.121	0.015
		International academic reputation	0.509	0.065
		Previous relationship	0.267	0.034
Research ability (RES)	0.257	Research capacity	0.280	0.072
		Research facilities	0.115	0.030
		Research quality	0.469	0.120
		Alignment of university research with industry needs and interests	0.136	0.035
Commercialization ability (COM)	0.532	Conducting more applied research	0.602	0.321
		Entrepreneurial academic spin-off activities	0.315	0.168
		University licensing and patenting activity	0.082	0.044

[1] All the comparison matrices are consistent (consistency ratio (CR) of the matrices are in the range of 0.00 to 0.051).

The non-parametric Wilcoxon Signed Rank Test is conducted to examine the median difference between the obtained results, at three levels (weights of universities considering different sub-criteria, local weights of the criteria, and the final aggregated weights for the universities) from the two models fuzzy AHP and conventional AHP (see Tables 4-6). The comparison results show that there is no significant difference between the results of the two models (α = 0.01), showing the validity of the proposed fuzzy AHP for this study.

Table 4 Comparison results of the weights of universities considering different sub-criteria obtained by fuzzy AHP and conventional AHP (Wilcoxon Signed Rank Test)

Ranks (FAHP-AHP)				Test Statistics (FAHP-AHP)[a]	
	N	Sum of Ranks	Mean Rank	*Z*	-0.242[b]
Negative ranks	10	166.00	16.60	Asymptotic Sig. (2-sided test)	0.809
Positive ranks	16	185.00	11.56		
Ties	13				

a. The significance level α = 0.01
b. Based on negative ranks

Table 5 Comparison results of the local weights obtained by fuzzy AHP and conventional AHP (Wilcoxon Signed Rank Test)

Ranks (FAHP-AHP)				Test Statistics (FAHP-AHP)[a]	
	N	Sum of Ranks	Mean Rank	*Z*	-0.454[b]
Negative ranks	9	52.00	5.78	Asymptotic Sig. (2-sided test)	0.650
Positive ranks	4	39.00	9.75		
Ties	0				

a. The significance level α = 0.01
b. Based on positive ranks

Table 6 Comparison results of the final aggregated weights for the universities obtained by fuzzy AHP and conventional AHP (Wilcoxon Signed Rank Test)

Ranks (FAHP-AHP)				Test Statistics (FAHP-AHP)[a]	
	N	Sum of Ranks	Mean Rank	*Z*	0.000[b]
Negative ranks	2	3.00	1.50	Asymptotic Sig. (2-sided test)	1.000
Positive ranks	1	3.00	3.00		
Ties	0				

a. The significance level α = 0.01
b. The sum of negative ranks equals the sum of positive

6. Conclusion and Future Research

In a time when the relationship between firms and universities is becoming increasingly important to firms, choosing the most suitable university is one of the challenging issues facing firms. The result of the selection can directly affect both the way in which the firm governs its relationship with universities and the performance of that relationship. In this paper, we introduced the university selection problem as a multi-criteria decision-making problem and proposed a systematic model to help managers make an optimal decision in an uncertain situation. The main criteria for this strategic decision of firms are: (1) Networking and knowledge exchanging ability; (2) General attractiveness; (3) Research ability; and (4) Commercialization ability. Each criterion has a number of sub-criteria. The goal is to find the best alternative (university) based on the relative importance of the criteria and sub-criteria. To obtain the relative importance (weights) of the criteria, we used an MCDM called fuzzy AHP, in which experts express the relative importance of the criteria in a pairwise fashion. In contrast to traditional AHP, fuzzy AHP is able to handle the vagueness of the judgment, because it works with fuzzy numbers instead of crisp numbers. Fuzzy numbers are used as the mathematical values of the linguistic variables, like ‘strongly agree’, people use in their judgment. Applying fuzzy AHP, we calculated the final relative importance of the universities, which is in fact the ultimate goal of this model.

This study has also several interesting managerial implications. For example, this study, by proposing a structured model for university selection: (1) allows managers of firms to consider both qualitative and quantitative criteria in evaluating universities; (2) allows managers to update their decisions by adding new criteria and/or alternatives; (3) increases the chance of a successful collaboration, which in turn increases the likelihood of a continued collaboration.

For future research, we suggest applying other MCDM methodologies, like TOPSIS, and fuzzy rule-based systems, to the problem. ANP can be considered as a very good methodology for this problem in order to handle the potential interdependencies which might exist among the criteria. We also suggest applying the proposed method by considering the effect of different firms’ objectives to involve in collaboration, on the selection process. It would also be interesting to investigate how different types of relationship channels between firm and university influence the firm’s selection.

7. Appendices

Definition 1. (van Laarhoven and Pedrycz 1983) Triangular fuzzy number (TFN): A fuzzy number N on $\Re$ is defined to be a TFN if its membership function $\mu_N(x):\Re \to [0,1]$ be:

$$\mu_N(x) = \begin{cases} \dfrac{x-l}{m-l}, & l \le x \le m, \\ \dfrac{u-x}{u-m}, & m \le x \le u, \\ 0, & \text{otherwise}, \end{cases} \quad \text{(a1)}$$

where l, and u are the lower and upper bound of the support N respectively and m is the modal value. This triangular fuzzy number can be noted by the triple (l,m,u).

The operational laws of two TFNs

$N_1 = (l_1, m_1, u_1)$ and $N_2 = (l_2, m_2, u_2)$ are as follows.

Fuzzy number addition $\oplus$:

$$\begin{aligned} N_1 \oplus N_2 &= (l_1, m_1, u_1) \oplus (l_2, m_2, u_2) \\ &= (l_1 + l_2, m_1 + m_2, u_1 + u_2). \end{aligned} \tag{a2}$$

Fuzzy number multiplication $\otimes$:

$$\begin{aligned} N_1 \otimes N_2 &= (l_1, m_1, u_1) \otimes (l_2, m_2, u_2) \\ &\cong (l_1 \times l_2, m_1 \times m_2, u_1 \times u_2). \end{aligned} \tag{a3}$$

where l_i, m_i, u_i are all positive real numbers.

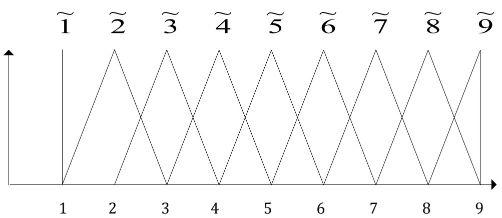
Fuzzy number division $\oslash$:

$$\begin{aligned} N_1 \oslash N_2 &= (l_1, m_1, u_1) \oslash (l_2, m_2, u_2) \\ &\cong (l_1 / u_2, m_1 / m_2, u_1 / l_2), \end{aligned} \tag{a4}$$

where l_i, m_i, u_i are all positive real numbers.

It suffices that the DM provides at most $n(n-1)/2$ pairwise comparisons $\tilde{a}_{ij}$, $i = 1, 2, \ldots, n-1$, $j = 2, 3, \ldots, n$, $j>i$.

TFNs used for the fuzzy AHP:



8. Acknowledgments

The authors would like to thank the two reviewers for their constructive comments on the initial version of the paper.

References

[1] Agrawal, A.K. (2001). University-to-industry knowledge transfer: Literature review and unanswered questions. International Journal of Management Reviews, 3 (4): 285-302.

[2] Balconi, M. & Laboranti, A. (2006). University-industry interactions in applied research: the case of microelectronics. Research Policy, 35 (10): 1616-1630.

[3] Bathelt, H., Malmberg, A. & Maskell, P. (2004). Clusters and knowledge: Local buzz, global pipelines and the process of knowledge creation. Progress in Human Geography, 28 (1): 31-56.

[4] Bekkers, R. & Bodas Freitas, I.M. (2008). Analysing knowledge transfer channels between universities and industry: to what degree do sectors also matter? Research Policy, 37 (10): 1837-1853.

[5] Bellman, R.E. & Zadeh, L.A. (1970). Decision-making in a fuzzy environment. Management Science, 17 (4): B141-B164.

[6] Betts, Julian & Carolyn, W.B. Lee. (2005). Universities as drivers of regional and national innovation: an assessment of the linkages from universities to innovation and economic growth. In C.M. Beach, R.W. Boadway, and R. Marvin McInnis (eds). Higher Education in Canada. Kingston, Ont.: McGill-Queen's University Press.

[7] Boschma, R.A. (2005). Proximity and innovation: a critical assessment. Regional Studies, 39 (1): 61-74.

[8] Bramwell, A. & Wolfe, D.A. (2008). Universities and regional economic development: the entrepreneurial University of Waterloo. Research Policy, 37 (8): 1175-1187.

[9] Briggas, S. (2006). An exploratory study of the factors influencing undergraduate student choice: the case of higher education in Scotland. Studies in Higher Education, 31 (6): 705-722.

[10] Buckley, J.J. (1985). Fuzzy hierarchical analysis. Fuzzy Sets and Systems, 17 (3): 233-247.

[11] Butcher, J. & Jeffrey, P. (2007). A view from the coal face: UK research student perceptions of successful and unsuccessful collaborative projects. Research Policy, 36 (8): 1239-1250.

[12] Carayannis, E.G., Rogers, E.M., Kurihara, K. & Allbritton, M.M. (1998). High-technology spin-offs from government R&D laboratories and research universities. Technovation, 18 (1): 1-11.

[13] Carlsson, H., Kettis, A. & Soderholm, A. (2011). Research quality and the role of the university leadership. Commissioned by the Association of Swedish Higher Education (SUHF)/Experts' Committee on Quality. Available via DIALOG. https://gupea.ub.gu.se/bitstream/2077/27835/1/gupea_2077_27835_1.pdf. Cited March 11, 2015.

[14] Chang, D.Y. (1996). Applications of the extent analysis method on fuzzy AHP. European Journal of Operational Research, 95 (3): 649-655.

[15] Cortés-Aldana, F.A., García-Melón, M., Fernández-De-Lucio, I., Aragonés-Beltrán, P. & Poveda-Bautista, R. (2009). University objectives and socioeconomic results: a multicriteria measuring of alignment. European Journal of Operational Research, 199 (3): 811-822.

[16] D'Este, P. & Patel, P. (2007). University-industry linkages in the UK: what are the factors underlying the variety of interactions with industry? Research Policy, 36(9): 1295-1313.

[17] David, P. (1997). The knowledge factory: a survey of universities. The Economist, 345: 1-22.

[18] Dill, D. D. & Soo, M., 2005. Academic quality, league tables, and public policy: a cross-national analysis of university ranking systems. Higher Education, 49(4): 495-533.

[19] Donaldson, B. & Mcnicholas, C. (2004). Understanding the postgraduate education market for UK-based students: a review and empirical study. International Journal of Nonprofit and Voluntary Sector Marketing, 9 (4): 346-360.

[20] Druilhe, C. & Garnsey, E. (2004). Do academic spin-outs differ and does it matter? The Journal of Technology Transfer, 29 (3-4): 269-285.

[21] Druker, P. (1994). Post-capitalist Society. Butterworth Heinemenn, Oxfrod.

[22] Florida, R. (2002). The rise of the creative class. The Washington Monthly, 34(5): 15-25.

[23] Geiger, R. (2004). Knowledge and Money: Research universities and the paradox of the marketplace. Stanford University Press, Stanford.

[24] Gertler, Meric S. & Vinodrai, T. (2005). Anchors of creativity: how do public universities create competitive and cohesive communities? In Taking Public Universities Seriously. Toronto: University of Toronto Press.

[25] Geuna, A. & Muscio, A. (2009). The governance of university knowledge transfer: a critical review of the literature. Minerva, 47(1): 93-114.

[26] Gibbs, G. & Coffey, M. (2004). The impact of training of university teachers on their

teaching skills, their approach to teaching and the approach to learning of their students. Active Learning in Higher Education, 5(1): 87-100.

[27] Goldfarb, B. & Henrekson, M. (2003). Bottom-up versus top-down policies towards the commercialization of university intellectual property. Research Policy, 32 (4): 639-658.

[28] Henderson, R., Jaffe, A. B. & Trajtenberg, M. (1998). Universities as a source of commercial technology: a detailed analysis of university patenting, 1965–1988. Review of Economics and Statistics, 80(1): 119-127.

[29] Herrmann, A., Huber, F. & Braunstein, C. (2000). Market-driven product and service design: bridging the gap between customer needs, quality management, and customer satisfaction. International Journal of Production Economics, 66 (1): 77-96.

[30] Hirai, Y., Watanabe, T. & Inuzuka, A. (2013). Empirical analysis of the effect of Japanese university spinoffs' social networks on their performance. Technological Forecasting and Social Change, 80(6): 1119-1128.

[31] Kembera, D., Hoa, A. & Honga, C. (2010). Initial motivational orientation of students enrolling in undergraduate degrees. Studies in Higher Education, 35 (3): 263-274.

[32] Lam, K. & Zhao, X. (1998). An application of quality function deployment to improve the quality of teaching. International Journal of Quality & Reliability Management, 15(4): 389-413.

[33] Lawton Smith, H. (2003). Universities and clustering. Paper presented at the Academic Summit, TCI conference, Chalmers University, 15 September 2003.

[34] Lee, J.N. & Kim, Y.G. (1999). Effect of partnership quality on IS outsourcing success: conceptual framework and empirical validation. Journal of Management Information Systems, 15(4): 29-61

[35] Leung, L.C. & Cao, D. (2000). On consistency and ranking of alternatives in fuzzy AHP. European Journal of Operational Research, 124 (1): 102-113.

[36] Levin, D. Z., Walter, J. & Murnighan, J. K. (2011). Dormant ties: the value of reconnecting. Organization Science, 22(4): 923-939.

[37] Link, A.N. & Scott, J.T. (2005). Opening the ivory tower's door: an analysis of the determinants of the formation of U.S. University spin-off companies. Research Policy, 34 (7): 1106-1112.

[38] Lockett, A., Siegel, D., Wright, M. & Ensley, M.D. (2005). The creation of spin-off firms at public research institutions: managerial and policy implications. Research Policy, 34 (7): 981-993.

[39] Mikhailov, L. (2003). Deriving priorities from fuzzy pairwise comparison judgements. Fuzzy Sets and Systems, 134 (3): 365-385.

[40] Mok, K.H. (2005). Fostering entrepreneurship: changing role of government and higher education governance in Hong Kong. Research Policy, 34 (4): 537-554.

[41] Morandi, V. (2013). The management of industry-university joint research projects: how do partners coordinate and control R&D activities? The Journal of Technology Transfer, 38(2): 69-92.

[42] Mowery, D.C., Nelson, R.R., Sampat, B.N. & Ziedonis, A.A. (2001). The growth of patenting and licensing by U.S. Universities: an assessment of the effects of the Bayh-Dole act of 1980. Research Policy, 30(1): 99-119.

[43] Nanoka, I. & Takeuchi, H. (2005). The Knowledge-Creating Company. Oxford University Press, New York.

[44] National patterns of research and development resources. (1998). National Science Foundation: NSF, Washington DC. Available via DIALOG. www.nsf.gov/sbe/srs/pubdata.htm.

[45] Nicholls, M. G. (2007). The development of a benchmarking methodology to assist in managing the enhancement of university research quality. Higher Education Quarterly, 61(4): 539-562.

[46] Nonaka, H. Takeuchi. (1995).The Knowledge-Creating Company. Oxford University Press, New York.

[47] OECD. (1999). The response of higher education institutions to regional needs. Paris: OECD.

[48] Owen-Smith, J. & Powell, W.W. (2003). The expanding role of university patenting in the life sciences: assessing the importance of experience and connectivity. Research Policy, 32 (9): 1695-1711.

[49] Perkmann, M., Tartari, V., McKelvey, M., Autio, E., Broström, A., D'Este, P., Fini, R., Geuna, A., Grimaldi, R., Hughes, A., Krabe, S., Kitson, M., Llerena, P., Lissoni, F., Salter, A. & Sobrero, M. (2013). Academic engagement and commercialisation: a review of the literature on university-industry relations. Research Policy, 42(2): 423-442.

[50] Perkmann, M. & Walsh, K. (2007). University-industry relationships and open innovation: towards a research agenda. International Journal of Management Reviews, 9(4): 259-280.

[51] Phan, P.H., Siegel, D.S. & Wright, M. (2005). Science parks and incubators: observations, synthesis and future research. Journal of Business Venturing, 20 (2): 165-182.

[52] Polat, S. (2012). The factors that students consider in university and department selection: a qualitative and quantitative study of Kocaeli University, faculty of education students. Procedia - Social and Behavioral Sciences, 47: 2140-2145.

[53] Ponds, R., Van Oort, F. & Frenken, K. (2007). The geographical and institutional proximity of research collaboration. Papers in Regional Science, 86(3): 423-443.

[54] Rezaei, J. & Ortt, R. (2013). Multi-criteria supplier segmentation using a fuzzy preference relations based AHP. European Journal of Operational Research, 225 (1): 13, 75-84.

[55] Rezaei, J. & Ortt, R., Scholten, V. (2012). Measuring entrepreneurship: expert-based vs. data-based methodologies. Expert Systems with Applications, 39(4): 4063-4074.

[56] Rezaei, J. & Ortt, R., Scholten, V. (2013). An improved fuzzy preference programming to evaluate entrepreneurship orientation. Applied Soft Computing, 13(5): 2749-2758.

[57] Rothaermel, F.T. & Thursby, M. (2005). Incubator firm failure or graduation? The role of university linkages. Research Policy, 34 (7): 1076-1090.

[58] Rotter, J.S., Foerster, D. & Bridges, J.F.P. (2012). The changing role of economic evaluation in valuing medical technologies. Expert Review of Pharmacoeconomics & Outcomes Research 12(6): 711-723.

[59] Saaty, T. L. (1980). The Analytic Hierarchy Process. McGraw-Hill, New York.

[60] Saaty, T. L. (1977). A scaling method for priorities in hierarchical structures. Journal of Mathematical Psychology, 15(3): 234-281.

[61] Saaty, T.L. & Vargas, L.G. (2012). Models, methods, concepts & applications of the analytic hierarchy process. International Series in Operations Research & Management Science, Vol.175, Springer Science & Business Media, US.

[62] Salimi, N. & Rezaei, J. (2013). University Relationship Management: an introductory overview. Paper presented at the 19th IEEE & ICE-ITMC International conference on Technology and Innovation Management, June 24-26 2013, Den Haag, The Netherlands.

[63] Salimi, N., Bekkers, R. & Frenken, K. (2013). Governance and success of university-industry collaborations on the basis of Ph.D. projects – an explorative study. ECIS working paper, 13.05.

[64] Salimi, N., Bekkers, R. & Frenken, K. (2014). Does working with industry come at a price? A study of doctoral candidates' performance in collaborative vs. non-collaborative Ph.D. projects. ECIS working paper, 14.09.

[65] Salimi, N., Bekkers, R. & Frenken, K. (2014). Governance mode choice in collaborative Ph.D. projects. The Journal of Technology Transfer, DOI: 10.1007/s10961-014-9368-5.

[66] Santoro, M.D. & Bierly, P. (2006). Facilitators of knowledge transfer in university-industry collaborations: a knowledge-based perspective. Engineering Management, IEEE Transactions on, 53 (4): 495-507.

[67] Shattock, M. (2010). Managing Successful Universities. McGraw-Hill International.

[68] 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. Research Policy, 32 (1): 27-48.

[69] Simoesa, C. & Soaresa, A.M. (2010). Applying to higher education: information sources and choice factors. Studies in Higher Education, 35 (4): 371-389.

[70] Smedlund, A. (2006). The roles of intermediaries in a regional knowledge system. Journal of Intellectual Capital, 7 (2): 204–220.

[71] Stokes, D.E. (1997). Pasteur's Quadrant: Basic science and technological innovation. Brookings Institution Press.

[72] Thune, T. (2009). Doctoral students on the university-industry interface: a review of the literature. Higher Education, 58 (5): 637-651.

[73] Thursby, J.G. & Kemp, S. (2002). Growth and productive efficiency of university intellectual property licensing. Research Policy, 31 (1): 109-124.

[74] Thursby, J.G., Jensen, R. & Thursby, M.C. (2001). Objectives, characteristics and outcomes of university licensing: a survey of

major U.S. universities. The Journal of Technology Transfer, 26 (1): 59-72.

[75] Van Gils, M.J. (2012). The Organization of Industry-Science Collaboration in the Dutch Chemical Industry. Dissertation. University Nijmegen.

[76] Van Laarhoven, P.J.M. & Pedrycz, W. (1983). A fuzzy extension of Saaty's priority theory. Fuzzy Sets and Systems, 11 (1–3): 199-227.

[77] Vinodh, S., Varadharajan, A.R. & Subramanian, A. (2013). Application of fuzzy VIKOR for concept selection in an agile environment. The International Journal of Advanced Manufacturing Technology, 65(5-8): 825-832.

[78] Walsh, J. W. (2002). Public research, patents and implications for industrial R&D in the drug, biotechnology, semiconductor and computer industries. In: Wessner, C.W. (ed.), capitalizing on new needs and new opportunities: Government-industry partnerships in biotechnology and information technologies, pp. 223-243. National Academy Press, Washington DC.

[79] Wang, Y.M., Elhag, T.M.S. & Hua, Z. (2006). A modified fuzzy logarithmic least squares method for fuzzy analytic hierarchy process. Fuzzy Sets and Systems, 157 (23): 3055-3071.

[80] Wright, M., Clarysse, B., Lockett, A. & Knockaert, M. (2008). Mid-range universities' linkages with industry: knowledge types and the role of intermediaries. Research Policy, 37 (8): 1205-1223.

[81] Zhu, K.J., Jing, Y. & Chang, D.Y. (1999). A discussion on extent analysis method and applications of fuzzy AHP. European Journal of Operational Research, 116 (2): 450-456.

Negin Salimi is a post-doc researcher at Delft University of Technology, The Netherlands. She holds a PhD from faculty of Industrial Engineering & Innovation Sciences, Eindhoven University of Technology, the Netherlands. Her research interests include university-industry relationships, knowledge management, innovation management, responsible innovation, and multi-criteria decision-making. She has published in highly ranked journals including the International Journal of Production Economics, the International Journal of Systems Science, and The Journal of Technology Transfer.

Jafar Rezaei is an assistant professor of operations and supply chain management at Delft University of Technology, the Netherlands, where he obtained his Ph.D. in 2012. His main research interests are in the areas of logistics and supply chain management, and multi-criteria decision-making. He has presented his works in several international conferences, and has published in various academic journals, including the International Journal of Production Economics, the International Journal of Production Research, Industrial Marketing Management, Expert Systems with Applications, Applied Soft Computing, the IEEE Transactions on Engineering Management, and the European Journal of Operational Research.