Technological Forecasting & Social Change xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Technological Forecasting & Social Change

The technology networks and development trends of university-industry collaborative patents

Shu-Hao Chang

Science and Technology Policy Research and Information Center, National Applied Research Laboratories, 14F., No. 106, Sec. 2, Heping E. Rd., Da'an Dist., Taipei 10636, Taiwan, ROC

ARTICLE INFO

Article history:
Received 25 March 2016
Accepted 6 February 2017
Available online xxxx

Keywords:
University-industry collaboration
Patent network
Network analysis
Key technology

ABSTRACT

In recent years, the number of studies pertaining to university-industry collaboration (UIC) has increased exponentially apace with the increasing attention attached to UIC issues and the development of UIC. However, the majority of previous UIC studies pertaining focus on investigating the motivations of UIC, types of collaboration, and UIC performance, and studies that highlight the focal technology fields, technology development trends, and technology network distribution of UIC remain scarce. Moreover, previous studies seldom mention the position and ranking of countries in technology networks. The present study employed a two-mode network analysis (countries and technology fields) method to highlight the pivotal role of various countries in technology networks. Finally, the dynamic analysis method was employed to analyze data in different periods to determine technology development trends. Findings revealed discrepancies between the focus of technologies over time. The key technologies in the more recent UIC technology network were largely in the fields of measurement and chemistry, which are characterized as basic sciences with cross-disciplinary traits. In addition, the development of these technology reflects the recent efforts of various countries promoting emerging technology fields. Findings also indicated that Japan and the United Stated served crucial roles in UIC technology networks.

1. Introduction

Recent studies have indicated that a country's university-industry research and development collaboration benefits its national innovation capacity and economic growth (Schofield, 2013; Temel and Glassman, 2013). Through university-industry collaboration (UIC), university researchers are able to gain research funding while offering their views and skills to companies. Firms can utilize and internalize these views and skills to promote scientific advancement and product innovation (Link and Scott, 2005; Veugelers and Cassiman, 2005). Since the passing of the Bayh-Cole Act in the United States in 1980, which changed previous policies that obligated inventors to assign inventions produced through federal funding over to the federal government, university patent applications and efforts to gain industrial support have increased exponentially (Baldini, 2009; Feller and Feldman, 2010; Tantiyaswasdikul, 2012). Thereafter, methods to promote UIC and the application and expansion of relevant research outcomes gradually attracted global attention (Bodas Freitas et al., 2013; Rasmussen and Sørheim, 2012)

UIC research has gained considerable attraction in recent years, where progress can be observed in three primary directions. The first group of studies is based on the triple helix model and relevant theories, and advocates increased association between universities, government departments, and private businesses (Etzkowitz, 2003). These studies further investigate the mechanisms and motives for promoting UIC (Rasmussen and Sørheim, 2012; Schofield, 2013; Temel and Glassman, 2013). The next group of studies is prompted by the increasingly important function of universities in the creation of new systems. They primarily investigate the patterns of UIC (Ngar-yin Mah and Hills, 2014; Powers and McDougall, 2005; Santoro and Chakrabarti, 2002). The final group of studies focuses on the complementary assets and knowledge of UIC, which create more opportunities for research partners to share knowledge and exchange resources. Therefore, these studies largely assess the output and performance of UIC (Al-Ashaab et al., 2011; Lee et al., 2012; Rigby and Edler, 2005).

However, the aforementioned studies failed to elaborate which technology fields are central to UIC, and studies that focus on the technology fields relevant to UIC and the industries that are potentially affected by UIC remain scarce. The present study endeavors to mitigate this research gap by examining emerging UIC technologies based on UIC patents. A two-mode network analysis method is employed to separately analyze the technology fields of UIC patents and the nationalities of assignees. The analysis results are then used to create UIC patent technology networks and highlight the differences in the UIC technology fields in various countries. Data from different time periods are then examined to track the development trends of UIC technologies.

Focusing on the technology networks of UIC, the present study adopts a patent analysis method to establish a network model for UIC

E-mail address: shchang@narlabs.org.tw.

http://dx.doi.org/10.1016/j.techfore.2017.02.006

technologies. Patents directly reflect innovative output. Therefore, they can serve as an indicator for measuring national technology output (Eaton and Kortum, 1996) and UIC achievement industrialization (Casper, 2013; Lee et al., 2012; Okamuro and Nishimura, 2013; Ponomariov, 2013). Moreover, numerous previous studies have adopted patent-analysis methods to measure technology transfer (Branstetter et al., 2006; Feller and Feldman, 2010; Park et al., 2012), and thus patent data can serve as an indicator for measuring technology development. Hence, the present study analyzes patent data to determine the development trends of UIC technologies and identify key technology fields.

In brief, the distinction of the present study from previous UIC mechanism and performance evaluation studies is that the present study aims to examine the key technologies of UIC, where prominence is attached to establishing a technology network model and determining technology development trends. In addition, the present study adopts a longitudinal research design, where patent data from different periods are analyzed to determine the development trends of UIC technologies. The findings of the present study can serve as a reference for the government, relevant industries, and academic institutes.

2. Literature review

The literature review performed in the present study is largely characterized into three parts, namely, investigating UIC and technology industrialization, collaborative patents, and patent network analysis.

2.1. UIC and technology industrialization

UIC research has gain a steady annual growth, particularly following the introduction of the triple helix model (Calvert and Patel, 2003; Etzkowitz and Leydesdorff, 2000). Many countries endeavor to strengthen interdepartmental relationships between helices, which include the collaboration of universities and industries. An increased number of funding projects are introduced for collaborative research projects. For example, the "SIGNO Germany" project endeavors to reinforce the innovation activities in small and medium enterprises (SMEs). Subsequently, the "SIGNO University" sub-project focuses on promoting the mid- and long-term collaboration and partnerships between universities and industries, and supports the technology transfer between the two sectors (BMWi, 2014). Another example is the Israeli "Magnet Project." This particular project encourages paired collaboration between universities and industries of the same discipline through government funding. Within a two-year collaboration period, industries are not only able to materialize university achievements, but also develop their research and development capabilities (The Office of the Chief Scientist, 2013). Under the consensus of all membership countries, the Framework Programmes: 2007–2013 (FP7) introduced the European Technology Platforms (ETPs) to reinforce narratives between interested academic and industrial parties, greatly improving the effectiveness of the Research Joint Venture.

From the preceding descriptions, it is evident that establishing close collaborative relationships through university-industry exchange has become a common practice for various countries in improving their national innovation capacity. The importance of UIC research partially reflects universities' demand for industry funding to conduct research (Powers, 2003), and partially reflects industries' demand for the industrialization of university research achievements. Since the 1980s, universities in the United States have attached increasing value to patent and authorization strategies. This increased value has elevated the importance of UIC research in universities such as the University of California and Stanford University and prompted the emergence of various integrated technology transfer strategies (Mowery, 2007). A number of universities have attempted to transition into "entrepreneurial universities" in the active promotion of UIC research and pursuit of establishing and solidifying their market knowledge and innovation networks (Guerrero and Urbano, 2012; Powers and McDougall, 2005).

In fact, numerous studies have proposed evidence supporting the benefits of increased university-industry relationships on the industrialization of academic research and development (O'Shea et al., 2005; Powers, 2003), and that the provision of industrial funding into academic research positively affects development of patents and spin-off companies (Di Gregorio and Shane, 2003; O'Shea et al., 2005; Powers, 2003; Powers and McDougall, 2005). Relative to government-funded research, UIC research achievements are typically more practical and easier to industrialize (Di Gregorio and Shane, 2003; Powers, 2003). Di Gregorio and Shane (2003) found that industry-funded studies are typically more risk averse, and are thus more market-friendly, and that the lack of information asymmetry in terms of market demands in industry-funded studies renders the research achievements easier to industrialize. Additionally, UIC enables the interaction between university scientists and industry researchers. Such channels and networks of communication benefit the industrialization of research achievements. Festel (2013) found that UIC enables university research and development achievements to gain a diffusion effect, which increases the opportunity for universities to attract external resources and form new start-ups. The application of an open UIC model facilitates researchers in identifying potential and novel business opportunities and applying for patents to protect their research achievements (Okamuro and Nishimura, 2013; Ponomariov, 2013; Tantiyaswasdikul, 2012).

2.2. Collaborative patent

Patent data are an open and available data source. Numerous previous studies have used patent data to evaluate technology transfer (Branstetter et al., 2006; Feller and Feldman, 2010; Park et al., 2012) and UIC achievements (Casper, 2013; Lee et al., 2012; Okamuro and Nishimura, 2013; Ponomariov, 2013), confirming that patents are key indicators of national innovation performance and industrial technology development (Casper, 2013; Lee et al., 2012; Okamuro and Nishimura, 2013; Ponomariov, 2013). Patent analysis is a tool or technique employed in numerous studies to measure innovation (Branstetter et al., 2006; Casper, 2013; Feller and Feldman, 2010; Tantiyaswasdikul, 2012). In actuality, patent application information provides data concerning the inventors and assignees of technology collaborations and inventive processes. A number of studies have used patent analysis to examine the technology collaboration efforts and relevant information (Etemad and Seguin-Dulude, 1987; Hong and Su, 2013). Ma and Lee (2008) primarily analyzed the techno-globalism phenomenon through patent data, where the co-assignee index was used to measure the level of technology collaboration between the United States and other countries. Patents with shared ownership between technology collaborators are known as joint patents (Kim and Song, 2007). The present study evaluated patents with joint university-industry ownership, or collaborative patents, to measure the development trends of UIC technologies worldwide.

Evaluating collaborative patents facilitates researchers in gaining a better understanding of the expansion of knowledge (Guan and Chen, 2012), the collaboration networks within innovation systems (Fleming et al., 2007), and innovation performance of research and development alliances (Lin et al., 2012). The objectives of UIC are to promote the expansion of knowledge, establish collaboration networks between academia and industries, and form research and development alliances to enhance overall innovation performance. Therefore, using collaborative patents to evaluate UIC technology development satisfies the objectives of establishing UIC. In addition, the technology fields jointly emphasized by academia and industries can be identified by observing the key technologies in collaborative patents. Based on the preceding descriptions, the present study plotted the development trends of UIC technology networks through the analysis of collaborative patents.

Please cite this article as: Chang, S.-H., The technology networks and development trends of university-industry collaborative patents, Technol. Forecast. Soc. Change (2017), http://dx.doi.org/10.1016/j.techfore.2017.02.006

2.3. Patent network analysis

In recent years, a number of studies have used network analysis methods to evaluate the technology development pathways in specific industries (Cecere et al., 2014; Dolfsma and Leydesdorff, 2011; Goetze, 2010). Other studies have employed patent network analysis methods to determine the knowledge exchange and technology collaboration between specific regions or countries (Chen et al., 2013; Ejermo and Karlsson, 2006), and identify the knowledge maps and technology development trends of the research countries (Dolfsma and Leydesdorff, 2011; Lee and Kim, 2010). Patent network analysis presents two policy implications. First, when patents are used as the sources of technology and business knowledge, network analysis can be employed to determine the linkage of individual technologies, providing a useful tool for the management of research and development activities (Lee and Kim, 2010; Park et al., 2012). For instance, patent network analysis can be used to determine the centrality of individual technologies and define technical niches, which can serve as reliable policy indicators.

Second, patent network analysis can be used to determine the evolution patterns of technology centrality. Patents provide objective and reliable data, including quantity, approval dates, and technology types (Park et al., 2012). Thus, observing the evolution of technologies over time can improve technology management ad achieve effective strategic planning. The present study employed a patent network analysis method over different periods to observe the distribution of UIC patents over time, thereby determining technology development trends.

3. Research design

3.1. Data collection

In terms of data sources, the present study primarily collected data from the United States Patent and Trademark Office (USPTO) for the following reasons: (1) The USPTO database is a representational database. Inventors typically apply for protection in the United States along with other countries. (2) The United States is the world's largest commercial market. (3) The USPTO possesses an extensive database, with system development and patent data dating back to 1975. (4) The US patent system is considered a universal database for international technology analysis (Bass and Kurgan, 2010). Subsequently, a survey on five intellectual property offices conducted in 2015 showed that the nationality distribution of patent applicants in the USPTO is extremely diverse. In terms of Taiwanese applicants, the number of applications submitted to the USPTO far exceeds the number of applications submitted to the Japan Patent Office (JPO) and the State Intellectual Property Office of the People's Republic of China (SIPO) (Five IP Offices, 2015), highlighting the appeal of the USPTO to patent applicants in other countries. The present study aimed to conduct a hierarchical analysis on nationalities, and thus selected the USPTO database for patent analysis.

In terms of the research period, data concerning UIC patent technologies were collected in two separate periods, specifically 2004 to 2008 and 2009 to 2013, to observe technology development trends. The present study set 2013 as the cutoff year for patent approvals. This was because patent applications require a specific review period, and because review times are inconsistent with each patent application. To avoid biases in the UIC achievement and technology data caused by different patent review periods, the present study excluded all patents approved after 2013. For instance, when achievements produced by a single UIC projects are submitted for protection, they should theoretically be approved in the same year. However, due to the different review periods for each achievement, certain achievements are approved after 2014. This leads to the right truncation problem. To prevent the occurrence of this problem, the present study only collected patents approved prior to 2013, although data following 2013 were available in the database.

In terms of the technology classification of UIC patents, the present study adopted the International Patent Classification (IPC) analysis framework. Although many previous studies have used the United States Patent Classification (USPC) as the basis for the coding of their technology fields (Choe et al., 2013; Kim et al., 2015), USPC adopts a horizontal classification system, where neighboring subclasses are not closely associated. This causes analysis results to be disorderly and complex and cross-classification technologies to be unintuitive. For example, the classification codes for surgical instruments are 128, 600, 601, and 602 (White, 2010). Furthermore, although the USPTO and the European Patent Office (EPO) jointly introduced the Cooperative Patent Classification (CPC) in early 2013, the present study continued to use the IPC framework to classify the technology networks of the patents in three stages. The reason was that the present study primarily analyzed patents approved between 2004 and 2013. In addition, the three-stage IPC coding method was similar to that used in CPC, and thus produced similar classification results.

3.2. Classification of assignees

Information contained in patent documents can provide valuable messages for evaluating inventive activities. For example, the Inventor or Assignee fields can be used to evaluate collaboration conditions (Chen et al., 2013; Ejermo and Karlsson, 2006; Hong, 2008), where inventors refer to the creators of the innovative technologies, whereas assignees refer to the commercial rights holder of the technology. The present study focused on the key technology fields concerning UIC achievement industrialization, where industrialization processes are correlated to the commercial value of patents. Therefore, the Assignee field was the primary target of analysis. In terms of measuring UIC patents, the present study defined patents such as those that are co-assigned to universities and enterprises (Hong, 2008; Tantiyaswasdikul, 2012). The Organization for Economic Co-operation and Development (OECD) previously announced a set of crucial keywords/clues used to identify patentee sectors (OECD, 2009). The present study adopted this set of keywords/clues to classify patent assignees. In terms of assignee nationality, the Address field was used to determine assignee nationality. Assignees can largely be characterized into three classifications:

1. Single assignee: This refers to patents with only one assignee. The rights to such patents are exclusive and no collaboration behavior exists in the inventive process.
2. Multiple assignees: This refers to patents with two or more assignees. The rights to such patents are inclusive of all assignees and assignees have collaborative relationships. The present study primarily analyzed this class of patents.
3. No assignee: This refers to patents with a blank Assignee field. According to US Patent Law, in the event that an assignee is not provided during the application process, inventors reserve the right to file a litigation against the patent. Companies or enterprises that wish to acquire patent rights shall do so through the process of patent transfer. Therefore, patents with no assignees are owned by the inventors.

3.3. Assignee authority control

Assignee names may be presented in different forms on the patent. For example, companies may decide to use their full names or only their abbreviations. They may even choose to list the name of their affiliated companies. Therefore, authority control is essential. Authority control is a unification process for assignee names, which enhances the accuracy of research by preventing the patents of the same assignee from being recorded under different aliases. Additionally, authority control can be employed to rectify slight errors in assignee names, such as capitalization, spelling, and symbol errors, to maintain consistency.

Please cite this article as: Chang, S.-H., The technology networks and development trends of university-industry collaborative patents, Technol. Forecast. Soc. Change (2017), http://dx.doi.org/10.1016/j.techfore.2017.02.006

Moreover, a manual verification process was adopted to confirm the UIC of the patents.

3.4. UIC patent technology network

A single patent may comprise numerous technology fields, and the patents of a single country encompass a wide range of technology fields. Thus, the present study adopted a two-mode network analysis method to develop a country-technology network model, where one set of coordinates represents technology codes, and the other set represents country codes. A visual country-technology network model enables researchers to elucidate the positions of UIC patent technologies. Previous studies concerning country and technology networks have distributed the patents of single countries in technology classification systems to create patent interaction networks. These interaction networks were then used to explain the technology development strategies in those countries (Lee and Kim, 2010; Lee et al., 2009). Other studies have examined the patent co-classifications of different countries to determine technology development trends and evolution pathways (Graf, 2012). However, previous studies that adopted country-technology network methods to directly observe the position of a country in technology networks remain scarce. The present study adopted a two-mode network analysis method to analyze UIC patent technology networks and determine the core countries and technologies of UIC.

3.5. UIC technology development trends

The UIC patent technology network analysis method developed in the present study comprised two modes. The first mode was used to determine the key technologies in technology networks. This mode excluded time as a factor of analysis, and thus approval dates were not included as variables in the analysis process. The second mode was used to determine the movement and development trends of various technologies. In this mode, approval dates were included as variables in the analysis process to highlight the changes in technology development. The present study selected the technological changes in the recent decade as the target of analysis, where UIC patent technologies approved between 2004 and 2008, as well as 2009 and 2013, were examined to elucidate the trends of UIC technologies in these two periods (with 2008 as the cutoff point).

4. Results

4.1. Key UIC technologies

In terms of key UIC technologies, the present study established a network model with 562 patents approved between 2009 and 2013. The model was developed based on a three-stage IPC framework and using 161 IPC classification codes. The network model is illustrated in Fig. 1. The key IPC codes are tabulated in Table 1.

Closeness centrality and eigenvector centrality represent the association between technology fields, where technology fields with increased closeness and eigenvector values suggest an increased number of associations with other technology fields and an increased prominence with the technology network. According to Table 1, A61K, G01N, C08F, C12Q, C07F, and C07D were the technology fields with the highest closeness and eigenvector values, suggesting that UIC primarily focus on the fields of medicine (e.g., A61K), measurement (e.g., G01N), and chemistry (e.g., C08F, C12Q, C07F, and C07D). Betweenness centrality can be used to represent the reliance of certain nodes in a network on other nodes (mediators or media), which enables these nodes to connect with other nodes. In a technology network, nodes with higher betweenness centrality values represents that the representative technology holds a prominent position within the network structure, and that the connection and circulation of the other nodes in the network are dependent on the prominent nodes. Table 1 shows that G01N, H01L, G01R, G06F, and H01S were the technology fields with the highest betweenness centrality values, which belonged to the fields of measurement (e.g., G01N, G01R, and G06F) and electricity (e.g., H01L and H01S).

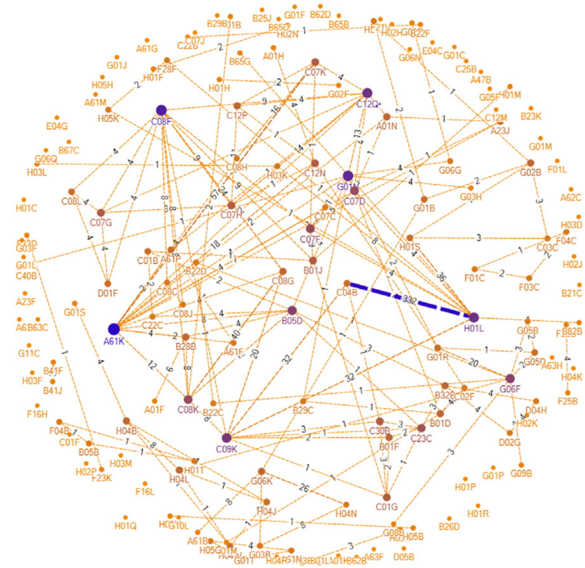

Fig. 1. The UIC network map under the three-stage IPC network. Note: The number of connections of each node is represented by size; a broader curve denotes a stronger connection.

4.2. Country-technology network analysis

The present study adopted a two-mode network analysis method to analyze country-technology networks. The results are illustrated in Fig. 2.

Fig. 2 shows that Japan was the country with the highest number of connected technology nodes in the UIC country-technology networks (92 nodes), followed by the United States (39 nodes) and China (24 nodes). The various key players in the two-mode network analysis are tabulated in Table 2.

Table 2 shows that Japan and the United States were the countries with the highest closeness and eigenvector centrality values, which suggest that in the UIC technology network, the technologies in these countries hold more associations, and that these countries hold prominent positions in the global network. Additionally, India was a particularly noticeable country, which ranked top five in the world for eigenvector centrality. Eigenvector centrality not only shows the number of connections a node has with other nodes, but also determines whether the connection between nodes possesses high centrality and considers the centrality contribution that neighboring nodes have on the node (Borgatti and Everett, 2006).

Table 1
Top five IPC codes for UIC.

Top five three-stage IPC codes	Closeness centrality	Top five three-stage IPC codes	Eigenvector centrality	Top five three-stage IPC codes	Betweenness centrality
A61K	36.762	A61K	0.571	G01N	1285.167
G01N	35.695	C12Q	0.468	H01L	1042.281
C08F	33.755	C08F	0.395	G01R	780
C12Q	33.679	G01N	0.370	G06F	670
C07F	33.467	C07D	0.364	H01S	552

Please cite this article as: Chang, S.-H., The technology networks and development trends of university-industry collaborative patents, Technol. Forecast. Soc. Change (2017), http://dx.doi.org/10.1016/j.techfore.2017.02.006

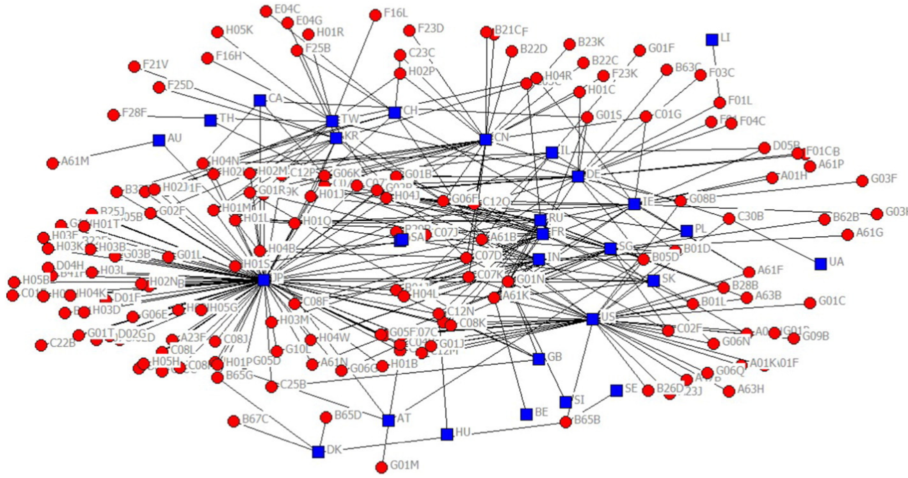

Fig. 2. The country-technology network map.

Technology nodes that are associated with India, such as A61K, C07F, C08F, and G01N, are nodes with high centrality. Therefore, India achieved a high eigenvector centrality value. In terms of betweenness centrality, Japan, the United States, China, Germany, and Taiwan achieved a high betweenness centrality value during the two-mode technology network analysis, suggesting that these countries function as key mediators in the technology network, responsible for the connection and circulation among technology nodes. The focal technologies of the top five countries in terms of betweenness centrality are tabulated in Table 3.

Table 3 shows that the UIC technologies are concentrated in the fields of semiconductors (H01L) and chemistry (C08F and C04B) in Japan, medicine (A61K) in the United States, chemistry (C07D and C30B) and electronic and digital data processing (G06F) in China, measurement in Germany (G01B and G01N), and electricity in Taiwan (H01F, H02M, H01Rl, and H05K).

4.3. UIC technology development trends

The present study also analyzed the technology networks in different periods to determine the changes in the focus of research and development over time. The results were used to describe the development trends of UIC technologies. Technology development movement and trends were determined by analyzing the increase and decrease in IPC code centrality values between two periods (with 2008 as the cutoff point). The results are tabulated in Table 4.

Table 4 shows that for UIC patents approved prior to 2008, B29C, B32B, and H01L were the technologies with the highest closeness and eigenvector centrality values, which were in the fields of operations and transportation (B29C and B32B) and semiconductors (H01L). Technology focus shifted to measurement (G01N) and chemistry (C08F, C12Q, C07F, and C07D) following 2008. Moreover, betweenness centrality values of technologies approved prior to 2008 were primarily concentrated in the field of operations and transportation (B29C and B32B), and those approved following 2008 were concentrated in the field of measurement (G01N, G01R, and G06F).

5. Conclusion

5.1. Discussion

The present study employed a network analysis method to examine UIC patent data and investigate the key technologies of UIC. In addition, a country-technology network analysis method was adopted to determine the mediating function of various countries within the UIC technology network, where network models of different periods were established to highlight the development trends of key technologies. The combined findings of the literature review and data analysis conducted in the present study are discussed in the following section.

Empirical results indicate that recent key fields in UIC include measurement and chemistry, which are basic sciences. These results also highlight the industries' need to collaborate with universities to effectively research, develop, and apply these technologies. Furthermore, these fields are cross-disciplinary technology fields. For example, technologies related to measurement include extraction devices, measuring electrical variables, and digital data processing; whereas those related to chemistry include polymerization processes, measuring microorganisms, and compounds. The application technologies currently under vigorous development in numerous countries, such as nanotechnology, advanced materials, biotechnology, and micro-system technology, are related to these basic technology fields. For example, the key technologies previously promoted in the Horizon 2020 (European Commission, 2016) and the High-tech Strategy 2020 for Germany, which was passed by the German Federal Government in 2010 (BMBF, 2010), highlighted clear goals and development directions for these technology fields. Therefore, the distribution of UIC technology fields reflects the global development trends of emerging fields.

The country-technology network analysis results revealed that Japan and the United Stated played crucial roles in the UIC technology network. In the past, Japan has invested considerable effort in UIC, such as the Hiranuma Plan proposed in 2001. The purpose of this plan was to promote the development of enterprises through the collaboration with universities, the industrialization of university research achievements, and the relationship between universities and industries

Table 2
The centrality of UIC networks worldwide.

Top 5 key player	Closeness centrality	Top 5 key player	Eigenvector centrality	Top 5 key player	Betweenness centrality
JP	125.917	JP	0.859	JP	10,483.867
US	90.200	US	0.285	US	3615.170
G06F	88.200	G01N	0.187	CN	1927.057
G01N	87.667	IN	0.175	DE	1724.194
A61K	84.367	A61K	0.171	TW	1326.622

Table 3
The focal technologies in leading countries.

Countries	Differences in focal technologies
JP	H01L, C08F, C04B, and G06K
US	A61K and G06Q
CN	C07D, C30B, G06F, and B01F
DE	G01B, G01N, B63C, and C07H
TW	H01F, H02M, H01R, H05K, and F28F

Please cite this article as: Chang, S.-H., The technology networks and development trends of university-industry collaborative patents, Technol. Forecast. Soc. Change (2017), http://dx.doi.org/10.1016/j.techfore.2017.02.006

Table 4
UIC technology development trends.

Centrality index	Focal technologies in period 1	Focal technologies in period 2	Added technology fields	Omitted technology fields
Closeness centrality	B29C, B32B, H01L, C12N, and A61K	A61K, G01N, C08F, C12Q, and C07F	G01N, C08F, C12Q, and C07F	B29C, B32B, H01L, and C12N
Eigenvector centrality	C12N, B29C, A61K, B32B, and H01L	A61K, C12Q, C08F, G01N, and C07D	C12Q, C08F, G01N, and C07D	C12N, B29C, B32B, and H01L
Betweenness centrality	B29C, B32B, H01L, A61K, and C12N	G01N, H01L, G01R, G06F, and H01S	G01N, G01R, G06F, and H01S	B29C, B32B, A61K, and C12N

Note: Period 1 comprised 245 patents over 147 IPC codes approved between 2004 and 2008.

(Walsh et al., 2008). In June 2001, Atsuko Toyama, minister of MEXT (Ministry of Education, Culture, Sports, Science and Technology) announced the "Structural Reforms Policies for National Universities" (Toyama Plan), which aimed to corporatize national universities and indirectly encourage universities to engage in UIC (Ono, 2012). By contrast, the United States established numerous innovative collaboration systems centered on universities. For example, Silicon Valley successfully linked academia and industry through Stanford University, and effectively converted university research and development achievements into applicable industrial technology. Another example is the Research Triangle Park, which is representational to the UIC in the United States and a benchmark for the development of science parks in other countries. In addition to Japan and the United States, China, Germany, and Taiwan have actively promoted UIC in recent years. For example, the State-level Science & Technology Industrial Parks in China and the Action Plan Nanotechnology 2015 in Germany emphasize enterprise participation and the practical application of research results produced in universities and research institutes. Another example is Taiwan's Major and Minor Alliances between Academia and Industry.

In terms of technology trends, findings revealed a significant shift of focus in UIC technologies over time. Currently, the focus of UIC technology development is largely in the fields of measurement and chemistry, which is relatively different to previous trends in the fields of operations and transportation. Measurement and chemistry are basic sciences, and are often applied in cross-disciplinary research. The findings of the present study also correspond to the development trends of current emerging fields.

In terms of theoretical contribution, the majority of previous studies pertaining to UIC focused on investigating the motivations of UIC (Schofield, 2013; Temel and Glassman, 2013), types of collaboration (Ngar-yin Mah and Hills, 2014; Powers and McDougall, 2005; Santoro and Chakrabarti, 2002), and UIC performance (Al-Ashaab et al., 2011; Lee et al., 2012; Rigby and Edler, 2005). However, studies that highlight the focal technology fields, technology development trends, and technology network distribution of UIC remain scarce. The present study endeavored to close this research gap by employing an unprecedented technology-field observation method to analyze UIC patents and determine emerging UIC technologies. In addition, a two-mode network analysis method was used to examine UIC patent networks and determine the development of UIC technology fields in various countries.

5.2. Policy implications

In terms of policy implications, the technology networks derived from the UIC patents can serve as extremely valuable information for the government. A two-mode network analysis method was used to examine these technology networks and elucidate the focal UIC technologies developed in various countries. These data can serve as a useful reference for the provision of research resources and the promotion of emerging technologies by the government. The practical contributions of the present study are explained in the following section.

1. Useful information for the provision of research resources

The technology policies in various countries are currently in a transitional stage. In addition to conventional research-oriented technology projects, policies should also focus on expanding the application of research achievements. Thus, universities began to seek industrial collaboration and reinforce the association between technology research and socioeconomic issues. In this context, relevant UIC mechanisms and research and development evaluations became key issues in national policies. The results of the present study are especially meaningful to university scientists, industry participants, and policy formulators during the allocation of resources, particularly for identifying key industrialized technologies.

In terms of defining key industrialized technologies, UIC patents typically implicate a portion of the technology's commercial value or application potential, and thus represents that the technology can achieve favorable industrial development and application. Analyzing UIC technology patent networks provides insight into which key technologies demonstrate the potential for industrialization, and is an effective evaluation tool for highlighting technologies with favorable market prospects. The findings of the present study indicated that A61K, G01N, C08F, and C12Q, which were largely in the fields of measurement and chemistry, were the key players in the UIC technology network (Table 1).

2. Useful information for the promotion of emerging technologies

The present study analyzed the development trends of UIC technologies in two successive periods (using 2008 as the cut-off point). Technological changes in the recent decade were examined to elucidate the changes in development focus. The results of this analysis can serve as a reference for the promotion of emerging technologies in various countries.

Finally, the present study proposed a UIC technology patent network model. A country-technology two-mode network analysis method was adopted to highlight the ranking of industrialized technologies in various countries. The proposed model clearly highlights the focus of technology development in leading countries, which can serve as a reference for the Taiwanese government.

5.3. Limitations and future research directions

First, the observations concerning the trends of technology development were made purely based on UIC patents. However, UIC output extends beyond patents and includes different forms of output and modes, such as personnel exchange, intangible technical collaboration, or specific products. Other forms of output and modes were not included in the scope of research. This was a major limitation in the present study. Second, the present study was a quantitative study that focused on the scope of research topic rather than depth. Future studies can consider including case analysis or other research methods to enhance the academic value of the present study. Finally, due to limited human and financial resources, the present study only analyzed patents stored in the USPTO database, the world's largest commercial transaction market. However, patents are territorial, and the application of patents is closely associated with local market factors. Thus, only analyzing the UIC technologies of US patents may cause results to be biased towards specific market preferences and trends. As a resolve, future studies with more adequate labor and financial resources may include data from other patent countries, such as the SIPO. According to the latest statistics of the WIPO, SIPO has showed most prominent growth among the top ten patent offices worldwide, with an annual growth of 26.4% in 2013

(WIPO, 2014). Therefore, including data from the SIPO and verifying different data sources through triangulation should greatly enhance the observation accuracy of emerging technology development.

Acknowledgements

The authors would like to thank the Ministry of Science and Technology of the Republic of China (Taiwan) for financially supporting this research under Contract No. MOST 105-2410-H-492-001.

References

Al-Ashaab, A., Flores, M., Doultsinou, A., Magyar, A., 2011. A balanced scorecard for measuring the impact of industry-university collaboration. Prod. Plan. Control 22 (5/6), 554–570.

Baldini, N., 2009. Implementing Bayh-Dole-like laws: faculty problems and their impact on university patenting activity. Res. Policy 38 (8), 1217–1224.

Bass, S.D., Kurgan, L.A., 2010. Discovery of factors influencing patent value based on machine learning in patents in the field of nanotechnology. Scientometrics 82 (2), 217–241.

BMBF, 2010. Ideas. Innovation. Prosperity: High-tech Strategy 2020 for Germany. BMBF, Berlin.

BMWi, 2014. Signo: Patent. BMWi, Berlin, DE.

Bodas Freitas, I.M., Geuna, A., Rossi, F., 2013. Finding the right partners: institutional and personal modes of governance of university-industry interactions. Res. Policy 42 (1), 50–62.

Borgatti, S.P., Everett, M.G., 2006. A graph-theoretic perspective on centrality. Soc. Networks 28 (4), 466–484.

Branstetter, L.G., Fisman, R., Foley, C.F., 2006. Do stronger intellectual property rights increase international technology transfer? Empirical evidence from US firm level panel data. Q. J. Econ. 121 (1), 321–349.

Calvert, J., Patel, P., 2003. University–industry research collaborations in the UK: bibliometric trends. Sci. Public Policy 30 (2), 85–96.

Casper, S., 2013. The spill-over theory reversed: the impact of regional economies on the commercialization of university science. Res. Policy 42 (5), 1313–1324.

Cecere, G., Corrocher, N., Gossart, C., Ozman, M., 2014. Technological pervasiveness and variety of innovators in Green ICT: a patent-based analysis. Res. Policy 43 (10), 1827–1839.

Chen, J.H., Jang, S.L., Chang, C.H., 2013. The patterns and propensity for international co-invention: the case of China. Scientometrics 94 (2), 481–495.

Choe, H., Lee, D.H., Seo, I.W., Kim, H.D., 2013. Patent citation network analysis for the domain of organic photovoltaic cells: country, institution, and technology field. Renew. Sust. Energ. Rev. 26, 492–505.

Di Gregorio, D., Shane, S., 2003. Why do some universities generate more start-ups than others? Res. Policy 32 (2), 209–227.

Dolfsma, W., Leydesdorff, L., 2011. Innovation systems as patent networks: The Netherlands, India and nanotech. Innov. Manag. Policy Pract. 13 (3), 311–326.

Eaton, J., Kortum, S., 1996. Trade in ideas-patenting and productivity in the OECD. J. Int. Econ. 40 (3–4), 251–278.

Ejermo, O., Karlsson, C., 2006. Interregional inventor networks as studied by patent coinventorships. Res. Policy 35 (3), 412–430.

Etemad, H., Seguin-Dulude, L., 1987. Patenting patterns in 25 large multinational enterprises. Technovation 7 (1), 1–15.

Etzkowitz, H., 2003. Innovation in innovation: the triple helix of university-industry-government relations. Soc. Sci. Inf. 42 (3), 293–337.

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.

European Commission, 2016. Horizon 2020: the EU framework programme for research and innovation. Resource Document. European Commission (http://ec.europa.eu/programmes/horizon2020/en/h2020-section/industrial-leadership. Accessed 25 January 2016).

Feller, I., Feldman, M., 2010. The commercialization of academic patents: black boxes, pipelines, and Rubik's cubes. J. Technol. Transfer. 35 (6), 597–616.

Festel, G., 2013. Academic spin-offs, corporate spin-outs and company internal start-ups as technology transfer approach. J. Technol. Transfer. 38 (4), 454–470.

five IP offices, 2015. 2014 Key IP5 Statistical Data. five IP offices, Munich.

Fleming, L., King III, C., Juda, A.I., 2007. Small worlds and regional innovation. Organ. Sci. 18 (6), 938–954.

Goetze, C., 2010. An empirical enquiry into co-patent networks and their stars: the case of cardiac pacemaker technology. Technovation 30 (7/8), 436–446.

Graf, H., 2012. Inventor networks in emerging key technologies: information technology vs. semiconductors. J. Evol. Econ. 22 (3), 459–480.

Guan, J., Chen, Z., 2012. Patent collaboration and international knowledge flow. Inf. Process. Manag. 48 (1), 170–181.

Guerrero, M., Urbano, D., 2012. The development of an entrepreneurial university. J. Technol. Transfer. 37 (1), 43–74.

Hong, W., 2008. Decline of the center: the decentralizing process of knowledge transfer of Chinese universities from 1985 to 2004. Res. Policy 37 (4), 580–595.

Hong, W., Su, Y.S., 2013. The effect of institutional proximity in non-local university-industry collaborations: an analysis based on Chinese patent data. Res. Policy 42 (2), 454–464.

Kim, C., Song, J., 2007. Creating new technology through alliances: an empirical investigation of joint patents. Technovation 27 (8), 461–470.

Kim, C., Jeon, H.H., Kim, M.S., 2015. Identification and management of opportunities for technology-based services: a patent-based portfolio approach. Innov. Manag. Policy Pract. 17 (2), 232–249.

Lee, S., Kim, M.S., 2010. Inter-technology networks to support innovation strategy: an analysis of Korea's new growth engines. Innov. Manag. Policy Pract. 12 (1), 88–104.

Lee, S., Kim, M.S., Park, Y., 2009. ICT co-evolution and Korean ICT strategy: an analysis based on patent data. Telecommun. Policy 33 (5–6), 253–271.

Lee, D.H., Seo, I.W., Choe, H.C., Kim, H.D., 2012. Collaboration network patterns and research performance: the case of Korean public research institutions. Scientometrics 91 (3), 925–942.

Lin, C., Wu, Y.J., Chang, C.C., Wang, W., Lee, C.Y., 2012. The alliance innovation performance of R&D alliances—the absorptive capacity perspective. Technovation 32 (5), 282–292.

Link, A.N., Scott, J.T., 2005. Universities as partners in U.S. research joint ventures. Res. Policy 34 (3), 385–393.

Ma, Z., Lee, Y., 2008. Patent application and technological collaboration in inventive activities: 1980–2005. Technovation 28 (6), 379–390.

Mowery, D.C., 2007. University-industry research collaboration and technology transfer in the United States since 1980. In: Yusuf, S., Nabeshima, K. (Eds.), How Universities Promote Economic Growth. World Bank, Washington, DC, pp. 163–182.

Ngar-yin Mah, D., Hills, P., 2014. Collaborative governance for technological innovation: a comparative case study of wind energy in Xinjiang, Shanghai, and Guangdong. Eviron. Plann. C. Gov. Policy 32 (3), 509–529.

OECD, 2009. OECD Patent Statistics Manual. OECD, Paris.

Okamuro, K., Nishimura, J., 2013. Impact of university intellectual property policy on the performance of university-industry research collaboration. J. Technol. Transfer. 38 (3), 273–301.

Ono, M., 2012. Historical aspects and current status of entrepreneurship in Japanese universities. Josai J. Bus. Adm. 8 & 9 (1), 1–16.

O'Shea, R.P., Allen, T.J., Chevalier, A., Roche, F., 2005. Entrepreneurial orientation, technology transfer and spinoff performance of U.S. universities. Res. Policy 34 (7), 994–1009.

Park, Y., Lee, S., Lee, S., 2012. Patent analysis for promoting technology transfer in multi-technology industries: the Korean aerospace industry case. J. Technol. Transfer. 37 (3), 355–374.

Ponomariov, B., 2013. Government-sponsored university-industry collaboration and the production of nanotechnology patents in US universities. J. Technol. Transfer. 38 (6), 749–767.

Powers, J.B., 2003. Commercializing academic research: resource effects of performance of university technology transfer. J. High. Educ. 74 (1), 291–311.

Powers, J.B., McDougall, P.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. Tech. Anal. Strat. Manag. 24 (7), 663–678.

Rigby, J., Edler, J., 2005. Peering inside research networks: some observations on the effect of the intensity of collaboration on the variability of research quality. Res. Policy 34 (6), 784–794.

Santoro, M.D., Chakrabarti, A.K., 2002. Firm size and technology centrality in industry-university interactions. Res. Policy 31 (7), 1163–1180.

Schofield, T., 2013. Critical success factors for knowledge transfer collaborations between university and industry. J. Res. Adm. 44 (2), 38–56.

Tantiyaswasdikul, K., 2012. The impact of the breadth of patent protection and the Japanese university patents. Int. J. Innov. Manag. Technol. 3 (6), 754–758.

Temel, S., Glassman, B., 2013. Examining university-industry collaboration as a source of innovation in the emerging economy of Turkey. Int. J. Innov. Sci. 5 (1), 81–88.

The Office of the Chief Scientist, 2013. Government-supported Incentive Programs. Ministry of Industry, Trade and Labor, Tel Aviv, IL.

Veugelers, R., Cassiman, B., 2005. R&D cooperation between firms and universities: some empirical evidence from Belgian manufacturing. Int. J. Ind. Organ. 23 (5–6), 355–379.

Walsh, J.P., Baba, Y., Goto, A., Yasaki, Y., 2008. Promoting university-industry linkages in Japan: faculty responses to a changing policy environment. Prometheus 26 (1), 39–54.

White, M., 2010. Patent searching: back to the future how to use patent classification search tools to create better searches. First Annual Conference of the Canadian Engineering Education Association. Queen's University (Kingston, Ontario).

WIPO, 2014. WIPO IP Facts and Figures. World Intellectual Property Organization, Switzerland.

Shu-Hao Chang got his Ph.D. at National Dong Hwa University, Taiwan. He is an associate researcher at the Science & Technology Policy Research and Information Center, National Applied Research Laboratories, Taipei, Taiwan. His research interests include innovation policy, technology management, patent analysis, and e-commerce. His work has appeared in *Technological Forecasting & Social Change*, *Innovation: Management, Policy & Practice*, *Social Science Information*, *Information Technology & People*, *Computers in Human Behavior*, *Lecture Notes in Electrical Engineering*, *Expert Systems with Applications*, *Soft Computing*, *Journal of Marketing Theory and Practice*, *Industrial Engineering & Management Systems*, *International Journal of Technology, Policy and Management*, *International Journal of Innovation Science*, and *Industrial Marketing Management*.