J Technol Transf (2019) 44:700–740
DOI 10.1007/s10961-017-9634-4

Where technology transfer research originated and where it is going: a quantitative analysis of literature published between 1980 and 2015

Heeyong Noh[1] · **Sungjoo Lee**[1,2]

Published online: 3 November 2017

Abstract This study aims to identify both where technology transfer research originated and where it is going. A quantitative approach was adopted in this study to observe the trends from an objective perspective. To do this, longitudinal bibliographic data of journal papers describing technology transfer from 1980 to 2015 are collected. Topic modeling and co-authorship network analyses are then applied to classify topics and identify an evolution of research groups. First, the principal transfer agent is changed from governmental organizations to universities, as technology donors, while industry plays the role of technology recipients. Second, major technology fields that researchers have focused on follow socially attractive interests. Third, the scope of focus gradually moves from national level research or international transfers to organizational level research. In addition, technology transfer research seems to change from a technology transfer application to a dynamic technology transfer process. In addition, six topics are identified and further discussed to understand future research directions. The research findings are expected to help us understand research trends in technology transfer and, thus, are expected to provide valuable insights to researchers in this field and policy makers who are in charge of developing policies to support technology transfer.

Keywords Technology transfer · Research trends · Topic modeling · Co-authorship network · Emerging topics

Electronic supplementary material The online version of this article (doi:10.1007/s10961-017-9634-4) contains supplementary material, which is available to authorized users.

✉ Sungjoo Lee
sungjoo@ajou.ac.kr

Heeyong Noh
nhy6692@ajou.ac.kr

[1] Department of Industrial Engineering, Ajou University, 206 Worldcup-ro, Yeongtong-gu, Suwon-si, Gyeonggi-do, South Korea

[2] Department of Industrial Engineering, Ajou University, San 5, Woncheon-dong, Yeongtong-gu, Suwon-si, Gyeonggi-do, South Korea

JEL Classification N01 · O38

1 Introduction

In the current globalized society, activities related to open innovation and interorganizational collaboration have been recently vitalized (Chesbrough 2006; Powell et al. 1996). Technological innovation can help firms thrive in market-based competition or even destroy an existing market order (Christensen et al. 2008; Slater and Mohr 2006); however, in this era of sophisticated and ever-changing technology, innovation is difficult to achieve, utilizing only a single enterprise's internal resources. Considering this reason, the search for technological opportunities, which is now common in the managerial and policy domains, has attracted great attention, with dual focus on the exploration and exploitation of external technologies. Hence, there have been numerous policy efforts to foster technology transfer (TT), starting in 1980 with the passage of the Bayh–Dole Act and Stevenson–Wydler Act in the United States of America (the United States) (Berman 2008; Kenney and Patton 2009). Other governments, such as those of various European countries, China, Japan, and South Korea, have also attempted to encourage TT as a method of leveraging their national competitiveness (Kim and Dahlman 1992; Liu and Jiang 2001; Rothwell and Dodgson 1992; Wright et al. 2007).

With TT receiving significant attention from both academia and industry, the number of relevant studies has been gradually increasing (Bozeman et al. 2015). However, due to the broad concept of TT, the research stream in TT is challenging to understand. Although several researchers attempted to explain the course of TT studies (e.g., Audretsch et al. 2014; Bozeman 2000; Wahab et al. 2012), this type of approach to understand research patterns and trends has two limitations: first, no consensus has been reached regarding previous TT research streams, and second, emerging research topics for the future are yet to be discovered. Considering the increasing significance of TT, overcoming these limitations is essential to capture valuable research opportunities in this field.

In order to narrow this research gap, this study aims to identify both, where TT research originated and where it is going. In particular, we employ a set of quantitative approaches to provide data-driven results, as it is impossible to use qualitative approaches to identify every journal article without introducing recognition bias. To do accomplish this, we collect longitudinal bibliographic data of journal papers on TT from 1980 to 2015. We then apply topic modeling and co-authorship network analyses to classify the topics and identify the evolution of research groups.

The remaining sections of this paper are as follows. Section 2 contains a brief overview of existing studies, including the scope and evolution of TT studies. Section 3 introduces a suggested conceptual framework to understand TT research based on relevant studies, using integrated perspectives and suppositions to consider the extant patterns of TT research. Section 4 explains the overall research process and methods in detail; the study's results are described in Sect. 5. After a discussion of the results in Sect. 6, Sect. 7 presents the implications and limitations of this research and provides certain concluding remarks.

2 Scope and evolution of TT research

2.1 Scope of TT research

TT continues to be a significant topic, not only for researchers but also for entrepreneurs and policymakers; investigations and theories regarding TT have been rapidly evolving. However, despite numerous academic and industrial findings, the definition of TT continues to be conceptually convoluted and contentious. Zhao and Reisman (1992) contended that TT knowledge is fragmented, unsystematic, and oriented to a single perspective, even though TT, as a subject of study, has accumulated a vast body of research. In addition, Bozeman (2000) argued that conceptual dissonance can be drawn from a number of TT studies. Many of these challenges in defining TT are due to its limitless possible configurations.

Scholars (e.g., IPCC 2000; Roger 1972; Shih and Chang 2009) have long described TT as a systematic process in which entities exchange technological knowledge. Under this perspective, the components of TT can be largely classified into two types (Battistella et al. 2016). The first type, a *transfer agent*, is an entity involved in a TT process; this includes donors, recipients, and intermediaries. The second type, *technological knowledge*, is considered as a transferable asset; it encapsulates both, embodied and disembodied forms of knowledge. Considering that there are countless TT configurations that are wholly constructed through combinations of transfer agents and technological knowledge, it is challenging to precisely define TT.

Firstly, in relation to a transfer agent, previous studies have described transfer agents' organizational settings and the methods by which relationships among these agents affect the manner in which a TT is formed. In terms of organizational settings, an agent's industrial field helps to determine the differences in TT mechanisms. Gilsing et al. (2011) investigated various TT mechanisms in the industrial fields and found that scientific publications, patents, and academic spinoffs are more valued under science-based regimes but that joint research and development (R&D), conference or workshop attendance, and expert networks are more valued under a development-based regime. In addition, Fosfuri (2006) showed that an agent's market positioning has a meaningful impact on their TT strategies. Agents' environmental contexts (e.g., national innovation systems) significantly influence the determination of TT mechanisms. Firms in catching-up countries tend to expand outputs by focusing on acquiring material technology rather than soft technical skills (Guan 2002; Guan et al. 2006), whereas firms in post-catching-up countries tend to diversify their TT strategies by increasing domestic R&D activities (Choung et al. 2014; Verspagen 1991). Kumar and Ganesh (2009) argued that TT works differently depending on the relationships among the agents. Such relationships are rather different between horizontal and vertical transfers. *Horizontal transfers* are those in which the focal firm's technological knowledge is transferred to competing firms in the same sector; whereas, *vertical transfers* are those in which knowledge is transferred through the supply chain from intermediate suppliers to producers, or more typically, from foreign-based enterprises to suppliers in a domestic market (Newman et al. 2015). The TT process for these transfer types must differ due to the relationships among the agents. According to Li and Lee (2015), structural differences between headquarters–subsidiary and subsidiary–subsidiary transfers are identified even if those transfers are carried out in a homogeneous network within a multinational company (MNC).

Secondly, considering technological knowledge, it can be understood through dichotomous dimensions—tacit and explicit—which are widely acknowledged in the context of knowledge management (Oliveira 1999). Hitt et al. (2000) summarized technological knowledge as follows:

> Technological knowledge, as a systematic body of knowledge, can be individual explicit (e.g., individual skills pertaining to a particular technology that can be codified), individual tacit (e.g., individual skills pertaining to a particular technology that is personal), collective explicit (e.g., standard operating procedures), or collective tacit (e.g., an organization's routines and culture regarding technology).

In this view, the two main transfer mechanisms in TTs are formal and informal (Link et al. 2007). A *formal transfer mechanism* involves the delivery of explicit knowledge under a legal system, as with a patent license or royalty agreement. In this case, a recipient receives proprietary intellectual property rights (IPRs) from a donor, and the main focus is on codified contracts (e.g., patent claims). On the other hand, in *informal transfer mechanisms*, the IPRs play a secondary role, and the obligation to deliver tacit knowledge is more normative. In this context, the preferable transfer mechanism depends on the scientific field. For example, life scientists are typically more concerned with the proprietary benefits of patents and on using them to obtain leverage with firms, but physical scientists typically apply for patents in order to publicize their work without fear of losing potentially valuable IPRs (Owen-Smith and Powell 2001, 2003).

2.2 Evolution of TT research

The explosion in attention on TT for the past two decades has led to hundreds of viewpoints; consequently, the definition of TT does not yet exhaustively consolidate these multidisciplinary perspectives (Bozeman 2000; Zhao and Reisman 1992). One of the reasons for this limitation is that governments have led and promoted TTs and have, in fact, played a significant role in the increased interest provided to TT as a topic. These governments have established policies to foster TT activities by resolving imperfections, such as incomplete appropriability (Arrow 1962), inability to bear risk (Schmookler 1966), and poor economies of scale (Hahn and Yu 1999) in the technology market. The history of technology policy in the United States involves three competing paradigms—market failure, mission, and cooperative technology (Bozeman 2000). Policies from these paradigms have affected TT activities, such as through government intervention to counteract market failures or through the practice of government-centered R&D. Other countries have laws and policies to promote TT as a way to enhance their technological competitiveness (Kim and Dahlman 1992; Liu and Jiang 2001; Rothwell and Dodgson 1992; Wright et al. 2007).

Although understanding technology policy is significant in understanding the focus of TT studies, portraying only those academic interests from the history of technology policy is insufficient. Therefore, we consider extant arguments with respect to historical changes in TT research; however, only a few papers refer to such trends in TT. First, Bozeman (2000) presents the changes in the TT research agenda from a national perspective. He argues that the TT agenda changed significantly in 1980. Prior to this year, the focus of TT research was on cross-national transfers, and in particular, on transfers from industrialized nations to less developed nations. Starting in the 1980s, major changes in technology policies inevitably attracted researchers' attention, and the study of TT was no exception.

Thus, 1980 was the turning point when the main research stream of TT studies shifted from cross-national transfers to domestic transfers.

Following Audretsch et al. (2014) from the perspective of globalization, trends in TT studies can be divided into two waves. The focus of the first wave of academic research on TT is often expressed as *North–South transfers*, in which technological knowledge is mainly delivered from developed and industrialized nations (the North) to the underdeveloped and poor nations (the South). This wave began in the 1990s, after the fall of the Berlin Wall. The main drivers of the North–South transfers are open economic policies, trade liberalization, technical advances in transport and communication, and foreign direct investment (FDI). These drivers act as key channels for international integration and TT. The second wave of academic research emerged in the 1990s with a main focus on value-added supply chains rather than North–South transfers. As production processes have become increasingly geographically fragmented due to the international division of labor, regional TT (often called *localization*) must be strongly considered. There is a vast body of literature on the methods by which knowledge and ideas can spill over to achieve economic growth and welfare.

Following Wahab et al. (2012), from the perspective of theory developments, TT research has developed largely in three periods. In the first period, the 1970s, studies adopted an economic, international-trade approach to developing linear TT models. In terms of theory, the international-trade approach consists of theories on classical trade, the factor proportion, and the product life cycle. These theories provide appropriate explanations on how trade between countries contributes to the flow of goods and services, which have technology embedded in them. In the second period, the 1980s, TT studies significantly emphasized the effectiveness of specific transferred technologies. In particular, FDI-related theories, such as those concerning international production, internationalization, and transaction costs, were introduced in the 1980s; another significant consideration was the mechanism through which MNCs' FDIs became the main channel for intra-firm TT. In the third period, from the late 1980s to the early 1990s, TT theories expanded by absorbing the principles of organizational-learning and knowledge-based perspectives. These perspectives contributed to the development of TT studies as they appeared to subsume most contributions of the TT literature (Daghfous 2004).

Although there are dissimilar viewpoints on the evolution of TT studies, we can identify areas of agreement in the aforementioned research. First, the focus of TT studies has generally shifted from the international context to the regional context. In other words, researchers have shifted their focus from easily observable, big phenomena (e.g., international trade, FDI, and North–South transfer) to narrower TT processes (e.g., value-added supply chains and organizational learning). Nevertheless, there is no consensus on the actual time when this shift occurred or on the details of these changes in TT research; such details will be a part of this study's focus.

3 Conceptual framework

3.1 Basic viewpoint

As it continues to be challenging to compile hundreds of viewpoints on TT due to the broad scope of TT studies, scholars (e.g., Audretsch et al. 2014; Bozeman 2000; Wahab et al. 2012) have explained the evolution of TT research through various ways based on their individual focus. These limitations indicate that, to understand the origins and future of TT research, a conceptual framework that can integrate the broad scope of TT studies is required. In this case, two components (*transfer agent* and *technological knowledge*) of TT should be considered while constructing a conceptual framework. By addressing these components, this study essentially aligns with the Mode 2 and Triple Helix theories. Mode 2 has been described as a new way of producing scientific knowledge, when compared to previous knowledge production (the so-called Mode 1), by referring to the background of knowledge production, theoretical base, social structure, accountability, quality of knowledge, and so forth (Gibbons et al. 1994). In addition, the common objective of Triple Helix is to realize an innovative environment or a knowledge-based society largely consisting of three principal agents (i.e., academia, government, and industry), though a structure of Triple Helix can be observed differently depending on the context.

As summarized in Sect. 2, TT is a set of sequential interactions among agents with the goal of achieving a knowledge-based innovation. These interactions are naturally dynamic and complex due to the agents' diverse characteristics. Therefore, Mode 2 provides a rather useful direction as it emphasizes on transdisciplinary and horizontal transfers involving network-embedded knowledge production with an institutional basis of science, practical industry, and policy. The Triple Helix offers a model to explain Mode 2 at the level of social structure (Etzkowitz and Leydesdorff 2000). The major advantage of the Triple Helix is that it is sufficiently flexible to explain the varying innovative systems through social structures involving the government, industry, and academia (as shown in Fig. 1). Considering this, scholars (e.g., Klofsten et al. 1999; Ranga and Etzkowitz 2013; Saad and Zawdie 2005) have widely used these theories as tools from the past two decades to investigate TTs.

From the Triple Helix viewpoint, TT that is accomplished at a certain point indicates that the transfer agents for the TT are positioned in a network that includes the government, academia, and industry. However, this theory is still insufficient to specify the changes in the overall TT research as it lacks an explanation of the characteristics of technological knowledge—the other significant component in describing TTs. In practice, Van Looy et al. (2003) argued that there is a need for domain-specific TT policies and strategies after empirically finding that, in the context of the Triple Helix, the structural intensity between science and technology varies depending on the technological domain. Therefore, this study's conceptual framework is more three-dimensional than the conventional Triple Helix, in order to present the differences between the technological fields. The scope of individual TT studies also varies from a macroscopic phenomenon to a microscopic

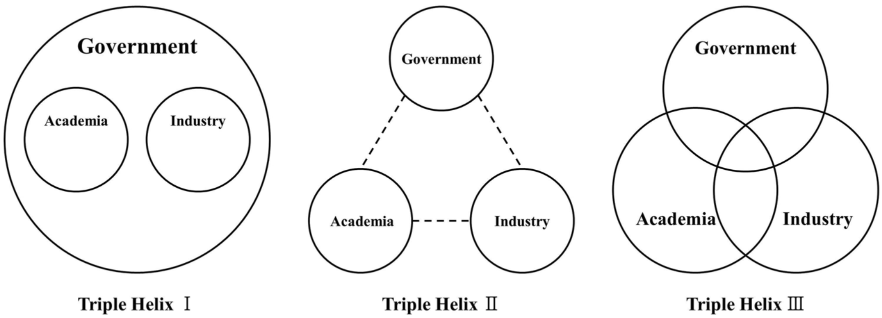

Fig. 1 Types of innovation systems (Etzkowitz and Leydesdorff 2000)

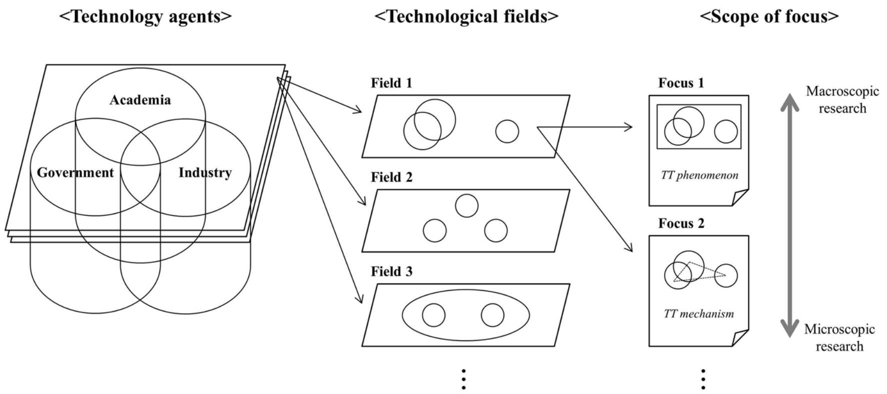

Fig. 2 Conceptual framework for exploring changes in TT research

system. Accounting for all these considerations, we developed this study's conceptual framework as a more broadly elaborated version of the Triple Helix, as shown in Fig. 2, and applied that framework as a basic viewpoint for exploring the evolution of TT studies.

3.2 Research trends in TT

Based on this study's conceptual framework, we can examine the research streams in TT by reviewing previous studies. Specifically, we focus on TT research from 1980 to the present, in 10-year intervals.[1]

In the 1980s, governmental organizations were mainly leading, or were at least involved in, TT, as they had established monumental science and technology policies to allow the transfer of government-funded technology (see Lee 1997 and Rothwell and Dodgson 1992, which reference the United States' and European TT policies, respectively). Hence, the governmental role was the main research target during that time. Although universities' roles as technology sources received significant attention following the Bayh–Dole Act of 1980, TT was not closely related to universities' patenting and licensing activities (Sampat 2006). Previous studies have also shown that the Bayh–Dole Act was not responsible for an increase in TT from universities (Henderson et al. 1998; Mowery et al. 2001). Consequently, universities were not the focus of TT research in the 1980s. As information emerged regarding fundamental scientific and technological concepts, computing technology became the main focus of TT studies as the computer played a central role in the emerging information age (Mahoney 1988). In this period, TT began to attract attention as a sound research subject in its own right—instead of a concomitant phenomenon of economic transactions (Seely 2003).

[1] Although Bozeman (2000) and Wahab et al. (2012) considered 1980 to be an important milestone, relatively few papers were published before that year. A search with the keyword *technology transfer* in the SCOPUS database results in very few studies before the mid-1970s. Additionally, it is commonly acknowledged that interest in TT increased in 1980 with the passage of the Bayh–Dole Act and Stevenson–Wydler Act in the United States (Shane 2004; Sampat 2006). Hence, this study examines TT research since 1980, using intervals of 10-years. Though a time interval can be larger or smaller than 10 years, the previous studies that we reviewed (e.g., Bozeman 2000; Wahab et al. 2012; Audretsch et al. 2014) employed 10-year intervals to describe changes in the research streams relating to TT. Hence, this study also uses a 10-year interval.

According to Lee (1997), scholars became interested in collaborative interactions with universities in the late 1990s. This means that, in the 1990s, there was a shift in focus in terms of transfer agents in TT research, from governmental organizations to universities. In relation to technological fields, transfer research related to biotechnology occupied a major role in the 1990s. This field attracted immense interest with the start of the Human Genome Project in 1990; various types of technological knowledge are required for a successful biotechnology project.

Since 2000, TT research has taken a major step forward and has become a sound discipline based on a vast body of case studies. Universities and hybrid organizations comprising academia, industry, and government have been intensively investigated as major transfer agents. With the advent of the twenty-first century's knowledge-based society (Hsu et al. 2008), an entirely new TT model that encapsulates more broad and complex TT interactions appeared, replacing the traditional TT model that focused on a well-defined technology moving from one well-defined economic unit (e.g., a department, lab, firm, or country) to another well-defined economic unit (Amesse and Cohendet 2001; Bozeman et al. 2015). The scope of TT research extended from simple TT cases to include nonlinear mechanisms and dynamics (Bozeman et al. 2015). Considering technological fields, environmental technology attracted attention in this period due to the Kyoto Protocol of 1997 and the shift from a manufacturing-centered economy to a knowledge-based one.

By integrating the aforementioned implications of previous studies, we create a map of TT research based on this study's conceptual framework, as illustrated in Fig. 3. However, this map is a very simple method of illustrating the changes in TT research since 1980, and on its own, it lacks sufficient insight or validation. To the best of our knowledge, no research has explained the changes in TT studies using quantitative evidence. Hence, this study aims to identify the changes in TT research by employing quantitative methods.

4 Research process and methods

In order to identify the changes in TT research in detail, the sequential steps of this study's research process are shown in Fig. 4. The process consists of two parts: understanding the origins of TT research and identifying where TT research is going. In the first part, multiple perspectives on TT are integrated to provide objective information. In the second part, an emerging research topic is identified.

4.1 Step 1: Collect and refine raw data

As this study focuses on changes in TT research, the SCOPUS database, the world's largest public database of bibliographic information for academic publications, is used to collect raw data related to TT. The TT domain can be represented by various terms (e.g., *spinoff*, *spillover*, *knowledge leakage*, *knowledge transfer*, *licensing*, and *technology transfer*), which makes it difficult to perform searches with all the terms. Thus, this study only considers studies from 1980 through 2015 that used the term *technology transfer* in the title, abstract, or keywords.[2] In addition, research published in authorized journals may have more fruitful and reliable implications than other kinds of academic publications,

[2] Numerous scholars have asserted the ambiguousness of the terms related to TT (e.g., Zhao and Reisman 1992; Gopalakrishnan and Santoro 2004; Bozeman 2000), as noted in Sect. 2 of this study. Hence, this study employs a quantitative approach with a robust search to collect raw data, despite the possibility of excluding some papers while using this method.

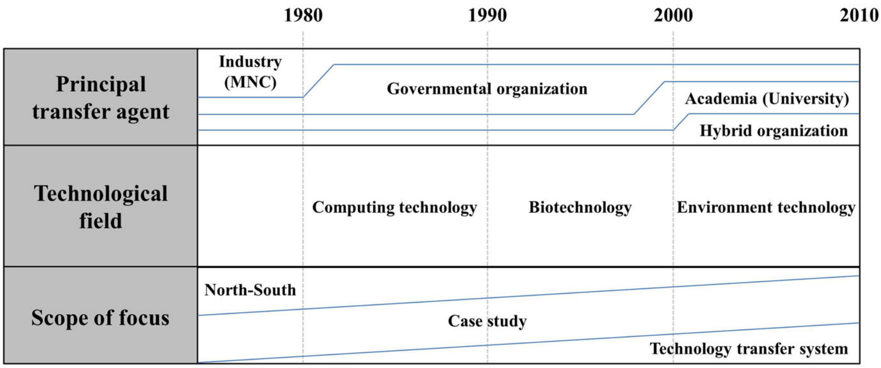

Fig. 3 Expected findings on TT research trends based on the conceptual model

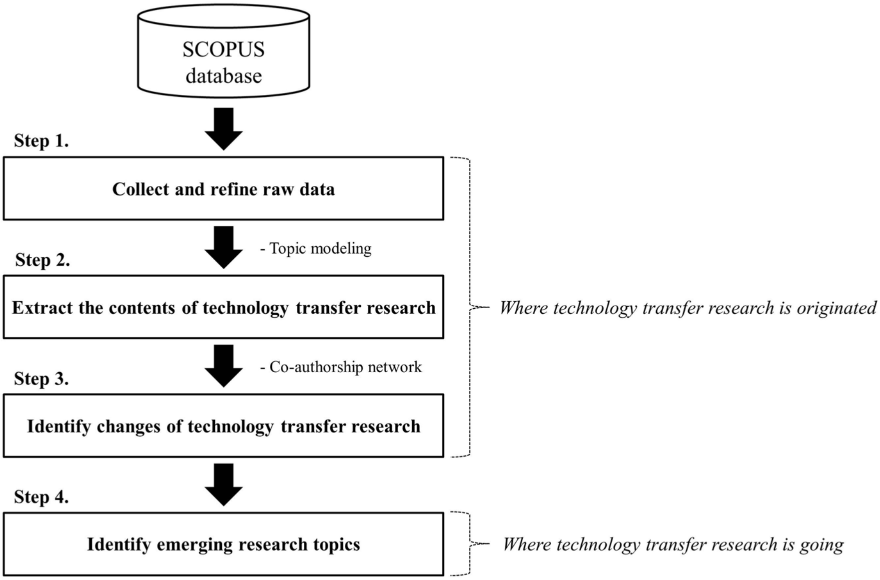

Fig. 4 Research process

such as conference papers, books, and magazines; thus, this search used only original research articles from Science Citation Index (SCI)/Social Science Citation Index (SSCI)/ Science Citation Index Expanded (SCIE) journals. To classify these articles, we screened journals based on the 2016 SCI/SSCI/SCIE journal list.

Despite the utility of raw data from the SCOPUS database, it does contain invalid information, particularly from the 1980s,[3] including overlapping abstracts and studies with no available abstract or author name. Therefore, we supplemented the author names and abstracts by searching the research articles again. In addition, as this study employs a co-authorship network analysis to identify the evolution of the TT research group, in this data-refinement step, certain major matters (e.g., abbreviated names and namesakes) require

[3] The digitization of publications from the 1980s could be the source of such errors.

caution. The SCOPUS database provides only abbreviated author names, though full author names are necessary to avoid namesake problems when conducting a co-authorship network analysis. Accordingly, we transformed all the abbreviated names into full names by manually searching affiliations, e-mail addresses, and original research articles.

4.2 Step 2: Extract the contents of TT research

Based on the preprocessed data in step 1, the correlated topic modeling (CTM) approach, as proposed by Blei and Lafferty (2007), was applied to identify what the individual papers described. A topic model is a probabilistic model that assigns a topic to every document in a corpus by calculating and comparing word distributions across the documents. The CTM functionally differs from the conventional topic modeling method (generally known as the *latent Dirichlet allocation*) as the CTM allows for correlational relationships among topics. The reason for employing the CTM in this study is that TT studies' research topics can overlap; in this study's conceptual framework, two TT studies can focus on a similar technological field and have a similar scope but consider distinct transfer agents. Thus, the CTM approach is logically more appropriate for this study than a general topic modeling method. In this study, we mainly use the topicmodels package (version 0.2.4) in R (Grün and Hornik 2016).

First, the title and abstract of each study are integrated into a single document; then, the CTM is applied to the corpus of studies from 1980 through 2015. Consequently, each individual study is assigned to the single topic (among a predefined number of topics) that has the highest probability. As each topic is labeled based on the terms and in a probabilistic order, we can easily identify the contents of each TT research article.

4.3 Step 3: Identify changes in TT research

In this step, changes in TT research since 1980 are identified in two ways. First, the trend of each research topic is traced based on the outcomes of step 2. Second, the evolution of TT research groups is examined through co-authorship network analysis. Although Wright (2014) argued that TT is now maturing as an area of study and policy, there is no quantitative evidence to support this claim. In this case, focusing on the bonds between scholars is a good way to examine whether TT is recognized as an area of study, as it is challenging to define TT as an area of study if it has no prolific research group. If TT has to be recognized as a distinct discipline rather than a field, a certain continuous research group that has accumulated a TT knowledge base should be observed. Hence, this study focuses on researchers' historical bonds by using a longitudinal examination of co-authorship, in contrast to studies that use co-authorship networks to examine the current literature, which only emphasize the patterns of scientific collaborations (Uddin et al. 2012).

4.4 Step 4: Identify emerging research topics

To identify the future development of TT research, this study uses two criteria to explore potential emerging research topics. First, a steep increasing trend should be detected for such topics as the total number of TT studies has gradually increased since 1980. Thus, an emerging research topic in the domain of TT should have a convincing upward trend relative to that of other TT research topics. Second, the number of papers related to an emerging research topic should be considerable, as a sudden upward trend can be easily observed when the number of papers is very small. Hence, we compare all the research topics derived from the CTM using these two criteria.

Specifically, this study employs the slope of a linear regression line as a tool for measuring the upward trend, as, in a time series, this slope consistently performs better than the other measures, according to Tseng et al. (2009). Additionally, the slope of linear regression is robust under different conditions (e.g., trend formulations, time spans, domains, and various data-collection scales) and is rarely affected, even when the time span is split into arbitrary periods (Tseng et al. 2009). Consequently, in order to explore potential emerging research topics, a portfolio is produced that consists of the slope of each topic's linear regression line and each topic's share in the total number of papers since 1980.

5 Results

5.1 Step 1: Collect and refine raw data

The search based on the aforementioned search expression initially extracted 11,732 papers in the period from 1980 to 2015. Although these outcomes are derived by searching for the term *technology transfer* in the title, abstract, and keywords, SCOPUS offers two types of search results in terms of keywords: an *index keyword* search, which the SCOPUS database supports to increase the efficiency of search, and an *author keyword* search, which is based on information provided by the authors of the original article. However, while using an index keyword search, we found papers that were not actually related to TT. SCOPUS' index keyword search functions like a thesaurus; such systems have been criticized in terms of semantic information problems, lack of structural simplicity, and ambiguousness. To resolve these problems, we eliminated papers that did not include the term *transfer* in the title, abstract, or author keywords to exclude the papers that were extracted by means of index keywords. There are a few TT-related studies that do not use the term *transfer* (e.g., those on absorbing capacity and university–industry cooperative research); these were eliminated, but most of the studies excluded in this manner were far from TT. Thus, 4988 papers (41.6%) were excluded from the initial 11,732. Among the remaining 6744 papers, some were not published in SCI/SSCI/SCIE journals. Thus, we used the 2016 SCI/SSCI/SCIE journal list from the Institute for Scientific Information to screen the articles; we identified 1338 unique journals and 4430 corresponding papers. The 1338 journals comprised a wide range of scientific, industrial, social, technological, and interdisciplinary fields: (1) the domains of primary industry-related journals included agriculture (e.g., *Agricultural Economics*), forestry (e.g., *Journal of Forestry*), and fishery (e.g., *Fisheries Science*); (2) the domains of secondary industry-related journals included textiles (e.g., *Fibers and Textiles in Eastern Europe*), manufacturing (e.g., *International Journal of Advanced Manufacturing Technology*), and construction (e.g., *Journal of Construction Engineering and Management*); and (3) the domains of tertiary industry-related journals included electronics (e.g., *Electronics Letters*), pharmacy (e.g., *Drug Development and Industrial Pharmacy*), communication (e.g., *Telecommunications Policy*), service (e.g., *Service Industries Journal*), and energy (e.g., *Energy Policy*). Among these, the top 10 journals in terms of

Table 1 Top ten journals in terms of number of papers on TT research

Rank	Journal	Number of papers (share of journal)
1	Journal of Technology Transfer	483 (10.97%)
2	Technovation	138 (3.14%)
3	Research Policy	128 (2.91%)
4	International Journal of Technology Management	108 (2.46%)
5	Energy Policy	67 (1.52%)
6	Technology Forecasting and Social Change	58 (1.32%)
7	Science and Public Policy	50 (1.14%)
8	IEEE Transactions on Engineering Management	46 (1.05%)
9	World Development	44 (1.00%)
10	R&D Management	37 (0.84%)

the number of papers found are presented in Table 1. This study's final sample¸ after manual efforts to exclude invalid and inappropriate papers, was 4401 papers.[4]

In order to conduct a co-authorship network analysis, we replaced abbreviated names with distinguishable full names by manually searching for the authors' original articles, affiliations, and e-mail addresses. If the authors shared a namesake, we included their affiliations next to their surnames to identify them.

5.2 Step 2: Extract the contents of TT research

Before conducting the CTM, we integrated the title and abstract of each study into a single document; we then preprocessed the set of 4401 documents to increase the performance of the CTM analysis by (1) removing punctuation, numbers, and stopwords; (2) conducting stemming; and (3) excluding documents that had insufficient words. We used term frequency and inverse document frequency (TF-IDF) to classify papers with insufficient words, as certain articles did not have sufficient distinguishable words. We excluded documents from the CTM analysis when they did not have any terms with more than 0.1 TF-IDF. Thus, 4355 papers remained to be properly analyzed using CTM.

Considering that the number of topics in a topic modeling analysis must be fixed a priori, an exploratory analysis was first undertaken. In this study, four metrics were used to determine the appropriate number of topics. Three metrics (those of CaoJuan2009, Arun2010, and Deveaud2014) were examined using the ldatuning package (version 0.2.0) in R (Nikita 2016); the fourth metric was the marginal corpus likelihood. The number of topics produced a better result when CaoJuan2009 and Arun2010 were minimized and Deveaud2014 and marginal corpus likelihood were maximized. For this study, we selected 120 topics based on the exploratory analysis (as shown in Fig. 5).

After selecting 120 topics, we ran variational inferences until the relative change in the probability bound was less than 10^{-4}. We then ran variational expectation–maximization

[4] In the raw data, some papers did not have author or abstract information. Making additional effort, we filled in the missing information manually. Moreover, although this study screened inappropriate papers by index keyword, a few inappropriate papers included *transfer* in the title, abstract, or author keyword remained (e.g., those on heat transfer and build–operate–transfer). Thus, we checked the 4430 individual papers to determine the final sample, and 4401 papers were consequently identified as a proper set for analysis.

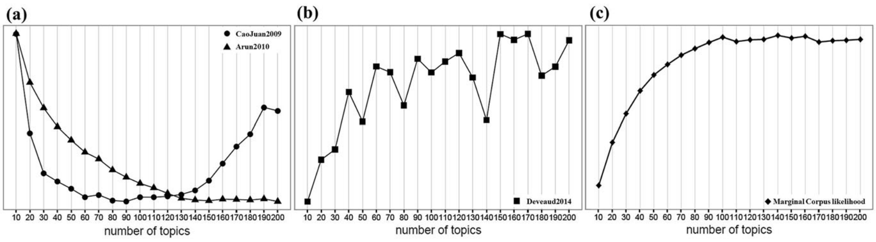

Fig. 5 Exploratory analysis results for determining the number of topics. **a** CaoJuan2009 and Arun2010; **b** Deveaud2014; **c** marginal corpus likelihood

until the relative change in the likelihood bound was less than 10^{-3}. Consequently, the topic with the highest probability (among 120 topics) was assigned to each of the 4355 papers. The mean and median values for the probabilities of the assigned topics were 76 and 88%, respectively. Each topic could be interpreted based on a set of terms that was assigned to it in a probabilistic order. However, it is difficult to show labels for all the 120 topics in this study. Instead, the corresponding terms and term probabilities for all topics that are directly referenced in this study are described in "Appendix".[5]

5.3 Step 3: Identify changes in TT research

This study aims to show the changes in TT research by identifying the histories of research topics and the evolution of research communities. Research topic histories are identified based on the outcomes of the CTM analysis, and the evolution of research groups is understood based on the results of the co-authorship analysis.

5.3.1 Histories of research topics

The topics that mostly appeared in each time span until a rate summation of the topics reached 30% were considered as major research streams, as described in Table 2. The labels shown in Table 3 help us understand and interpret the trends in TT research based on this study's conceptual framework.

In the 1980s, government-led TT (topic 6) attracted the most attention, and the role of universities (topic 7) was relatively less investigated. Regarding technological fields, four kinds of technologies attracted the most interest: computer or software engineering (topics 13 and 98); natural resources, particularly water, minerals, and livestock or agricultural goods (topics 13, 49, and 69); industrial health (topic 104); and the military (topic 85). The most notable point in these fields is that postwar conditions and manufacturing-based economy of the 1980s posed significant influence. Information (topics 13 and 98) became more significant in the period of the Cold War, and a vast number of technologies derived from military science were transferred to industry (topic 85). Moreover, TT in health care for disabled veterans (topic 85) was also important. From the perspective of a manufacturing-based economy, TT frequently occurred in the industrial health fields (topic 104). TT to leverage the efficiency of acquiring natural resources (topics 13, 49, and 69) was also

[5] In this study, the label for a topic is fundamentally determined based on the terms and their probabilities. We then double-check against the abstracts of the articles. Detailed information is described in Table 6 of "Appendix".

Table 2 Major research streams in each time span

1980s (n = 496)			1990s (n = 1270)			2000s (n = 1414)			2010–2015 (n = 1175)		
Topic	Number of papers	Share (%)	Topic	Number of papers	Share (%)	Topic	Number of papers	Share (%)	Topic	Number of papers	Share (%)
6	25	5.04	49	50	3.94	7[a]	91	6.44	7[a]	108	9.19
13	18	3.63	83	44	3.46	108[a]	56	3.96	35[a]	66	5.62
83	17	3.43	13	38	2.99	35	47	3.32	116	58	4.94
49	17	3.43	108	34	2.68	47[a]	45	3.18	49	42	3.57
98	16	3.23	86	31	2.44	13	35	2.48	47	38	3.23
85	14	2.82	85[a]	30	2.36	104	33	2.33	109	37	3.15
69	11	2.22	76	30	2.36	111	32	2.26	118	31	2.64
47	11	2.22	109	29	2.28	17[a]	30	2.12			
104	11	2.22	104	28	2.20	116	30	2.12			
7	11	2.22	19	27	2.13	19	29	2.05			
			7[a]	26	2.05						
			6[a]	24	1.89						
Total		30.44	Total		30.79	Total		30.27	Total		32.34

[a]A main research theme of a research group is classified by the co-authorship network analysis as more than half of the papers in a group were assigned to this topic

Table 3 Research topics in the major research streams

Topic	Label
6	Studies on TT led by a federal government or other governmental-organization
7	University-based academic entrepreneurship
13	TT applications in fields related to water development or software engineering
17	TT applications in medical devices or health rehabilitation
19	TT applications in advanced materials
35	TT applications in fields related to carbon emissions
47	TT-related issues in China
49	TT applications in fields related to agriculture or livestock
69	TT applications in the resource mining and nuclear/atomic fields
76	TT applications in marine and aquaculture fields
83	Representative case of successful North–South TT: South Korea and Japan
85	TT applications with respect to war (e.g., military weapons or soldiers' health care)
86	TT applications in agriculture (particularly soil nutrients)
98	TT with respect to computing systems
104	TT applications in fields related to occupational safety and health
108	Investigating licensing contracts from the perspective of international economics
109	TT applications in medical diagnostics
111	TT through MNC–subsidiary spillover
116	TT through IPR systems
118	TT applications in pharmaceutical vaccine technology

significant in ensuring a stable resource supply. For the scope of TT research in the 1980s, North–South transfer (topics 47 and 83) was a major research topic. The economic growth of Northeast Asia (e.g., China, South Korea, and Japan) served as a good benchmarking case for North–South transfers.

In the 1990s, we find large changes in the share of research topics compared to that of the 1980s. Although two-thirds of the topics from the top 30% in the 1980s (topics 6, 13, 49, 83, 85, and 104) remained within the top 30% in the 1990s, most of them lost some of their share, with the exceptions being topics 49 and 83. However, topics related to biotechnology (topics 49, 76, 86, and 109) emerged. In particular, studies related to agricultural biotechnology increased in this period. According to the Office of Technology Assessment of the United States Congress (1990), there are two main reasons for the sudden increase in TT research with respect to agricultural biotechnology in the 1990s: (1) agricultural research broadened beyond its traditional focus, which was on increasing production, and began to address issues of food safety and environmental quality as the biotechnology and information-technology eras began; and (2) courses in the required technological disciplines for agricultural innovation (e.g., cellular physiology, biochemistry, and genetics) were generally lacking in colleges of agriculture. In relation to the transfer agents, studies related to governmental organizations (topic 6) were notably lacking, and studies related to universities (topic 7) were still far from attracting primary interest. However, we can infer that industrial commercialization based on international TT actively occurred in the 1990s as investigations on the economic benefits of formal TT mechanisms (topic 108) increased sharply and the appearance of TT research related to the specific technological fields within the top 30% of topics was relatively conspicuous when compared to the results for other periods. Regarding the scope, international TT (topic 83) remained the main research stream, and the share of North–South transfer studies remained the same between the 1980s and 1990s.

In the 2000s, the paradigm of TT research shifted. First, universities (topic 7) began to be considered as technology sources in this period. Although topic 7 had been found in the top 30% since the 1980s, both, its number of papers and its share of all research topics, dramatically increased in the 2000s. However, investigations of governmental organizations (topic 6) began to disappear from the major research streams in the 2000s. For technological fields, there was a sudden appearance of TT applications in the carbon-emission field (topic 35). On the other hand, major research topics related to specific technological fields from the 1990s lost their share (topics 13 and 19) or maintained their share with a slight difference (topic 104). In relation to the scope, as China emerged as the world's largest potential market after becoming a member of the World Trade Organization in December 2001, TT studies related to China (topic 47) significantly increased. This could also explain why investigations of MNC–subsidiary spillovers (topic 111) entered the top 30% of topics in the 2000s. In addition, research topics related to formal TT mechanisms (topics 108 and 116) maintained their growth as sound research subjects.

Between 2010 and 2015, universities (topic 7) continued to attract immense interest as principal transfer agents. Considering TT research from the perspective of the technological field, environmental impacts derived from global warming and sustainable development influenced several TT studies. Carbon-emission-related technologies (topic 35) were regarded as attractive research subjects in TT studies since 2000, and agricultural biotechnology became a significant research topic again (topic 49) due to the potentially huge impacts of climate change on agriculture, shaping the products and practices that are most suitable for each location (Lybbert and Sumner 2012). Regarding the scope, patent ownership and other IPRs (topic 116) were increasingly investigated.

To recap, we identified changes in TT research under this study's conceptual framework. First, the principal transfer agent changed from governmental organizations to universities; and industry played the role of technology recipient. Thus, most scholars have focused on governments and academia, though some have also investigated industrial interfirm TT. Second, the technology fields that researchers have focused on the most are based on socially attractive interests, as policies strongly affect TT and must be sensitive to social trends in the globalized world. Third, the scope gradually moved from national-level research and international transfer to organizational-level research. In addition, the focus of TT research seems to have changed from TT applications to dynamic TT processes. There are two reasons attributed to the scope of TT research becoming narrow and more specific. First, the geographically fragmented production processes of the 1990s affected the focus of academic interests, which moved from national-level to organizational-level interactions (Audretsch et al. 2014). Second, as individual organizations began to actively engage with external environments by recognizing the increasing significance of open innovation (Chesbrough 2006), dynamic TT processes and organizational-level knowledge transfers became the main concern. Based on these results, the evident TT research trends are shown in Fig. 6.

5.3.2 Evolution of research communities

Co-authorship network analysis is useful because co-authorship can reveal scholars' social relationships and communal research interests. In addition, co-authorship tends to increase,

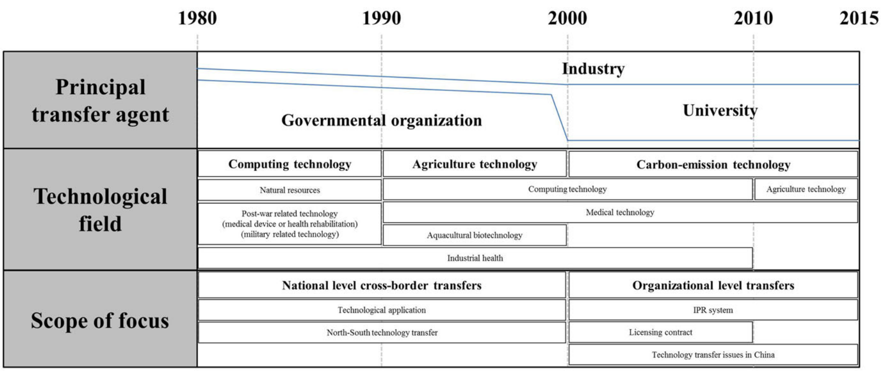

Fig. 6 TT research trends

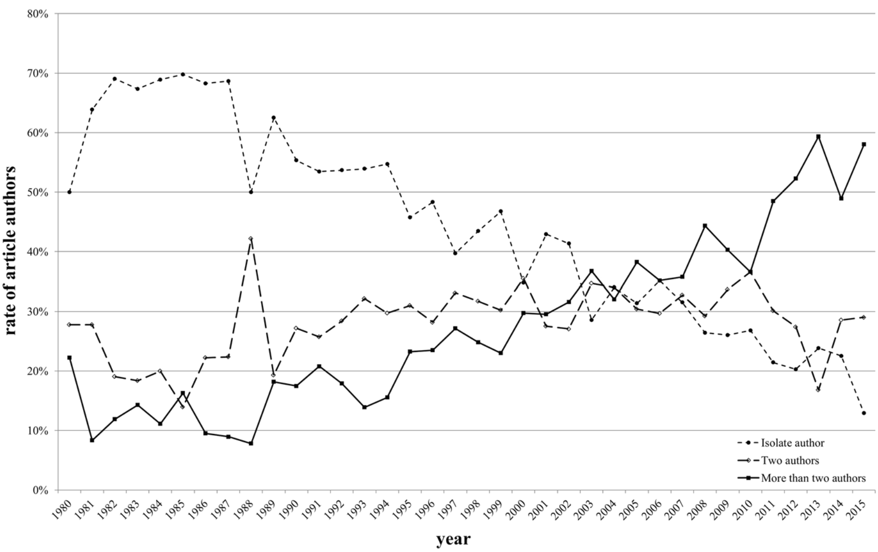

Fig. 7 TT research trends in co-authorship

as scientific collaboration is commonly regarded as an easy way to enhance the quality of research. Increasing co-authorship is also observed in TT research (see Fig. 7). This study focuses on co-authorship networks to examine the evolution of TT studies. The regression slopes on the rates of single-author, two-author, and three-or-more-author studies are − 0.0149, 0.0022, and 0.0127, respectively. This indicates that scholars tend to collaborate rather than work alone while undertaking TT research.

A co-authorship network can include a group that is occasionally built from a one-time article. However, this study focused on research groups with more than one article. This is important because the evolution of the TT research groups is one of this study's focuses, and a research group consisting of only one article is not helpful to identify an evolutionary

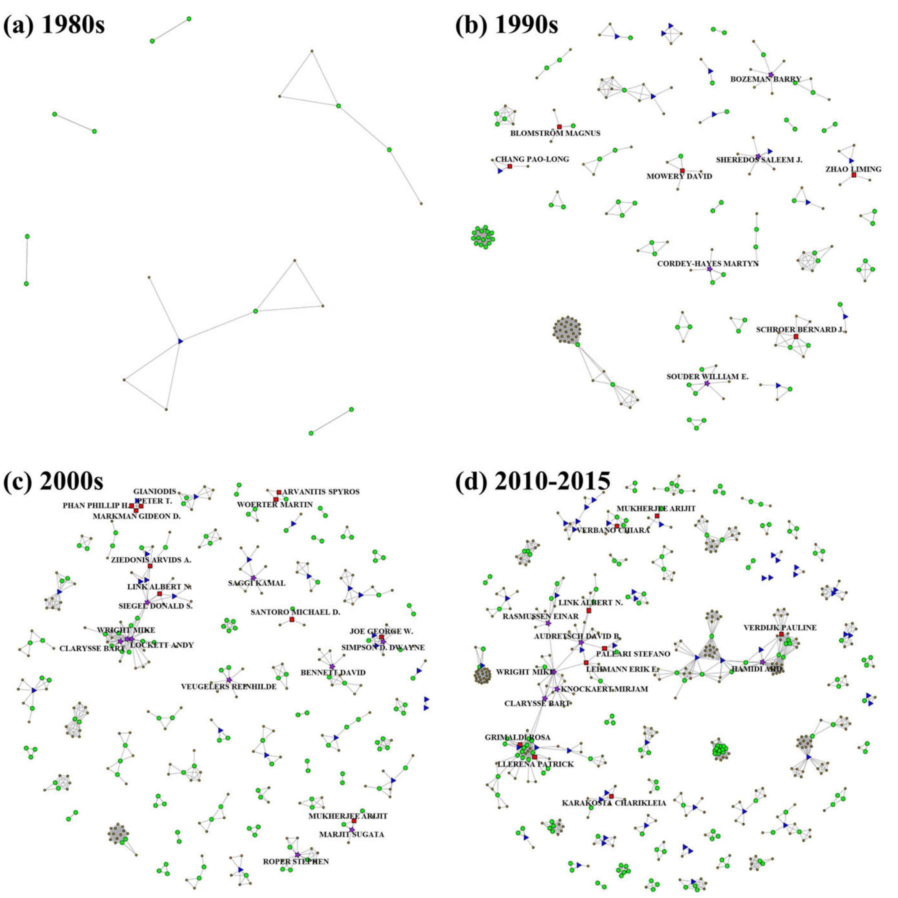

Fig. 8 Evolution of co-authorship networks in TT research

Table 4 Number of authors with high betweenness centrality

Betweenness centrality	1980s	1990s	2000s	2010–2015s
> 1000	0	0	0	7
> 500	0	0	0	7
> 100	0	2	3	20
> 10	1	6	22	22

path. Based on this approach, co-authorship networks were derived for the 1980s, 1990s, 2000s, and 2010–2015, as illustrated in Fig. 8.[6] We also found the scholars who acted as a knowledge hub by calculating the betweenness centrality, as described in Table 4. In the

[6] The authors who published more than three articles (red squares and purple stars) in each period are labeled in Fig. 8. Wholly labeled co-authorship networks are presented in Fig. 11 of "Appendix". (1980s), Fig. 12 of "Appendix" (1990s), Fig. 13 of "Appendix" (2000s), and Fig. 14 of "Appendix" (2010–2015).

co-authorship network, a node is a certain author, and an arc between the authors is a paper. The width of a line is thicker when the authors have combined to write more papers. Moreover, each node is distinguished with a set of shapes and colors: authors with one, two, three, four, and more than four co-authored papers are represented by a small gold circle, large green circle, blue triangle, red square, and purple star, respectively.

In the 1980s, professional research group barely existed. Most of the authors in this period published just one paper, and the observed research topics in each individual network were not consistent; no major research topics served as the main research theme of a network in this decade (see Table 2). In the 1990s, more networks existed, four of which had a prolific author who published more than four papers. This indicates that knowledge started to be accumulated in TT research in the 1990s. However, the main research themes of the co-authorship groups were still far from the major research topics of the decade. The research groups that investigated TT-related issues intensively emerged in the 2000s. In particular, the main research theme for the largest research group aligned with the top-ranked research topic of the decade (topic 7). This means that a research community that had accumulated professional knowledge had begun to lead TT research for the first time. From 2010 through 2015, both the number and size of the networks were much larger than in the 2000s. Furthermore, as the number of scholars who had strong academic impacts considerably increased in this period (as presented in Table 4),[7] TT research significantly advanced as a sound academic discipline in this period.

5.3.3 *Geographical distributions of co-authorships*

There was a definite shift in co-authorship where TT scholars were gradually inclined to work together (see Fig. 7). Considering that the distances among the scholars would possibly affect research collaborations, geographical distributions of co-authorship are also important to encapsulate the changes in TT research. Based on the affiliation information of authors, this study tracked the geographical distributions of co-authorship.

Rather than focusing on all the authors in the data, we investigate influential scholars who have more than 0 betweenness centrality score in co-authorship networks as these authors have a marginal impact on academia. Though this study uses a 10-year interval from 1980, the period of 1980s is not considered in this section because only four authors have more than 0 betweenness centrality in the co-authorship network in the 1980s. Under this context, two proportions are used to examine the geographical distributions of co-authorships; simple proportions of author numbers and proportions weighted by the number of journal articles. As a result, interesting changes are identified in the geographical distributions of co-authorships as shown in Fig. 9 (see Table 8 in "Appendix" for detailed information).

In relation to geographical proportions of influential authors, European scholars had gradually increased and finally occupied more than half of the ratios (65.2%) in 2010–2015, while more than half of the influential authors were located in North America in the 1990s (72.7%). In addition, the geographical distributions of influential authors in TT co-authorship networks seem to be diversified as the rates of prolific scholars in Asia, South America, and Oceania significantly increased from 1990 to date. This shift in the geographical distributions of co-authorships is more clearly observed when the geographical proportions weighted by the number of journal articles are considered. While

[7] Detailed information of researchers with high betweenness centrality is described in Table 7 of "Appendix".

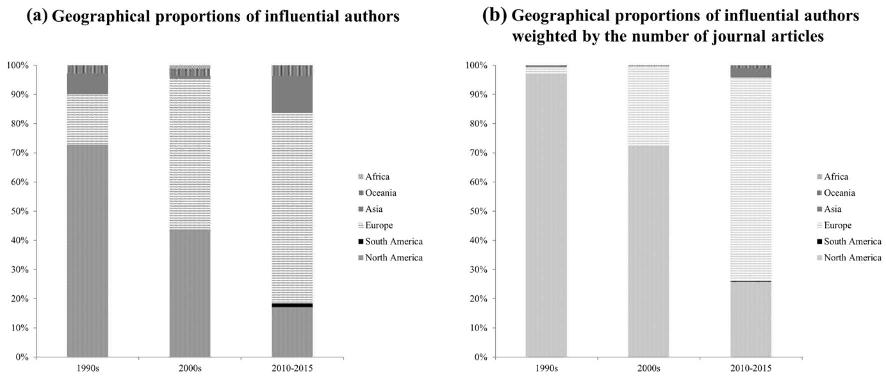

Fig. 9 Geographical distributions of co-authorships

most of the notable authors in the 1990s are located in North America (97.1%), the influences of European TT scholars radically increased from 2.2% in 1990s to 69.7% for the period of 2010–2015. Despite the lack of geographical ratios of influential authors in Asia, South America, and Oceania, their ratios also significantly increased in recent times when compared to the past; sextuple increments of Asian authors (from 0.6% to 3.3) and decuple increments of Oceanian authors (from 0.1 to 1.0%). More specifically, TT scholars in latecomer countries (e.g., China, South Korea, Japan, Taiwan, or New Zealand) have started raising their voices, while focusing on enhanced technological capabilities and domestic R&D activities in their countries from 2010.

5.4 Step 4: Identify the emerging research topics

Based on the results of the CTM and co-authorship network, a considerable shift occurred in 2000, making that year the turning point of TT research: research interests largely changed in terms of the principal transfer agent and scope, and research groups with accumulated professional knowledge started to emerge and take lead on a main research agenda. Therefore, we split the study's time span into two periods (before 2000 and since 2000) to further explore potential emerging research topics. We then produced a portfolio by calculating the slope of the linear regression and share of overall papers for the two periods, as shown in Fig. 10. In the portfolio, we set the third quartiles of the slope of linear regression (9.5) and of the share of papers (1.14%) as reference lines; the emerging research topics are in quadrant 1. Approximately two-thirds of the emerging topics (topics 7, 17, 19, 35, 47, 108, 109, 111, 116, and 118) corresponded with the aforementioned major research streams of the 2000s and 2010–2015; and the others (topics 25, 38, 50, 63, 92, and 101) were not derived from major research streams. This indicates that the topics that were not major research streams could be emerging research topics due to their increasing growth propensity (Table 5).

Therefore, we should focus on these six topics to understand the future development of TT research. First, agricultural TT (topics 25 and 38) is increasingly becoming a noteworthy research topic, particularly for less agriculturally developed countries. Topic 25 refers to TTs in agricultural water management for water-scarce countries located in sub-Saharan Africa or Arabia; topic 38 is related to on-farm training or TTs with farmer participation. Second, investigations of spillovers and their effects (topic 50) have

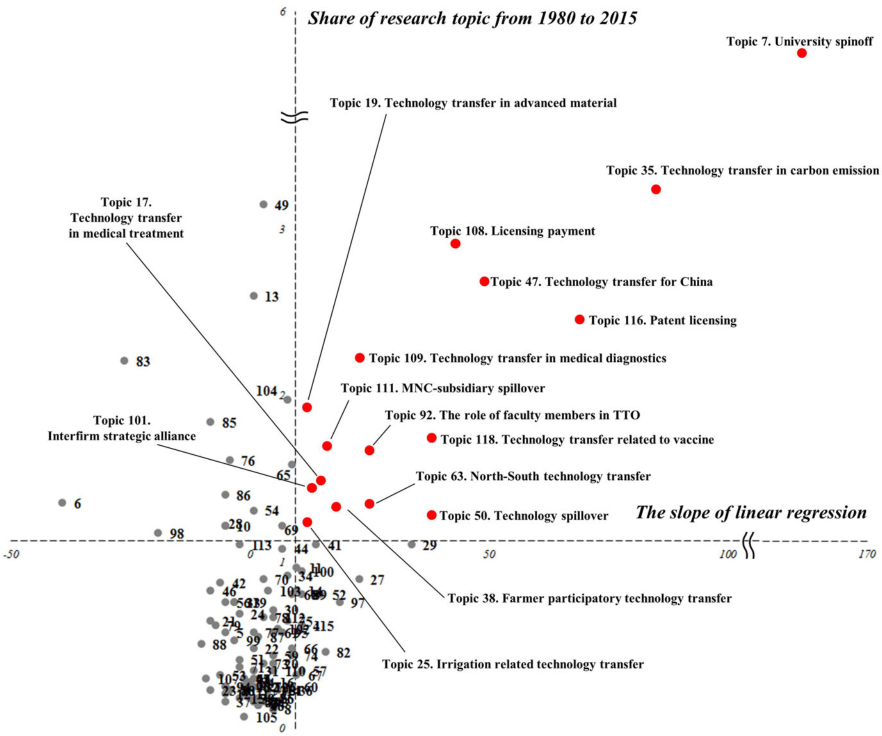

Fig. 10 Portfolio analysis to identify the emerging research topics

geometrically increased. This indicates that scholars have begun to expand their interests to include informal, unintentional, and uncompensated TT mechanisms. Third, changes in North–South transfer (topic 63) are increasingly observed due to advances in indigenous technological capabilities in less developed countries. This is quite interesting because topic 63 is the opposite of the conventional debates on other potentially emerging topics. Although TT has been regarded as a significant way to leverage competitiveness, scholars (e.g., Lall 1992; Pack and Saggi 1997; Wei 1995) have expressed that it is difficult to expect North–South TT to have meaningful effects when the Southern country has insufficient technological capabilities for assimilating the transferred technology. However, topic 63 claims that the gap between the Northern and Southern countries has narrowed, so novel implications could exist. Fourth, the role of faculty members in university and technology-transfer-office (TTO) interactions (topic 92) has emerged as university-centered TT research has become more fashionable since 2000. Finally, TTs based on interfirm strategic alliances (topic 101) could be a good research topic for the future. An interfirm strategic alliance is a very interesting topic from the principal transfer agent's perspective as a strategic alliance differs from conventional partnership or cooperation; multiple firms can supplement each other, not only by transferring technology but also by sharing overall managerial resources, such as raw materials and management know-how. Therefore, TT mechanisms featuring strategic alliances can be carried out in a more complex and risky—but more effective and efficient—manner. Consequently,

Table 5 Emerging research topics

Emerging topics		Number of papers before 2000	Number of papers after 2000	Percentage of papers from 1980 to 2015 (share of papers)	Linear slope between before and after 2000
7[a]	University-based academic entrepreneurship	37	199	236 (5.42%)	162
17[a]	TT applications in medical devices or health rehabilitation	25	40	65 (1.49%)	15
19[a]	TT applications in advanced materials	36	48	84 (1.93%)	12
25	TT applications in irrigation	21	33	54 (1.24%)	12
35[a]	TT applications in fields related to carbon emissions	28	113	141 (3.24%)	85
38	Farmer participatory TTs	20	38	58 (1.33%)	18
47[a]	TT-related issues in China	34	83	117 (2.69%)	49
50	Technology spillover	9	47	56 (1.29%)	38
63	North–South TTs	17	42	59 (1.35%)	25
92	Role of faculty members in TTO	24	49	73 (1.69%)	25
101	Interfirm strategic alliances	25	38	63 (1.45%)	13
108[a]	Investigating licensing contracts from the perspectives of international economics	42	85	124 (2.92%)	43
109[a]	TT applications in medical diagnostics	37	60	97 (2.23%)	23
111[a]	TT through MNC-subsidiary spillover	29	45	74 (1.70%)	16
116[a]	TT through IPR systems	19	88	107 (2.46%)	69
118[a]	TT applications in pharmaceutical vaccine technology	19	57	76 (1.75%)	38

[a]The topics that are included in major research streams since the 2000s

investigations on TT tend to examine the inherent or underlying interactions within the transfer process, focusing on the increasingly nonlinear TT mechanisms.

6 Discussion

This study examines the patterns of TT research since 1980, using quantitative analyses. Thus, this study sheds light on TT research by suggesting a conceptual framework that would integrate diverse aspects of TT, and by identifying major research topics and historical developments in scholarly communities. In this section, the implications of this study's results and insights are discussed in detail.

Through examining co-authorship networks in TT research, this study demonstrates that TT can be regarded as a sound discipline globally, rather than merely being a good research subject based on clear evidences; this aligns with Wright's (2014) argument that TT is now maturing as an area of study. Although numerous researchers (e.g., Becher and Trowler 2001) have argued that the notion of a discipline is not precisely defined, we can discuss whether TT can be regarded as a sound discipline by following Krishnan (2009). According to Krishnan (2009), the characteristics of a distinct discipline are (1) having a particular object of research, (2) having a body of accumulated specialist knowledge referring to that object of research, (3) having theories and concepts that the accumulated specialists can use to effectively organize their knowledge, (4) using specific terminologies or a specific technical language that has been adjusted to the research object, (5) having specific research methods that match the specific research requirements, and (6) having institutional manifestations in the form of subjects taught in universities or colleges. The first five characteristics seem to be satisfied when considering that the first journal, *The Journal of Technology Transfer* which began in 1977, deals only with TT issues. Moreover, other renowned journals have published professional articles in relation to TT, and these articles used specific terminologies and theories from the past. Addressing the last characteristic, this study shows that professional knowledge on TT, particularly for academic entrepreneurship, has accumulated since 2000. In addition, individuals explaining TTs have increasingly diffused globally in recent times. Hence, organizing historical patterns of TT research, which is the main purpose of this study, provides significant insights to understand TTs as a sound and promising discipline.

Theoretically, this study expands the renowned theoretical model (i.e., Triple Helix) to suggest a new conceptual framework that would integrate the fragmented perspectives on TT, although this framework can be elaborated upon. There are three components of the framework: transfer agent, technological field, and scope. These components are useful to identify trends in TT at a glance, but for several reasons, they may be ambiguous when attempting to acquire a deeper understanding. First, although TT should contain at least two agents (donor and recipient), this study focused on the conspicuous transfer agents, which attract more attention. Second, the technological field, as a component of the conceptual framework, seems to require not only a technological field itself, but also a policy or a social driver. This study's results imply that TT scholars' attention in relation to specific technological fields increases for good reasons (e.g., a postwar environment or global climate change). Third, the scope of TT research can be narrower than in other fields as it can be classified using the micro-meso-macro architecture: cross-border TT at the national (macro) level, interfirm spillover at the organizational (meso) level, and transfer among technology users at the individual (micro) level. Considering that a national-level phenomenon (i.e., a macroeconomic effect) can strongly affect organizational- or individual-level actions (i.e., microeconomic events), this study's explanation of macroeconomic research (e.g., international FDI and North–South transfers) through microeconomic research (e.g., university spinoffs and TTO) at the same level (i.e., scope) is a critical limitation; however, we mainly focused on describing the changes in academic interests.

Methodologically, this study, to the best of our knowledge, is unique as a set of quantitative analyses is applied to investigate the changes in TT research, while previous studies were undertaken qualitatively (e.g., Audretsch et al. 2014; Bozeman 2000; Cunningham et al. 2017; Wahab et al. 2012). A large data set, which comprises of 1338 journals and 4430 corresponding papers, is analyzed, and is challenging to accomplish in a qualitative analysis. Despite this contribution, the learning from other qualitative studies continues to provide valuable opportunities and insights. For example, previous studies that were designed to create models for organizing TT literature (e.g., Bozeman et al. 2015; Battistella et al. 2016) can be helpful in elaborating this study's conceptual framework. In addition, the results of Cunningham et al. (2017), which synthesize qualitative case studies in relation to TT from 1996 through 2015, are also beneficial in understanding the changes in TT research. Although our study mainly focuses on providing objective and data-driven results, Cunningham et al. (2017) qualitatively identified the in-depth trends in TT research. In addition to providing other interesting viewpoints for exploring the evolution of TT research (e.g., gender, geographical location, and data-collection approach), Cunningham et al.'s (2017) results were rather identical to our own. In particular, they claimed that investigations of TT mechanisms and TTOs are the predominant focus of TT research. This is quite similar to our study's results regarding the changing scope of TT studies from the national (macro) level to the organizational or individual (meso and micro) level since 2000. Furthermore, they showed how the sectoral contexts in TT research have changed from manufacturing-industry cases to high-tech and emerging industrial cases, such as those in health and biotechnology, information and communication technology, and energy and renewable resources. This finding is also similar to our study's results. Thus, scholars can gain further understanding and future research opportunities with respect to TT by cautiously matching our research, which provides quantitative evidence, with other qualitative studies, which provide in-depth and complementary insights.

Regarding practical contributions, this study can not only be a good lens to unify previous viewpoints on changing patterns of TT research, but also a milestone to suggest further research opportunities. Although there are obvious differences in the details between this and previous studies (e.g., the time when the research paradigm shifted and specific viewpoints used in interpreting research agendas), we provide analytical evidences showing that the larger vein of research trends is similar. For example, the focus of TT research has been narrowed from national-level transfers (e.g., North–South transfers and FDIs) to organizational-level transfers (e.g., university spinoff businesses and MNC–subsidiary spillovers). This change is also similarly argued in previous studies. Bozeman (2000) and Audretsch et al. (2014) claimed that the paradigm of TT research had shifted from international to domestic transfers, and Wahab et al. (2012) stated that organizational learning theory had subsumed TT research from the late 1980s to the early 1990s. In order to address future research opportunities, this study also presented the emerging research topics which have academic potential. For instance, we found that TT has now emerged at the individual level (e.g., among faculty members, topic 92, and agricultural technology users, topic 38). The emerging research topics imply that scholars tend to focus more on deepened, inherent, and underlying interactions of the TT process.

7 Conclusion

The purpose of this study is to identify both, where TT research originated and where it is going. In order to accomplish this, this research follows four steps. First, bibliographic data in relation to TT is collected from SCI/SSCI/SCIE journal articles in the SCOPUS database. Further, the CTM is applied to reveal 120 distinguishing research topics. The co-authorship network analysis is used to identify the evolution of research groups and to track the changes in major research interests until now. Consequently, as our findings are comprehensively synthesized and mapped based on this study's conceptual framework, historical changes in TT research are identified using both, intuition and objective analytical evidence. In the final step, emerging research topics—those that are expected to have significant impact in the future—are identified using portfolio analysis. Theoretically, as this study suggests a conceptual framework that narrows the broad scope of TT studies, previous conflicts in relation to the best way to explain the changes or trends in TT domains can now be resolved using objective analytical evidence. Practically, this study contributes to research by demonstrating how TT studies should be directed, indicating that this study can act as a guide for further investigations.

Despite this study's implications, two limitations remain and should be examined further. First, even though SCOPUS is the world's largest database of academic publications, many academic publications are not in that database. Moreover, this study only focused on SCI/SSCI/SCIE journal articles. Thus, extending the bounds of the data is a requirement for future research. Second, we only considered one topic (the one with the highest probability in the topic model) for each paper. However, the second- or third-highest probabilities for a given paper can be meaningful because a paper is often best explained using two or more topics. Accordingly, experts providing qualitative validation could be helpful in enhancing this study's quality.

Acknowledgements This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (2016R1D1A1B03933943).

Appendix

See Tables 6, 7 and 8; Figs. 11, 12, 13 and 14.

Table 6 Topics and corresponding terms

Topic 6		Topic 7		Topic 13		Topic 17	
Term	Probability	Term	Probability	Term	Probability	Term	Probability
feder	0.70101	spinoff	0.105447	water	0.167113	treatment	0.059374
commerc	0.030135	ventur	0.092035	softwar	0.043672	devic	0.056787
law	0.018026	entrepreneuri	0.072746	reus	0.028608	counselor	0.032169
ttos	0.016742	entrepreneurship	0.061495	treatment	0.021479	medic	0.030007
taxpay	0.013601	entrepreneur	0.044207	citi	0.020665	patient	0.029255
chamber	0.013601	startup	0.042448	wast	0.020491	physician	0.028233
geodet	0.010881	tacit	0.021104	municip	0.019067	rehabilit	0.021258
hardwar	0.008452	commercialis	0.019198	basin	0.010936	disabl	0.019954
ngs	0.00816	universitybas	0.012037	wastewat	0.010306	abus	0.019493
relationsfocus	0.00816	incub	0.008988	contamin	0.010014	addict	0.016845
Topic 19		Topic 25		Topic 35		Topic 38	
Term	Probability	Term	Probability	Term	Probability	Term	Probability
metal	0.037734	irrig	0.080224	cdm	0.10538	farmer	0.117406
aircraft	0.032988	water	0.039167	emiss	0.101986	women	0.039643
composit	0.027191	defenc	0.035949	carbon	0.0706	agricultur	0.035906
weld	0.019023	tanzania	0.028655	energi	0.065578	gender	0.028549
powder	0.011423	revolut	0.022873	china	0.021774	farm	0.01807
bond	0.010872	subsaharan	0.021488	ghg	0.017186	weed	0.017103
foam	0.01087	clone	0.020022	india	0.016302	pest	0.017099
alloy	0.010326	ldcs	0.019396	abat	0.014701	ngos	0.016228
ndt	0.007609	saudi	0.019032	renew	0.014628	ipm	0.01622

Table 6 continued

Topic 47		Topic 49		Topic 50		Topic 63	
Term	Probability	Term	Probability	Term	Probability	Term	Probability
china	0.350796	agricultur	0.142417	spillov	0.355478	south	0.20876
chines	0.10826	rice	0.049695	fdi	0.086368	northern	0.06613
wind	0.074962	food	0.039211	vertic	0.066113	ipr	0.053233
india	0.051224	farm	0.0361	tfp	0.050883	northsouth	0.046684
offshor	0.020468	zone	0.031556	horizont	0.041259	ireland	0.02774
indigen	0.018705	crop	0.027474	frontier	0.02207	wage	0.025268
rural	0.017405	farmer	0.021503	affili	0.020626	welfar	0.020315
turbin	0.016548	genom	0.017185	backward	0.020594	inequ	0.017546
automot	0.013566	rural	0.013947	ownership	0.014647	worker	0.017513
energi	0.011422	agroclimat	0.009266	ucdm	0.014331	indigen	0.016545
Topic 69		**Topic 76**		**Topic 83**		**Topic 85**	
Term	Probability	Term	Probability	Term	Probability	Term	Probability
mine	0.070968	speci	0.040525	japan	0.178691	autom	0.057505
nuclear	0.05424	biodivers	0.02972	japanes	0.158451	arm	0.044094
radiat	0.049762	aquacultur	0.024144	korea	0.060861	phd	0.029579
ktt	0.04355	fisheri	0.021384	consortia	0.031481	healthcar	0.025722
librari	0.025387	latin	0.021341	korean	0.024613	prosthet	0.022807
iaea	0.022406	biolog	0.018578	south	0.018429	weapon	0.019745
snow	0.022398	marin	0.017117	textil	0.015626	militari	0.017641
swiss	0.018228	gene	0.01709	export	0.012903	prosthes	0.014444
miner	0.017408	bank	0.014249	governmentsponsor	0.010699	fabric	0.013711
web	0.016214	metro	0.010695	ozon	0.008265	prosthesi	0.011404

Table 6 continued

Topic 86		Topic 92		Topic 98		Topic 101	
Term	Probability	Term	Probability	Term	Probability	Term	Probability
soil	0.073201	faculti	0.16339	comput	0.294037	allianc	0.252192
crop	0.048635	confer	0.062782	remot	0.079646	interfirm	0.046724
moistur	0.023048	tto	0.049338	gis	0.033181	brazilian	0.040696
agricultur	0.022462	director	0.030638	algorithm	0.019982	fusion	0.038171
nutrient	0.020051	disclosur	0.027673	standardis	0.017095	randd	0.018401
farmer	0.019695	ttos	0.022798	softwar	0.015551	interorganiz	0.017964
assimil	0.017496	dental	0.017301	aquat	0.013137	brazil	0.017468
cotton	0.014899	fellow	0.01502	selfefficaci	0.011831	res	0.012917
agroforestri	0.014235	crcs	0.013838	cdrom	0.01181	pig	0.010523
surfac	0.012218	specialti	0.013832	computer	0.011675	buyersuppli	0.010515
Topic 104		Topic 108		Topic 109		Topic 111	
Term	Probability	Term	Probability	Term	Probability	Term	Probability
treatment	0.067674	licens	0.351829	cell	0.042166	multin	0.261676
ergonom	0.041552	royalti	0.041502	imag	0.040909	subsidiari	0.115167
therapi	0.028935	equiti	0.034617	hospit	0.030798	mnes	0.053617
substanc	0.024147	payment	0.021599	cancer	0.029413	mncs	0.037091
hazard	0.02161	license	0.019867	patient	0.023576	spillov	0.028244
worker	0.021096	tariff	0.01856	treatment	0.01333	affili	0.020779
occup	0.020873	fee	0.017673	medic	0.012813	bargain	0.02011
abus	0.018693	licensor	0.017086	diagnost	0.011422	parent	0.018557

Table 6 continued

Topic 104		Topic 108		Topic 109		Topic 111	
Term	Probability	Term	Probability	Term	Probability	Term	Probability
evidencebas	0.01707	welfar	0.013914	tissu	0.011207	fdi	0.017539
wast	0.013817	export	0.013079	molecular	0.010094	mne	0.016666

Topic 116		Topic 118	
Term	Probability	Term	Probability
patent	0.507245	vaccin	0.112803
incub	0.025656	drug	0.05343
citat	0.025584	pharmaceut	0.043825
ipr	0.016925	hiv	0.040919
ownership	0.014254	india	0.023568
inventor	0.013878	conjug	0.018977
tripl	0.013153	assay	0.018918
helix	0.012538	hib	0.016012
disput	0.010016	hivaid	0.01364
write	0.00994	immunogen	0.012717

Table 7 Detailed information of researchers with high betweenness centrality (> 10)

1980s		1990s		2000s		2010–2015	
Author	Betweenness centrality	Author	Betweenness centrality	Author	Betweenness centrality	Author	Betweenness centrality
Raz Baruch	11.0	McGuire Tom	203.0	Wright Mike	467.2	Wright Mike	2546.5
		Anerella Michael D.	128.0	Siegel Donald S.	415.5	Clarysse Bart	2122.4
		Bozeman Barry	38.0	Ziedonis Arvids A.	176.0	Audretsch David B.	1368.0
		Rogers Everett M.	25.0	Bozeman Barry	75.0	Hamidi Ahd	1179.9
		Coker Karen	21.0	Lockett Andy	60.9	Hendriks Jan	1070.5
		Carayannis Elias G.	17.0	Link Albert N.	39.5	Tartari Valentina	1014.0
		Souder William E.	13.0	Fontes Margarida	38.0	Salter Ammon	1014.0
		Schroer Bernard J.	12.3	Ensley Michael D.	38.0	Rasmussen Einar	773.0
				Lowe Robert A.	38.0	Sobrero Maurizio	698.2
				Roper Stephen	33.0	Geuna Aldo	595.0
				Saggi Kamal	29.0	Lehmann Erik E.	575.0
				Bennett David	29.0	Franzoni Chiara	524.0
				Gorschek Tony	24.3	Verdijk Pauline	518.4
				Rojec Matija	21.0	Suhardono Mahendra	509.1
				Simpson D. Dwayne	19.4	Jadhav Suresh	488.0
				Veugelers Reinhilde	19.0	Link Albert N.	441.0
				Thursby Jerry G.	18.5	Bodas Freitas Isabel M.	435.0
				Thursby Marie C.	18.5	Knockaert Mirjam	326.0
				Amesse Fernand	18.0	Paleari Stefano	267.5
				Cohendet Patrick	18.0	Mohammadi Ali	267.0
				Liu Xiaming	16.0	De Boer Otto	253.6
				Maskus Keith E.	15.0	Llerena Patrick	224.0
				Feldman Maryann	14.0	Martino Steve	215.0
				De Lucia Andrea	12.3	Huynh Chuong	198.0

Table 7 continued

1980s		1990s		2000s		2010–2015	
Author	Betweenness centrality	Author	Betweenness centrality	Author	Betweenness centrality	Author	Betweenness centrality
				Foley C. Fritz	12.0	Bekkers Rudi	180.0
						Perkmann Markus	180.0
						McKelvey Maureen	180.0
						Bakker Wilfried A.M.	163.9
						Van Oijen Monique	163.9
						Holleman Marit	154.6
						Storti Susan A.	154.0
						Munari Federico	149.0
						Amodeo Maryann	120.0
						Grimaldi Rosa	119.9
						Siegel Donald S.	91.0
						Hulsbeck Marcel	91.0
						D'este Pablo	51.6
						Collin Nicolas	68.0
						Hoogenboom Gerrit	60.0
						Jones James W.	52.0
						Lissoni Francesco	44.0
						Ockwell David	36.0
						Hussinger Katrin	29.6
						Toschi Laura	29.6
						Griffith John F.	28.0
						Fini Riccardo	26.2
						Grimpe Christoph	24.0
						Watson Jim	24.0

Table 7 continued

1980s		1990s		2000s		2010–2015	
Author	Betweenness centrality	Author	Betweenness centrality	Author	Betweenness centrality	Author	Betweenness centrality
						Cao Yiping	20.0
						Fu Xiaolan	20.0
						Psarras John	15.0
						Gong Yundan	15.0
						Plewa Carolin	15.0
						Buenstorf Guido	14.0
						Toole Andrew A.	12.6
						Lau Chi K.M.	12.0

Note: As betweenness centrality quantifies the number of times a certain node acts as a bridge along the shortest path between two other nodes, an author with high betweenness centrality indicates that they play a pivotal role in scholar networks as a knowledge hub

Table 8 Changes in geographical distributions of co-authorships

1990s			2000s			2010–2015		
Country	Proportion (%)	Weighted proportion (%)	Country	Proportion (%)	Weighted proportion (%)	Country	Proportion (%)	Weighted proportion (%)
(a) Distribution of individual countries								
United States	69.09	96.67	Unites States	37.93	70.87	United States	13.48	24.29
United Kingdom	10.00	1.61	United Kingdom	17.24	20.22	Italy	12.77	21.66
Belgium	3.64	0.39	Italy	9.20	3.29	United Kingdom	11.35	19.65
Sweden	3.64	0.20	Canada	5.75	1.49	Netherlands	9.93	12.99
India	3.64	0.39	Germany	4.60	0.73	France	6.38	4.74
Taiwan	3.64	0.20	Sweden	4.60	1.10	Belgium	4.96	3.33
Canada	3.64	0.39	Netherlands	3.45	0.55	Germany	4.96	3.33
Australia	2.73	0.15	Switzerland	3.45	0.75	India	4.26	1.96
			Australia	2.30	0.18	Canada	3.55	1.50
			Belgium	2.30	0.37	Greece	2.84	1.20
			Cyprus	1.15	0.05	New Zealand	2.84	0.90
			France	1.15	0.05	South Korea	2.84	0.80
			Greece	1.15	0.05	Sweden	2.84	0.90
			India	1.15	0.11	Denmark	2.13	0.53
			Ireland	1.15	0.05	Switzerland	2.13	0.45
			Portugal	1.15	0.045	Argentina	1.42	0.20
			Slovenia	1.15	0.07	Ireland	1.42	0.30
			South Africa	1.15	0.05	Japan	1.42	0.20
						Luxembourg	1.42	0.25
						Spain	1.42	0.25
						Australia	0.71	0.08
						Cambodia	0.71	0.05
						China	0.71	0.05

Table 8 continued

1990s			2000s			2010–2015		
Country	Proportion (%)	Weighted proportion (%)	Country	Proportion (%)	Weighted proportion (%)	Country	Proportion (%)	Weighted proportion (%)
						Hong Kong	0.71	0.05
						Indonesia	0.71	0.08
						Norway	0.71	0.15
						Taiwan	0.71	0.05
						Turkey	0.71	0.05

1990s			2000s			2010–2015		
Continent	Proportion (%)	Weighted proportion (%)	Continent	Proportion (%)	Weighted proportion (%)	Continent	Proportion (%)	Weighted proportion (%)
(*b*) *Distribution of continents*								
North America	72.73	97.06	North America	43.68	72.36	North America	17.02	25.80
South America	0.00	0.00	South America	0.00	0.00	South America	1.42	0.20
Europe	17.27	2.20	Europe	51.72	27.30	Europe	65.25	69.74
Asia	7.27	0.59	Asia	1.15	0.11	Asia	12.77	3.28
Oceania	2.73	0.15	Oceania	2.30	0.18	Oceania	3.55	0.98
Africa	0.00	0.00	Africa	1.15	0.05	Africa	0.00	0.00

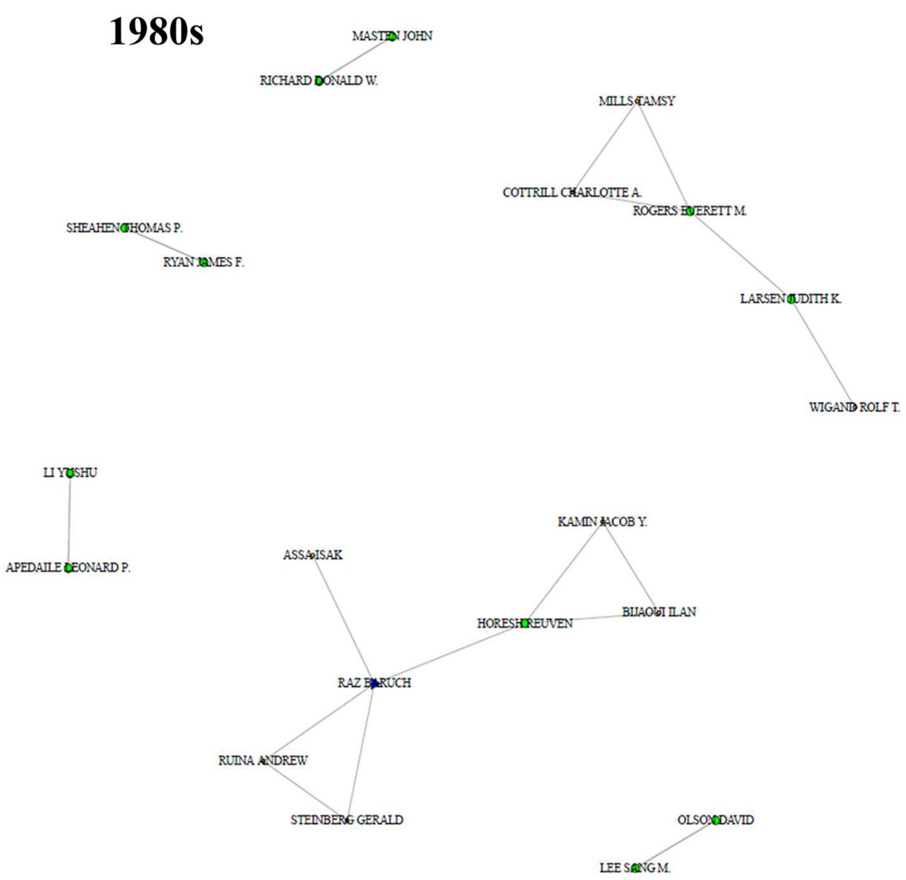

Fig. 11 Co-authorship network for TT research in the 1980s (labeled)

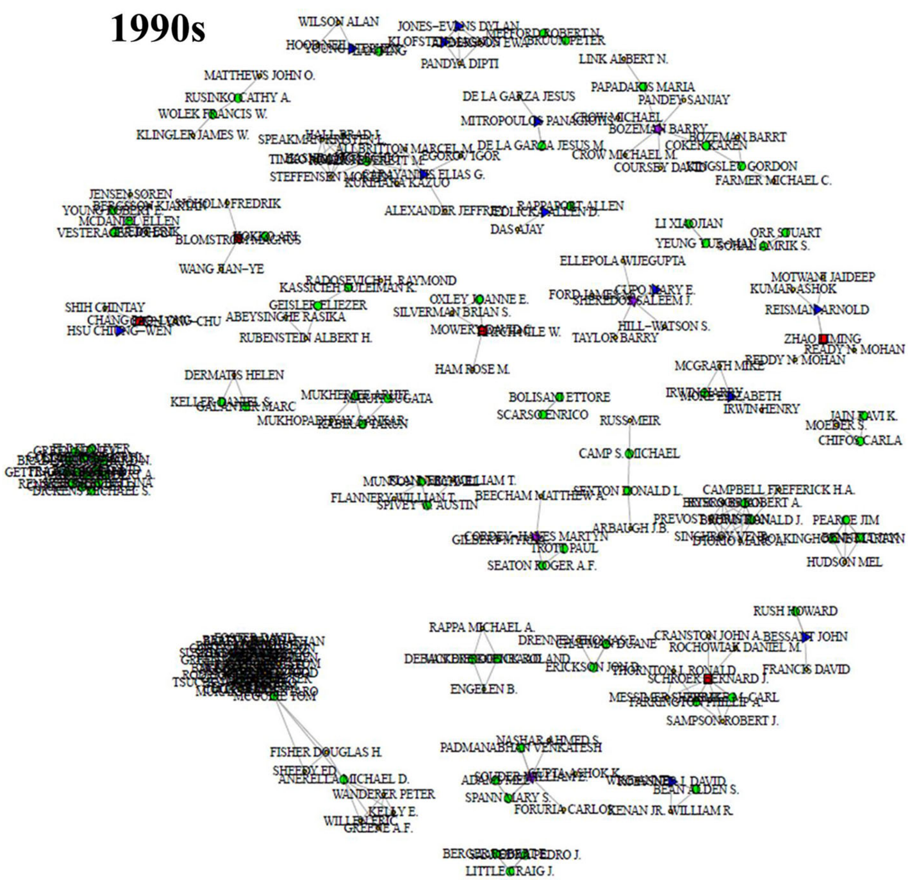

Fig. 12 Co-authorship network for TT research in the 1990s (labeled)

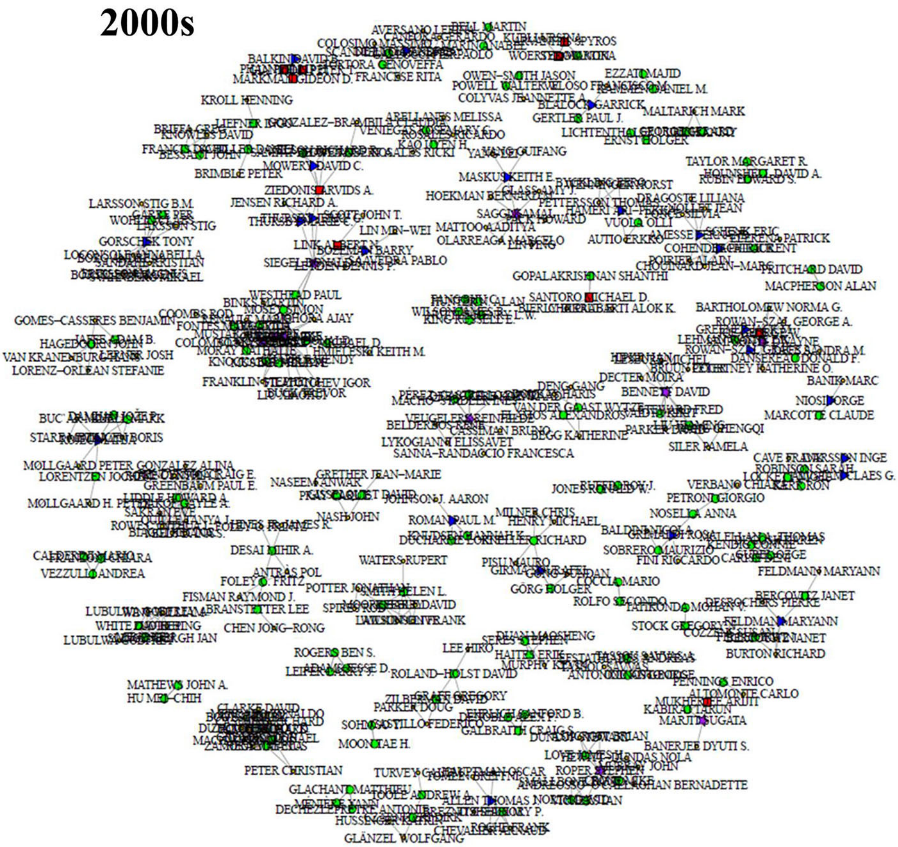

Fig. 13 Co-authorship network for TT research in the 2000s (labeled)

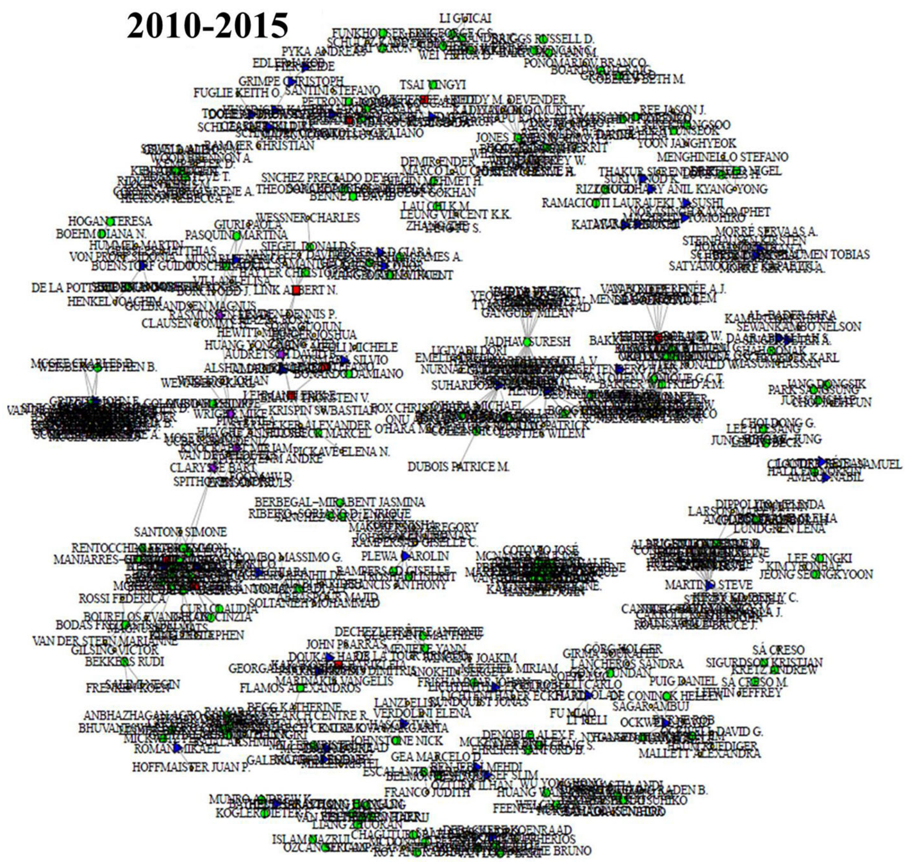

Fig. 14 Co-authorship network for TT research between 2010 and 2015 (labeled)

References

Amesse, F., & Cohendet, P. (2001). Technology transfer revisited from the perspective of the knowledge-based economy. *Research Policy, 30*(9), 1459–1478.

Arrow, K. (1962). Economic welfare and the allocation of resources for invention. In R. Nelson (Ed.), *The rate and direction of inventive activity: Economic and social factors* (pp. 609–626). Princeton, NJ: Princeton University Press.

Audretsch, D. B., Lehmann, E. E., & Wright, M. (2014). Technology transfer in a global economy. *The Journal of Technology Transfer, 39*(3), 301–312.

Battistella, C., De Toni, A. F., & Pillon, R. (2016). Inter-organisational technology/knowledge transfer: A framework from critical literature review. *The Journal of Technology Transfer, 41*(5), 1195–1234.

Becher, T., & Trowler, P. R. (2001). *Academic tribes and territories: Intellectual enquiry and the cultures of disciplines*. Buckingham: The Society for Research into Higher Education and the Open University Press.

Berman, E. P. (2008). Why did universities start patenting? Institution-building and the road to the Bayh–Dole Act. *Social Studies of Science, 38*(6), 835–871.

Blei, D. M., & Lafferty, J. D. (2007). A correlated topic model of science. *The Annals of Applied Statistics, 1*(1), 17–35.

Bozeman, B. (2000). Technology transfer and public policy: A review of research and theory. *Research Policy, 29*(4), 627–655.

Bozeman, B., Rimes, H., & Youtie, J. (2015). The evolving state-of-the-art in technology transfer research: Revisiting the contingent effectiveness model. *Research Policy, 44*(1), 34–49.

Chesbrough, H. W. (2006). *Open innovation: The new imperative for creating and profiting from technology*. Boston: Harvard Business Press.

Choung, J. Y., Hwang, H. R., & Song, W. (2014). Transitions of innovation activities in latecomer countries: An exploratory case study of South Korea. *World Development, 54,* 156–167.

Christensen, C. M., Horn, M. B., & Johnson, C. W. (2008). *Disrupting class: How disruptive innovation will change the way the world learns*. New York: McGraw-Hill.

Cunningham, J. A., Menter, M., & Young, C. (2017). A review of qualitative case methods trends and themes used in technology transfer research. *The Journal of Technology Transfer, 42*(4), 923–956.

Daghfous, A. (2004). An empirical investigation of the roles of prior knowledge and learning activities in technology transfer. *Technovation, 24*(12), 939–953.

Etzkowitz, H., & Leydesdorff, L. (2000). The dynamics of innovation: from National Systems and "Mode 2" to a Triple Helix of university–industry–government relations. *Research Policy, 29*(2), 109–123.

Fosfuri, A. (2006). The licensing dilemma: Understanding the determinants of the rate of technology licensing. *Strategic Management Journal, 27*(12), 1141–1158.

Gibbons, M., Limoges, C., Nowotny, H., Schwartzman, S., Scott, P., & Trow, M. (1994). *The new production of knowledge: The dynamics of science and research in contemporary societies*. London: Sage.

Gilsing, V., Bekkers, R., Freitas, I. M. B., & Van der Steen, M. (2011). Differences in technology transfer between science-based and development-based industries: Transfer mechanisms and barriers. *Technovation, 31*(12), 638–647.

Gopalakrishnan, S., & Santoro, M. D. (2004). Distinguishing between knowledge transfer and technology transfer activities: The role of key organizational factors. *IEEE Transactions on Engineering Management, 51*(1), 57–69.

Grün, B., & Hornik, K. (2016). *Package 'topicmodels'.* ftp://cran.r-roject.org/pub/R/web/packages/topicmodels/topicmodels.pdf. Accessed November 29, 2016.

Guan, J. (2002). Comparison study of industrial innovation between China and some European countries. *Production and Inventory Management Journal, 43*(3/4), 30–46.

Guan, J. C., Mok, C. K., Yam, R. C., Chin, K. S., & Pun, K. F. (2006). Technology transfer and innovation performance: Evidence from Chinese firms. *Technological Forecasting and Social Change, 73*(6), 666–678.

Hahn, Y. H., & Yu, P. I. (1999). Towards a new technology policy: The integration of generation and diffusion. *Technovation, 19*(3), 177–186.

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.

Hitt, M. A., Ireland, R. D., & Lee, H. U. (2000). Technological learning, knowledge management, firm growth and performance: An introductory essay. *Journal of Engineering and Technology Management, 17*(3), 231–246.

Hsu, G. J., Lin, Y. H., & Wei, Z. Y. (2008). Competition policy for technological innovation in an era of knowledge-based economy. *Knowledge-Based Systems, 21*(8), 826–832.

IPCC, (2000). *Methodological and technological issues in technology transfer, International Panel on Climate Change*, Working Group III, Cambridge.

Kenney, M., & Patton, D. (2009). Reconsidering the Bayh–Dole Act and the current university invention ownership model. *Research Policy, 38*(9), 1407–1422.

Kim, L., & Dahlman, C. J. (1992). Technology policy for industrialization: An integrative framework and Korea's experience. *Research Policy, 21*(5), 437–452.

Klofsten, M., Jones-Evans, D., & Schärberg, C. (1999). Growing the Linköping technopole—A longitudinal study of triple helix development in Sweden. *The Journal of Technology Transfer, 24*(2), 125–138.

Krishnan, A. (2009). *What are academic disciplines? Some observations on the disciplinarity vs. interdisciplinarity debate*. ESRC National Centre for Research Methods, NCRM Working Paper Series. http://eprints.ncrm.ac.uk/783/1/what_are_academic_disciplines.pdf. Accessed December 6, 2016.

Kumar, J. A., & Ganesh, L. S. (2009). Research on knowledge transfer in organizations: A morphology. *Journal of Knowledge Management, 13*(4), 161–174.

Lall, S. (1992). Technological capabilities and industrialization. *World Development, 20*(2), 165–186.

Lee, Y. S. (Ed.). (1997). *Technology transfer and public policy*. Westport: Greenwood Publishing Group.

Li, J., & Lee, R. P. (2015). Can knowledge transfer within MNCs hurt subsidiary performance? The role of subsidiary entrepreneurial culture and capabilities. *Journal of World Business, 50*(4), 663–673.

Link, A. N., Siegel, D. S., & Bozeman, B. (2007). An empirical analysis of the propensity of academics to engage in informal university technology transfer. *Industrial and Corporate Change, 16*(4), 641–655.

Liu, H., & Jiang, Y. (2001). Technology transfer from higher education institutions to industry in China: Nature and implications. *Technovation, 21*(3), 175–188.

Lybbert, T. J., & Sumner, D. A. (2012). Agricultural technologies for climate change in developing countries: Policy options for innovation and technology diffusion. *Food Policy, 37*(1), 114–123.

Mahoney, M. S. (1988). The history of computing in the history of technology. *Annals of the History of Computing, 10*(2), 113–125.

Mowery, D. C., Nelson, R. R., Sampat, B. N., & Ziedonis, A. A. (2001). The growth of patenting and licensing by US universities: An assessment of the effects of the Bayh–Dole act of 1980. *Research Policy, 30*(1), 99–119.

Newman, C., Rand, J., Talbot, T., & Tarp, F. (2015). Technology transfers, foreign investment and productivity spillovers. *European Economic Review, 76,* 168–187.

Nikita, M. (2016). *Package 'ldatuning'*. ftp://cran.r-project.org/pub/R/web/packages/ldatuning/ldatuning.pdf. Accessed November 29, 2016.

Oliveira, M. (1999). Core competencies and the knowledge of the firm. In M. A. Hitt, P. G. Clifford, R. D. Nixon, & K. P. Coyne (Eds.), *Dynamic strategic resources: Development, diffusion and integration* (pp. 17–41). New York: Wiley.

Owen-Smith, J., & Powell, W. W. (2001). To patent or not: Faculty decisions and institutional success at technology transfer. *The Journal of Technology Transfer, 26*(1–2), 99–114.

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.

Pack, H., & Saggi, K. (1997). Inflows of foreign technology and indigenous technological development. *Review of Development Economics, 1*(1), 81–98.

Powell, W. W., Koput, K. W., & Smith-Doerr, L. (1996). Interorganizational collaboration and the locus of innovation: Networks of learning in biotechnology. *Administrative Science Quarterly, 41*(1), 116–145.

Ranga, M., & Etzkowitz, H. (2013). Triple Helix systems: An analytical framework for innovation policy and practice in the Knowledge Society. *Industry and Higher Education, 27*(4), 237–262.

Roger, E. (1972). *Key concepts and models: Including technology change for economic growth and development*. East Lansing: Michigan State University Press.

Rothwell, R., & Dodgson, M. (1992). European technology policy evolution: Convergence towards SMEs and regional technology transfer. *Technovation, 12*(4), 223–238.

Saad, M., & Zawdie, G. (2005). From technology transfer to the emergence of a triple helix culture: The experience of Algeria in innovation and technological capability development. *Technology Analysis & Strategic Management, 17*(1), 89–103.

Sampat, B. N. (2006). Patenting and US academic research in the 20th century: The world before and after Bayh–Dole. *Research Policy, 35*(6), 772–789.

Schmookler, J. (1966). *Invention and economic growth*. Cambridge: Harvard University Press.

Seely, B. E. (2003). Historical patterns in the scholarship of technology transfer. *Comparative Technology Transfer and Society, 1*(1), 7–48.

Shane, S. (2004). Encouraging university entrepreneurship? The effect of the Bayh–Dole Act on university patenting in the United States. *Journal of Business Venturing, 19*(1), 127–151.

Shih, H., & Chang, T. (2009). International diffusion of embodied and disembodied technology: A network analysis approach. *Technological Forecasting and Social Change, 76*(6), 821–834.

Slater, S. F., & Mohr, J. J. (2006). Successful development and commercialization of technological innovation: Insights based on strategy type. *Journal of Product Innovation Management, 23*(1), 26–33.

Tseng, Y. H., Lin, Y. I., Lee, Y. Y., Hung, W. C., & Lee, C. H. (2009). A comparison of methods for detecting hot topics. *Scientometrics, 81*(1), 73–90.

Uddin, S., Hossain, L., Abbasi, A., & Rasmussen, K. (2012). Trend and efficiency analysis of co-authorship network. *Scientometrics, 90*(2), 687–699.

U.S. Congress, Office of Technology Assessment. (1990). *Agricultural Research and Technology Transfer Policies for the 1990s—A special report of OTA's assessment on engineering agricultural technology: Issues for the 1990s (OTA-F-448).* Washington DC: Government Printing Office.

Van Looy, B., Zimmermann, E., Veugelers, R., Verbeek, A., Mello, J., & Debackere, K. (2003). Do science-technology interactions pay off when developing technology? *Scientometrics, 57*(3), 355–367.

Verspagen, B. (1991). A new empirical approach to catching up or falling behind. *Structural Change and Economic Dynamics, 2*(2), 359–380.

Wahab, S. A., Rose, R. C., & Osman, S. I. W. (2012). The theoretical perspectives underlying technology transfer: A literature review. *International Journal of Business and Management, 7*(2), 277–288.

Wei, L. (1995). International technology transfer and development of technological capabilities: A theoretical framework. *Technology in Society, 17*(1), 103–120.

Wright, M. (2014). Academic entrepreneurship, technology transfer and society: Where next? *The Journal of Technology Transfer, 39*(3), 322–334.

Wright, M., Clarysse, B., Mustar, P., & Lockett, A. (2007). *Academic entrepreneurship in Europe*. Cheltenham: Edward Elgar Publishing.

Zhao, L., & Reisman, A. (1992). Toward meta research on technology transfer. *IEEE Transactions on Engineering Management, 39*(1), 13–21.