A Literature Review with Citation Analysis of Technology Transfer

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Abstract--**In this study, we reviewed papers from the 1970s to the present on the theory development of technology transfer (TT). Using the Web of Science search engine, we extracted more than 6,000 papers from the Institute for Scientific Information database. Then, we selected 367 highly related journal papers and analyzed them with self-developed software. We found that the TT studies focused on international technology diffusion in the 1970s and 1980s. In particular, these studies used economic models to study TT activities and their impact on economic development at the global, national, and corporate levels. In the 1990s, with the emergence of technology management studies, research on TT emphasized technological issues, such as knowledge management, science and technology (S&T) policy, intellectual property rights management, and TT agents. The TT model in the 2000s (networking type) was more complicated than that in the 1970s (linear type). We successfully analyzed two major research tracks in our study; namely, the "economic" and "management of technology" tracks. The findings from our study will help scholars continue their work in each track. Finally, we also present the notion that there is no "one size fits all" TT model. We believe this is an issue that will lead to further studies.**

I. INTRODUCTION

Technology transfer (TT) has been studied for decades; however, few studies have focused on its progression and trends. Researchers have traced TT to as far back as the colonial period where colonial countries with superior agricultural, plantation, and mining technologies assimilated or eliminated those that could not develop and expand as rapidly. Since then, industrialization and globalization have triggered another long wave of TT worldwide, from developed nations to developing and underdeveloped countries. Over time, TT has become a more complicated process.

The definition of TT has some variations. In the narrow sense, TT is described as a linear process between two firms [1]. In this scenario, TT is an important part of the international business strategy of firms, and influences the economic performance of nations and firms [2]. Krugman [3] proposed the term "international TT." He stated that, in a broad sense, TT is a technological development and diffusion process, in which advanced technology holders transfer their know-how to recipients within an organization for commercialization, while leading firms diffuse their new technology to overseas manufacturers to extend their market size and market share. In this way, TT activities stimulate global innovation from the North (developed countries) to the South (developing countries) [3].

TT plays a major role in the economic development of nations; thus, improving its efficiency can continuously impact new economies. However, its role depends not only on economic climate, but also on the level of state regulations, S&T policy, investments, and industrialization. A loss of some of these factors can deeply affect the entire TT process (national TT). At the micro-level, TT can also be disrupted due to significant issues that may exist on the path from research and development (R&D) to commercialization of technology; for example, the lack of a transferees' skills to effectively manage the technology process. The right strategic option for TT offers significant benefits for companies seeking a greater competitive advantage (corporate TT).

The technology transfer model (TTM) is not a new business phenomenon. A process model of TT was proposed by Bar-Zakay in 1971, and may indeed be one of the earliest TT models [1]. Bar-Zakay used a linear process to describe how technology and knowledge are transferred from donors (transferors) to recipients (transferees). Continuous technological development, evolution of technologies, and emergence of factors such as outsourcing, globalization, introduction of a knowledge-based economy (KBE), and open innovation have significantly affected the process of intra and inter-firm TT [4,5,6]. Thus, we postulate that the study of TT has evolved, and may have generated various types of TT models.

The rest of this manuscript is organized as follows. First, we introduce our research method in Section II; 367 key papers were extracted and analyzed with an analytical tool. Data and basic statistics are provided in Section III. In Section IV, we provide our findings and divide our data into two major categories. Then, we explain the theory development and study trajectory of the TTM. Finally, we conclude our findings and offer suggestions in Section V.

II. METHODOLOGY

This study applied two citation-based methodologies: the g-index/h-index and main path analysis. The g-index/h-index was used to compare the influence of authors and journals on TT, while the main path analysis helped in comprehending the development of TT at a more detailed level.

A. The g-index and the h-index

The g-index and the h-index were proposed by Hirsch [7] and Egghe [8] as a way to measure a scientist's academic contribution based on citations of his/her publications. Here, we used these indices to quantify the contribution of authors and journals to the theory of TT. Hirsch index h is defined as "the number of papers with citation number h." For example,

a researcher has index h if h of his or her papers published over a certain period in a certain scientific field have at least h citations each, and his or her other papers in the same period and the same field have equal to or less than h citations each [7]. The g-index is an improvement over the h-index on this specific issue. If one lists a researcher's papers in decreasing order of the number of citations, "the g-index is the largest number such that the top g articles received at least g2 citations" [8].

The g-index and the h-index can also be applied to rate a journal's impact. Thus, we also used the g-index to compare the influence of TT and TTM authors and journals.

B. Main path analysis

Hummon and Doreian [9] introduced the concept of main path analysis and used citation information in academic papers to trace the main idea flow in a scientific discipline. The authors suggested main path analysis as a way of simplifying the task in a large citation network: tracing only the "main path." The main path not only indicates the development trajectory of a discipline, but also points out influential key works. The papers on the main path are significant in that both their direct and indirect influences are taken into consideration. Identifying the importance of each citation link in the network is the first step in finding the main path. The importance of each citation can be measured by counting the number of times a citation link has been traversed if one exhausts the search from a set of starting nodes to another set of ending nodes.

There are several ways to perform the count; however, in this study, we used the search path count (SPC). In a citation network, a "source" is a node that is cited but cites no other nodes; a "sink" is a node that cites other nodes but is not cited. In other words, sources are the origins of knowledge, while sinks are the endpoints of knowledge dissemination. Assuming that one exhausts searching all paths from all sources to all sinks, the SPC for each link is defined as the total number of times the link is traversed. The larger the SPC value, the more important the link's role in transmitting knowledge.

III. DATA AND STATISTICS

A. Data

To find papers related to TT and TTMs, we inputted key words such as "technolog*," "transfer*," and "model" into the Institute for Scientific Information (ISI) WOK and Scopus databases. The asterisk represents possible word variations such as "technological" and "transferring." After data were inputted, we found more than 6,000 papers. We excluded unnecessary papers by checking labels and ignoring journals and studies concerning economic modeling, science, and engineering, as well as book reviews, as these did not focus on TT. This narrowed our findings to 192 papers and 367 papers from the Scopus and ISI WOK databases, respectively. These papers provided a theoretical point of view and conclusions on TT and TTMs between 1970 and 2010. Due to the fact that the ISI database is bigger than Scopus and also differed in terms of format and context of information, we performed citation-based analysis using the ISI WOK database to identify key papers, and used longitudinal analysis to predict trends of TTM from a historical perspective.

B. Research Statistics

The g-index and h-index analyses are conceptually simple and have been successfully used to determine an author's influence in various scientific fields. They can also be applied for rating a journal's impact. This study used the g-index to compare the influence of TT authors and journals. Table 1 provides the results of g-index and h-index analyses for journal ranking.

The journal Technovation was ranked number one, followed by International Journal of Technology Management and Research Policy. Technovation had the highest citation power, in that it had the most significant impact and contribution to the study of TT. Nevertheless, the other two journals were also highly acknowledged in the TT and TTM fields. The Journal of Development Economics and Journal of International Economics were ranked number 4 and 5, respectively, followed by International Journal of Industrial Organization and IEEE Transactions on Engineering Management and two technology management journals, namely, Technological Forecasting and Social Change and R&D Management, which are quite influential and widely contribute to the theory of TT. The Canadian Journal of Economics was ranked in the top 10 journals (Table 1).

TABLE 1. THE *G*-INDEX AND *H*-INDEX ANALYSES FOR JOURNAL RANKING

The g-index and h-index analyses				Top ten journals
#	g-index	h-index	Active years	Name
1	18	12	1991-2010	Technovation
2	15	7	1995-2009	International Journal of Technology Management
3	13	7	1996-2010	Research Policy
4	12	6	1987-2010	Journal of Development Economics
5	11	5	1982-2010	Journal of International Economies
6	10	6	1993-2009	International Journal of Industrial Organization
7	9	5	1980-2009	IEEE Transactions of Engineering Management
8	8	6	1983-2010	Technological Forecasting and Social Change
9	7	4	1992-2010	R&D Management
10	7	3	1988-2007	Canadian Journal of Economics

According to the g-index and h-index analyses (Table 2) for author ranking, the most influential author in the 1990s and 2000s was K. Saggi, who made a significant contribution to the theory of international TT and trade between developed and developing countries. K. Saggi collaborated with the second most important author, A.J. Glass. Together, these authors outlined the importance of protecting intellectual property rights (IPR) and foreign direct investments (FDI) for industrial development [10,11,12,13,14]. The third most influential author was S. Marjit, who studied innovation via R&D organization [15]. This idea by S. Marjit was further developed by R. Veugelers, who emphasized the trend of R&D decentralization and knowledge spillovers. M. Cordey-Hayes studied the interactive nature of TT in the 1990s [16]. The sixth, seventh, and eighth most important authors were W.E. Souder, G. Szulanski, and J. Bessant, respectively. Key authors who contributed to TT theory from the perspective of KBE and the presence of multiple stakeholders, such as D. Francis and K.E. Maskus, were cited close to the top 10. Several authors also investigated the impact of environmental factors on the TT of Small and Medium Enterprises. Lastly, K.E. Maskus outlined the importance of IPR in TT.

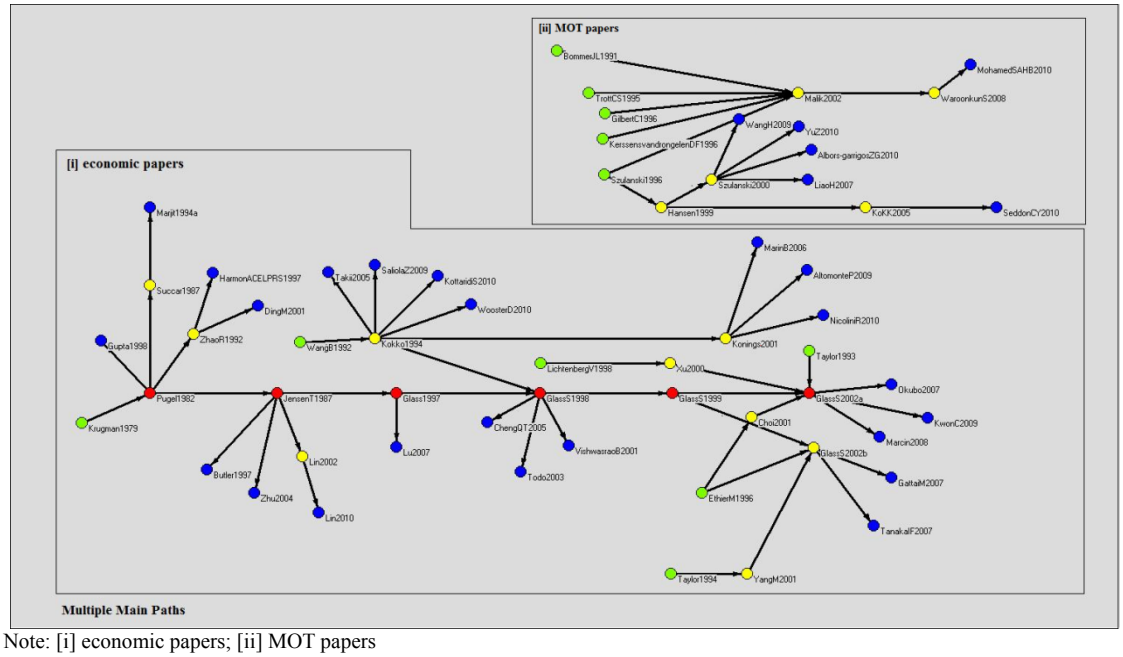
IV. MAIN PATH ANALYSIS

Main path analysis of the TT literature included global and local analyses, and also multiple main path analyses. As shown in Figure 2, all TT and TTM papers were divided into two parts: economic papers and management of technology (MOT)[1] papers. The main paths for economic and MOT papers are illustrated in Figure 1.

TABLE 2. THE *G*-INDEX AND *H*-INDEX ANALYSES FOR AUTHOR RANKING

The g-index and h-index analyses				Author ranking	
#	g-index	h-index	Active years	Name	Research domain
1	9	6	1998~2007	Saggi, K	ITT, product cycle, MNE
2	5	5	1997~2002	Glass, A.J	International trade, IPR, FDI
3	4	2	1988~2009	Marjit, S	ITT, technology cycle, innovation via R&D organization
4	4	2	2007~2008	Veugelers, R	MNEs, R&D decentralization, knowledge spillovers, technology transfer office, licensing, spin-off
5	3	3	1993~1996	Cordey-Hayes, M	TT & knowledge transfer, non-linear, interactive TTM
6	3	3	1987~1995	Souder, W.E	knowledge-based economy (KBE), entrepreneurship, TT agents, spin-off
7	3	3	1996~2001	Szulanski, G	KT, Intra-firm TT
8	3	2	1995~2005	Bessant, J	Innovation (product/service/process) via R&D
9	3	2	2001~2005	Francis, D	SME, internal & external environment & TT
10	3	2	2001~2009	Maskus, K.E	IPR, foreign direct investment (FDI), licensing, innovation

Abbreviations ITT: international technology transfer; MNE: multinational enterprise; TTO: technology transfer office; KT: knowledge transfer.



Note: [i] economic papers; [ii] MOT papers

Figure 1. Results of multiple main path analyses

1. The IAMOT (International Association for Management of Technology) was established by Khalil et al. in 1992. The terms "management of technology" (MOT) and "technology management" coexist in the literature. Thus, we used both terms in this study.

Economic scholars have studied TT issues for many decades. The earliest TT paper in the economic domain was written in the 1970s, while the first MOT paper on TT was published in the 1990s. It is obvious that economic scholars focused on TT issues earlier then MOT scholars. With the emergence of MOT, some scholars also started to study TT from the perspective of MOT. However, there is not enough literature on MOT to generate a long history of citations, so the main path analysis of key MOT authors extracted fewer authors than that of economic analysis. Most technology management scholars focused on TT issues towards the end of the 1990s, while economic scholars began their research in the 1970s.

It is worth noting that, compared to economic papers, MOT papers have higher citation numbers in both the g-index and h-index. This demonstrates that TT has been more emphasized and studied in the MOT field in the past decade. The main path analysis also allowed us to determine how key authors described the theory on the TT process and its effect on TTM during each decade. Then, we combined papers in both the economic and MOT fields to analyze the development of TT theory in each decade. Given the fact that economic scholars studied TT earlier than MOT scholars, we began our analysis with economic papers.

A. Main path analysis of economic papers

The results of multiple main path analyses of economic papers are shown in Figure 2. There were 6 sources and 23 sink scholars. Multiple main path analyses of economic papers enabled us to observe a wider scope of author contribution to the development of TT theory. Similar citations between authors were divided into four major groups for further analysis.

Group I. TT, international trade, and (global) innovation

The literature in this group was mainly devoted to developing theories based on the relationship between developed and developing countries important to trade, growth, TT, and the evolution and development of TT from an economic perspective. For example, Succar [17] analyzed the process of technological adaptation by least developed countries. Zhu [18] investigated how the creation of very skill-intensive goods induced the North to transfer production of older, less skill-intensive goods to the South. A similar idea was proposed by Marjit [15] who stated that "backward" technologies moved from the innovative North to the non-innovative South, thereby widening the wage gap between the regions. Gupta [19] introduced TT as the process of movement from foreign capital and technology to labor-intensive domestic firms in developing countries. From the micro-perspective, Harmon, Ardishvili, Cardozo et al. [20] stressed TT as a process that takes places from universities to the private sector, and plays a significant role in new business growth, the growth of existing businesses, and new job creation. Ding and Motwani [21] discussed the general economic situation in China, outlined the necessity and benefits of TT, noted several aspects of TT, and suggested a model of TT for achieving successful privatization.

The literature by this group of key scholars stated fundamental issues involved in the trade and international TT between developed and developing countries. Among these issues were strategic planning between the North and South to reduce the gap, innovation catch-up of developing countries (South) with the technological leader (North), R&D investments in the South along with strengthening IPR protection in the South to stimulate more licensing, and TT from MNEs.

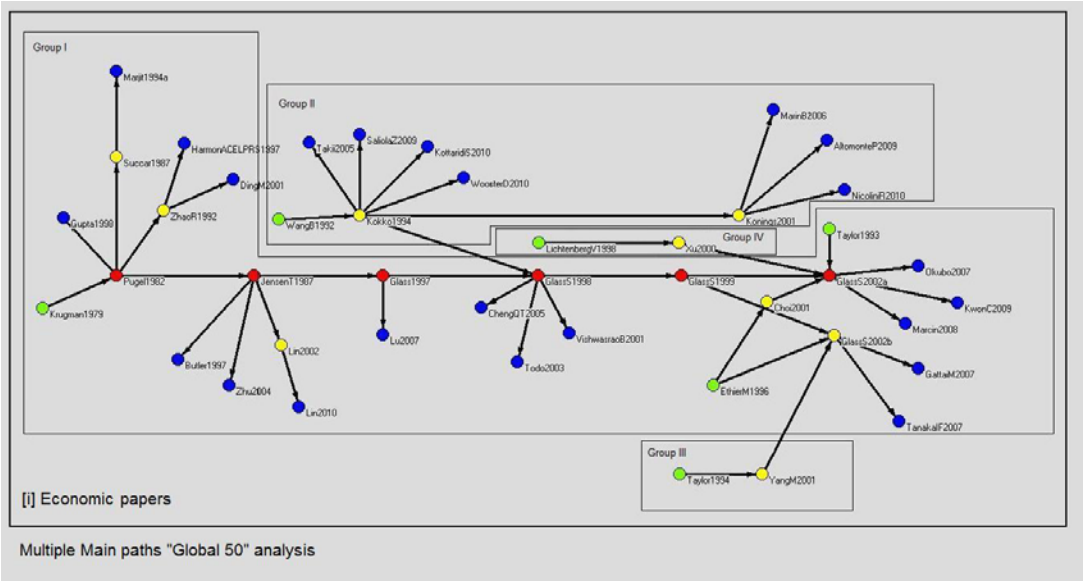


Figure 2. Multiple main path analysis of economic papers

Group II. The effect of technological spillover through FDI to domestic firms

Spillover can be described as an exchange of technological ideas and/or knowledge among organizations and/or individuals. The effect of technological and knowledge spillover has been studied by several authors. Kokko [22] suggested that advanced MNE technologies do not constitute obstacles to spillovers from FDI toward local industries with large technology gaps. Takii [23] supported the fact that TT has positive effects on spillovers. However, he also found that the magnitude of spillovers tended to be smaller and was sometimes negative when the technological gap between foreign and locally owned industries was relatively large. Altomonte and Pennings [24] studied technology spillovers from FDI and emphasized the importance of MNE subsidiaries, which act as transfer intermediaries on the way to technological adoption by domestic firms. Wooster and Diebel [25] had similar findings regarding the significance of technology spillovers from FDI in developing countries, while Kottaridi and Stengos [26] confirmed the positive effect of FDI on economic growth, especially in middle income countries. Nikolini and Resmini [27] outlined that regional demand (particularly in the EU) and productivity are two fundamental determinants of FDI. Wang and Blomstrom developed a model in which international TT (ITT) through FDI facilitates the strategic interaction between subsidiaries of MNE and host country firms. On the other hand, Konings [28] studied the effects of FDI on the productivity performance of domestic firms in countries of Central and Eastern Europe, and emphasized that FDI and presence of foreign businesses can have positive or negative effects on domestic firms, including their R&D strategy. Saliola and Zanfei [29] investigated knowledge transfer (KT), which is closely associated with the presence of global buyers in the local market, and the efforts of MNEs to adapt technology to local markets and the technical capabilities of domestic firms.

In summary, it is important to notice that technological spillovers through FDI have both positive and negative effects on the local industry. Examples of positive effects are increased productivity performance of domestic firms and economic growth, specifically in middle-income countries. Negative effects can occur when technological gaps between foreign and locally owned industries are relatively large, and when local enterprises do not have enough capacity, technical capability, or trained personnel to assimilate transferred technology.

Group III. The level of IPR protection affects the scope of TT

Taylor [30] emphasized the importance of IPR regimes to trade patterns, worldwide growth, and TT. The lack of an IPR protection policy reduces R&D activity, decreases the scope of TT across countries, and reduces growth. Yang and Maskus [31] found that stronger IPR enhances TT through licensing and may improve the ability of firms in developing countries to become exporters. These papers suggested that the scope of TT, R&D activity, and possibility of economic growth are strongly related to the level of IPR protection, and that licensing activity can be stimulated by an IPR protection policy.

Group IV. "Open to trade" policy improving R&D spillovers and ITT

Lichtenberg and Pottelsberghe [33] stressed that a country that is more open to trade is more likely to benefit from international R&D spillovers. Xu [34] investigated MNEs in the United States as a channel of international technology adoption, and showed that to benefit from TT in the United States, the MNE country needs to reach a minimum human capital threshold level; however, according to previous analyses, most underdeveloped countries do not meet this threshold requirement. Thus, economy openness and presence of vital channels of communication may improve R&D spillovers and enhance international technology diffusion (China is example of beneficiaries of "open to trade" policy).

B. Main path analysis of MOT papers

We can see that the most technology management scholars began studying TT issues in the early 1990s, while economic scholars began their research quite earlier in the 1970s. Due to the short study period of technology management from a TT perspective, we extracted relatively less key authors of MOT in our main path analysis. The multiple main path analysis of MOT papers (Figure 3) enabled us to group key scholars into three major groups according to the similarity of citations.

Group I. Knowledge management and diffusion in inter-unit and intra-firm

Szulanski [35] studied transfer of the best practices within the firm. According to his study findings, knowledge-related factors such as the recipient's lack of diffusion ability and the complicated relationship between the source and recipient are the major barriers to internal KT. Hansen [36] studied social networks and product innovation, and concluded that weak ties in sharing complex knowledge across organization subunits in multiunit organizations help to trigger a team search for useful knowledge in other subunits, but slows down the transfer of knowledge when it is highly complex. Yet, Szulanski [37] offered a process model of KT through intra-firm cooperation. Assuming a highly complex process, which often tends to be laborious and time consuming, the author identified stages of transfer and defined factors that affect the opportunity to transfer at each stage. Wang and Haggerty [38] believed that knowledge management and individual virtual competency are potential avenues for managing the complexity of KT in virtual settings to maintain and improve firm performance. The authors emphasized that virtual competency can facilitate effective KT in unfamiliar and novel situations. The communication ability of the virtual environment can be considered one factor of effective

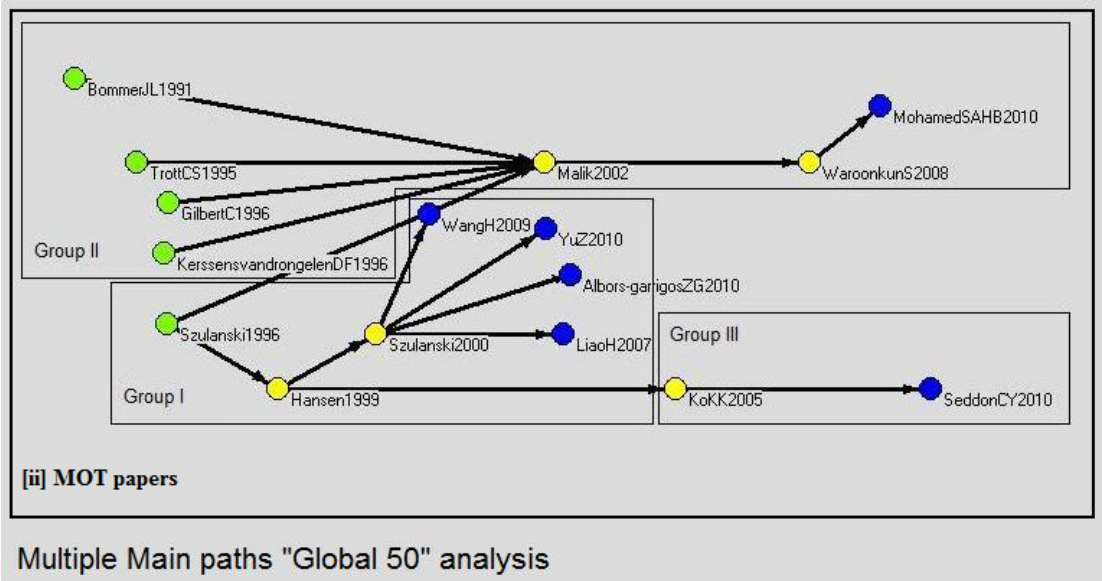


Figure 3. Multiple main path analysis of MOT papers

implementation. Albors-Garrigos, Zabaleta, and Ganzarain [39] conducted a study of Research and Technology Organizations (RTOs) that were established with the aim of improving R&D and TT efficiency. The authors proposed a model of RTO to identify critical elements that influence the performance and strategic alignment between R&D performers (RTOs) and their partners (in most cases SMEs). Yu and Zaheer [40] built a process model of the local adaptation of the conceptual, social, and technical dimensions of organization practices observing how organizational practice is adapted to a local setting that differs from its origins. The authors assumed that the right management of adaptation of practices may facilitate their successful implementation across borders. Liao and Hu [41] investigated the interrelationships among environmental uncertainty, KT, and competitive advantage based on Taiwan semiconductor companies, assuming a negative relationship between environmental uncertainty and KT and a positive relationship between KT and competitive advantage. This means that environmental uncertainty could pose obstacles to KT, while KT could build a firm's competitive advantage.

In summary, it is important to understand that TT is a complex, time-consuming, and laborious process. Lack of diffusion ability, weak ties, and poor communication ability between transferor and transferee under environmental uncertainty can have a direct negative influence on the effectiveness of transfer. Thus, knowledge management, R&D management, and successful transfer ability becomes crucial for a firm seeking to build competitive advantages.

Group II. Interactions among TT, organization learning, and environmental support

Bommer, Janaro, and Luper [42] developed a manufacturing strategy for international TT and described factors important to the strategic decisions of the international transfer of technology, including the purpose and mode of transfer, as well as the environmental conditions of the recipient country. Trott, Cordey-Hayes, and Seaton [43] stressed that many limitations and deficiencies in traditional TT mechanisms come from its linear model of innovation. The authors presented an alternative model of inward TT (accessibility-mobility-receptivity) that emphasized the interactive nature of the process through "awareness," "association," "assimilation," and "application." Gilbert and Cordey-Hayes focused on the ability of organizations to achieve successful technological innovation and technological and organizational change. The authors developed a conceptual model for understanding the processes of KT [16]. Kerssens-Van Drongelen, Nederhof, and Fisscher [44] placed the issue of knowledge management in the context of R&D management, and considered issues of information management, information technology in R&D, TT, communication, and organizational learning to achieve further improvement. Malik [45] confirmed that intra-firm TT is an interactive process involving actors who possess different levels of competencies accumulated over time, and that this process should command higher strategic significance in firms since many industrial companies are faced with competition characterized by product and market uncertainties, globalization, and rising R&D costs. Waroonkun and Stewart [46] proposed a model for ITT for constructing projects that accommodate the numerous factors that impact the process effectiveness and derived outcomes. Mohamed, Sapuan, and Ahmad [47] proposed a model for ITT for petroleum industry in Libya, including key factors of TT to evaluate TT performance, examine interrelationships between TT and government support, TT infrastructure, TT environment, and TT learning capability.

The interactive nature of technology calls us to pay more attention to knowledge, information management, R&D

management, and organizational learning. Moreover, to achieve further improvement, scholars recommend evaluating TT performance, and examining interrelations between TT and government support, TT infrastructure, TT environment, and TT learning capability.

Group III. Information technology (IT) system, consultants and TT

The antecedents of KT in the context of an inter-firm complex information systems implementation environment was examined by Ko, Kirsch, and King [48]. The authors examined the role of consultants in aiding with the implementation process. Client firms expect consultants to transfer their implementation knowledge to their employees so that they can contribute to successful implementations and learn to maintain the systems independent of the consultants. Seddon, Calvert, and Yang [49] developed a long-term, multi-project model of factors affecting organizational benefits from enterprise systems (ES) integration. These factors were process optimization, improved access to information, ongoing major ES business improvement projects, functional fit, and overcoming organizational inertia. All factors drove organizational benefits from ES over the long-term. The integration of TT into an IT system is vitally important for an industry seeking process optimization and remote access to information. IT is an inevitable part of the TT process and implementation.

V. CONCLUSION

A. The meaning of TT

From the business point of view, TT can be defined as a mutual agreement in which technology flows from an entity that owns the technology (the transferor) to an entity seeking the technology (the transferee). The agreement involves cost and expenditure that is negotiated and agreed upon by the transferee and transferor. The transfer is considered successful if the transferee can successfully utilize the technology for business profits and eventually assimilate it. The evolution of TT definitions from the 1970s to 2000s shows that TT represents itself as a process; it was simple and linear in the 1970s and became more sophisticated in the 2000s, engaging networks and multiple entities participating in transfer activities.

B. Two tracks of TT study

TT has had different meanings and research focuses in different decades. In the 1970s and 1980s, TT described the international diffusion of advanced technology, from developed countries toward developing countries. In some other cases, TT was applied to explain the internal transmission of organizational knowledge and technology. With the advent of the knowledge economy era, TT study in the 1990s was stressed in the domain of KM. In the 2000s, some innovation drivers, such as S&T policy, patents and licensing, and TT agents, were discussed in association with innovation, technology diffusion, and transfer. Key economic scholars in the field of TT include Krugman, Pugel, Jensen, Glass, and Saggi. Key MOT scholars in this field include Hensen, Szulanski, Malik, and Ko.

C. Nonlinear and networking type of TTM

In our study, some variables of TTM were summarized according to a particular decade. For example, in the 1970s and 1980s, TTM variables were simple and the model type was linear. In the 1990s, new variables were proposed by MOT scholars, which made the TTM more complex. In the 2000s, TTM was more complicated with regard to variables and the relationships among them. However, it is still early to conclude that there is a common TTM. The variables of TTM were proposed and integrated in a case-by-case manner. Naturally, we believe that there is no "one size fits all" TTM, and we consider this to be an issue that will lead to further study.

D. What's next?

The growth of TT papers offers us the momentum to conduct further studies on TT and TTM. We further analyzed the longitudinal trends in TT and TTM study by calculating the number of keywords addressed in our selected papers according to a certain timeframe. We found that the term KM is decreasing in recent days while international TT is increasing. The latter is emphasized in the sense that globalization still plays an essential economic and TT driver. In particular, emerging economies such as those in BRIC countries has piqued scholars' curiosity, and thus there have been many TT studies published in this domain. Similarly, innovation continues to be stressed in recent studies. In particular, open innovation has triggered many scholars to study some TT strategies at the industrial and organizational levels. We cannot predict how long these trends will last. However, we are certain that globalization, innovation, and TTM will continue to be studied for years to come.

E. Contribution – the merit of citation analysis and its limitations

This study analyzed the theory development of TT. Citation analysis was used to successfully find the most active journals, influential authors, and changes in the field of TT over time. We not only presented TT theory development in a systematic and scientific manner, but we also analyzed the key variables of TTM for further study. However, there were some limitations to the present study. First, we only analyzed journal papers written in English. Thus, second, some of our results cannot be applied to countries where English is not a primary language. Finally, we omitted conference papers and book reviews, thereby potentially neglecting some essential research topics.

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