Investigating the Knowledge Spillover and Externality of Technology Standards Based on Patent Data

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***Abstract*—Knowledge accumulation is considered a crucial factor for generating sustained economic growth. Therefore, both knowledge spillovers and externalities are considered drivers of economic development. Standardization is a vital feature of technological progress. It involves triggering adoptions of innovation by reducing market uncertainty between consumers and producers. Standards cannot be implemented without using technology covered by the claims of patents. This paper investigates knowledge spillover through the inward and outward knowledge flow from technology standards. Studies have investigated the quantitative and qualitative effects of technological standards. However, there still exists a lack of understanding regarding the knowledge spillover and externality that results from technological standardization. The aim of this paper is to fill this gap in the literature by elucidating the codified knowledge spillover that underlies patented technologies at the technical, organizational, and industrial standard levels. This paper explores the characteristic patterns of knowledge spillover associated with technology standards.**

***Index Terms*—Externality, knowledge spillover, technology standards.**

I. Introduction

THE importance of technological standards has increased considerably over the past three decades. The increasing attention toward the standardization process is attributed largely to the growth of the information and communication technology industry. Before an industry standard is selected, there exist various attractive technologies. However, after industry participants select a standard and take steps to implement it, alternative technologies become less attractive. Similarly, the increasing emphasis on patenting by standard setting organizations (SSOs) reflects the strategy of an increasing number of firms to apply for patents for earning revenue from royalty payments for the use of their technology embedded in an industry standard. The key function of SSOs is to aggregate information from many different entities and coordinate efforts on relevant intellectual property claims before deciding on a standard. The strategic behavior of patent owners and the knowledge externality involved in patent disclosure during the standard setting process have received considerable attention [1]. However, the knowledge influence of patented technologies derived from standard setting efforts and the externality of technology standards have not been analyzed in detail. Therefore, this paper proposes that analyzing the knowledge spillover and externality is a useful method of identifying the origin, direction, and magnitude of essential patents for supporting technology standards.

Knowledge flows are recognized as economically important because they enhance the efficiency of the innovation process [3], [4]. Although knowledge flows are regarded as major drivers of the innovation process and can create value, the market does not appraise them accordingly. Wider access to knowledge facilitates efficient innovation by reducing the need and cost to recreate what already exists elsewhere [4]. Knowledge transmission is of two different types. The first type of transmission, which is defined as knowledge transfer, involves the exchange of knowledge on purpose by the intended people or organizations. The second type of transmission, which is called knowledge spillover, involves the unintentional transmission of knowledge to others beyond the intended boundary. Studies have attempted to capture the effect of knowledge spillovers on innovation by measuring the increased innovative output, which has been used to explain the increased rate of innovation in technological clusters [6]–[8]. Furthermore, knowledge spillovers are considered a crucial mechanism underlying the endogenous growth of an economy. Through knowledge spillovers, knowledge is transmitted across firms, sectors, and borders [2], [9], [10]. Therefore, cross-border knowledge spillovers are important for raising the economic productivity of a nation [11].

This paper speculates that a technology standard facilitates a high degree of knowledge spillover and externality in terms of a comprehensive technological influence (both forward and backward), wide geographical reach, and long time span, especially when technological standardization is fulfilled. Despite the acknowledged importance of knowledge spillover, there exist very few studies on the origin, direction, magnitude, and externality of knowledge spillover, which influence the transmission of the spillover effect across boundaries. Therefore, investigations are required to deepen our understanding of knowledge spillover and the subsequent externalities. Technology standardization has successfully shifted policy and management attention toward building stocks of knowledge. However, there still exists substantial potential for further research on the knowledge origin

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and externality of a technology standard. Therefore, the objective of this paper is to investigate knowledge spillovers, which provide a holistic picture of the originality and externality of a technology standard.

The novelty of this paper is twofold. First, the knowledge spillover of a technology standard is demonstrated and measured. Second, the significance of knowledge spillovers is identified in terms of the originality and externality indicators. This paper is structured as follows. Section II includes a review of the empirical literature on knowledge spillover, externality, technology standards, and SSOs. Section III describes the method and data in detail. Section IV presents the results, and Section V concludes this paper.

II. Theoretical Background

A. Knowledge Spillover and Externality

Most externalities illustrate indirect effects, which have an impact on others unexpected to receive the influence [12]. For instance, R&D activities that add to the general body of knowledge also contribute to other discoveries and developments beyond those achieved by the funders of the research. Therefore, the unintended exchange of knowledge can be defined as a knowledge spillover that results in consequent externalities [13]. With the growth in the knowledge foundation over time, knowledge spillovers allow a large number of differentiated products to be introduced without a continual increase in research resources because the benefit of innovation accrues to the innovator and spills over to other organizations by raising the level of knowledge on which new innovations can be based. Studies have empirically demonstrated that knowledge spillovers not only cause a decrease in production costs in an industry, but also alter the structure of production [14]. Thus, knowledge spillovers can serve as the engine of technological innovation to provide further access to new knowledge and increase the productivity of economic actors [5].

Two main sources of potential externalities are generated by R&D activities, namely, rent spillover and knowledge spillover. The concept of knowledge spillover has emerged because of the imperfect appropriability of the knowledge associated with the innovation process. Studies have applied the concept of knowledge spillover for knowledge flows irrespective of whether the flows are intended or unintended. Knowledge can flow between agents in the form of knowledge transaction, product purchases, or another interaction. Therefore, when knowledge flows are not completely compensated, the knowledge transmission is called knowledge spillover. Knowledge spillover is generally characterized by the international transfer of technology, which may occur through different avenues.

Numerous studies have quantified knowledge spillovers by exploring organization-, industry-, and sector-level data [16]–[19]. The nature of knowledge spillovers from R&D activities and the role of knowledge flows within the dynamics of export market shares and specialization patterns have been explored [20]–[22]. Different types of knowledge spillovers have been investigated, such as intrasectoral spillovers, intersectoral spillovers, spillovers among firms in a research consortium, and spillovers from public research organizations to the whole economy [2], [10], [16], [17], [19], [23]. Furthermore, the significance, magnitude, and channels of international knowledge spillover effects have been estimated by previous studies [24]–[26]. The knowledge of a country can transcend geographical boundaries and further contribute to productivity growth. Moreover, a decrease in spillover effects results in a slowdown of technological progress [27]. Even the mobility of inventors can also facilitate knowledge flow across space and innovating organizations.

According to certain research strands on the process of knowledge creation and spillover, specialization externalities occur mainly within a specific industry due to geographical proximity, whereas diversity externalities favor the creation of new ideas across sectors. These two types of external economies may also occur within complementary industries that share the same scientific base with the industrial sector considered [28]. For measuring the extent of knowledge externalities, models of endogenous economic growth have been tested by estimating the form of R&D spillovers across firms and/or from universities and public labs to firms [29]. Thus, there exist two major challenges, namely, the measurement of pecuniary externalities and pure spillovers. Pecuniary externalities can be measured by R&D-intensive inputs, whereas pure spillover includes ideas borrowed by the research teams of one firm from the research results of another firm. Pure spillover is difficult to capture. Compared with normal market transactions of knowledge, studies have seldom investigated the role of knowledge spillovers. Studies have argued that patent citation is an appropriate proxy to measure the pure spillover of knowledge externality [29], [30]. Patent citations allow researchers to quantify and measure knowledge spillovers and develop indicators of the significance of individual patents, which provides an alternative method of capturing the value of patents [31].

According to previous studies, the geographical distance determines the beneficiaries of knowledge spillover and influences the different effects of tacit and codified knowledge. For instance, physical proximity can enhance firms' absorption of tacit knowledge [6], [32], [33]. For codified knowledge spillover, such as knowledge embedded in patent citations, the effect of geographical distance is largely alleviated in the Internet era. Codified knowledge can be immediately accessed by anyone who has a chance to hear or read it. Therefore, codified knowledge can be easily reproduced and travel a long distance. By contrast, tacit knowledge can only be transmitted through face-to-face interaction with mutual trust between the knowledge source and the recipients [29]. However, many of the mechanisms through which firms can learn the know-how and obtain competencies from competitors, such as patent disclosures, trade journals, and fairs, are insensitive to geographical distance. Empirical studies on the geography of innovation issues indicate the extent to which knowledge spillovers exist and whether these spillovers are bounded in space. Knowledge spillovers are strongly bounded in space because innovative activities are strongly concentrated at the geographical level (both in the United States

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and Europe) and firms located in certain areas are systematically more productive than firms located elsewhere [6]. Empirical evidence from previous studies indicates that knowledge flows remain geographically localized [16], [34]–[37]. The geographic reach of knowledge spillovers indicates that knowledge is subject to spatial decay. Knowledge spillovers generate externalities and tend to be geographically bounded [38], [39]. Alternatively, researchers have argued that knowledge spills over borders, such as city, state, and national boundaries [40]. Technological progress is regarded a public good and has large externalities and diffuse benefits. Its derived knowledge spillovers are not locally bounded but can freely move across borders due to globalization and standardization [40]. Therefore, the externalities, such as the extra costs and benefits, are increasingly borne by actors in other organizations, industries, and countries. As collective actions, globalization and standardization can increase the gap between externalities that are becoming increasingly international in reach.

B. Technology Standards and SSOs

The development of technology standards has been studied from different perspectives. One major perspective relates to firms' capabilities and resources [42]–[44]. Under this perspective, technology standards can be supported by dominant buyers or sellers, such as Microsoft, Intel, Qualcomm, and Cisco [45], [46]. Standards act as exemplars for guiding the pattern of technical change in advantageous directions, which can help overcome the numerous challenges caused by a hydra-headed technical change [47]. The second perspective considers technology standard development as a social process [48], [49], [51], [52]. The significance of social factors has increased with an increase in the degree of complexity of standardized technologies. The third perspective emphasizes coevolution between a technology and its environment [52]–[56]. Therefore, the emergence of a new standard is the result of interaction between a firm's proprietary activities, institutional arrangements, resources endowments, and consumer demand. For increasing the adoption of a technology and developing a new technology standard, network externality is a critical factor. When the adoption of a technology increases, network externalities increase the value of the technology to other users, even after the cost and other characteristics of the technology are controlled [56]. Therefore, network externalities can increase the relative attractiveness of a technology before one technological standard is selected. Conversely, the value and externality of a standard can be increased through the network effect [58].

During the technological standardization process, voluntary SSOs play the role of platform leaders in promoting coordinated technical changes, especially when the products and services are highly interdependent in the market. SSOs exhibit leadership among actors within the same sectors, which requires coordination, consensus building, and avoidance of forking, which results in standard wars [59]. The functions of SSOs mainly involve technical coordination, mitigation of hold-up problems, and promotion of open technologies [60]–[64]. Furthermore, the performance and effect of SSOs have been widely discussed and investigated [63].

There are five major SSOs, namely, the American National Standards Institute (ANSI), Institute for Electrical and Electronic Engineers (IEEE), Internet Engineering Task Force (IETF), International Telecommunications Union (ITU), and European Telecommunications Standards Institute (ETSI). Most of the patents disclosed to these five SSOs cover computing and communications technology. ITU was founded in 1865 and is now based in Switzerland. The original mission of ITU was to enhance international coordination among the various rapidly expanding domestic telephone networks. Currently, numbering and addressing, traffic management, monitoring and accounting, and service quality are the major domains handled by ITU. IEEE was founded in 1884 by several explorers in the field of electrical engineering. Its standard setting achievement comprises a wide range of subjects, including electrical safety, cryptography, standards for semiconductor testing equipment, and specifications for wireless networking. ANSI was formed in 1918 for coordinating the ongoing standard development efforts of numerous organizations, including hundreds of different US SSOs. IETF was formed from an academic computer networking community that emerged during the 1970s. It did not resemble a formal SSO until the late 1980s. IETF focuses on creating protocols used to run the Internet, including the Internet's core transport protocols. ETSI is an independent not-for-profit standardization organization in the telecommunications industry (equipment makers and network operators). The procedures adopted by these five major SSOs for creating a new standard are similar. The efforts made by these organizations result in the publication of a specification as a standard [59].

None of the aforementioned studies depict the knowledge spillovers and externality of technology standards. In particular, the knowledge spillover across technical, organizational, and national borders may help the dominant design (standard) to be accepted and adopted in the global market. To fill the research gap, the origin, direction, and magnitude of the knowledge spillover of technology standards are investigated in this paper by using patent information.

III. Data and Method

A. Data

In this section, the contents of the dataset and the statistical method are discussed. Patents have long been recognized as very rich data sources for studying innovation and technical change [65]–[67]. Patents can directly represent the competitive knowledge of an industry. The variation in the trends of patented technologies in an industry as a whole directly influences the R&D strategies of all involved actors. There exist numerous advantages in using patent data. Each patent contains highly detailed information on the innovation, engineering heuristics, and problem-solving process. Patents provide wide-coverage knowledge in terms of the technologies, inventors, assignees, sectors, and geography. Due to the endorsement of intellectual property rights, patent citations are carefully inspected by the

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inventor, inventor's attorney, and United States Patent and Trademark Office (USPTO). Therefore, patent citation information can reveal linkages between inventions, inventors, and assignees along time and space. Patent citations enable a detailed quantitative study of spillovers along geographical, institutional, and technological dimensions. They also allow other dimensions of innovations, such as the originality and generality, to be investigated [31]. Moreover, patent citations convey technological and economically significant information. For instance, if firms invest in further R&D of an innovation disclosed in an existing patent, then the follow-up (citing) patents presumably signify that the cited innovation is economically valuable. Typically, patent citations are continuously made over a long run, which provides abundant time to dissipate the original uncertainty regarding the technological viability and commercial worth of the cited innovation.

Patent data have been used to illustrate knowledge flow [68]–[70]. Therefore, patent citations can be used to track direct knowledge flows from academic research into corporate R&D [71]. The presumption in the use of citation data is that citations provide information regarding links between patented technologies. Patent citations comprise a paper trail for capturing knowledge spillover. For instance, patent B citing patent A is indicative of knowledge flowing from A to B [31]. For capturing the dynamics of the knowledge spillover that occurs during technology standardization, utility patents are downloaded from the USPTO patent database. The reasons for using the USPTO database are as follows: 1) the United States is the biggest market and is regarded as the hub of technology standardization. As a result, technology patents are filed at the USPTO, which increases the quality and quantity of the knowledge flow provided in a USPTO patent document; 2) the USPTO database is considered a reliable data source for investigating global technology innovation [72], [73]; and 3) the USPTO has a well-established and well-maintained database, which enables researchers to conduct research in fields such as technology, innovation, and knowledge management.

A patent that controls any part of the technology used in a standard is called a standard-essential patent (SEP). An SEP is a patent that claims an invention that must be used to comply with a technological standard. Patents supported by SSOs (SSO patents) can receive more citations than other patents from the same technological field and application year, which suggests that SSO patents have a high degree of economic and technological importance and monetary worth. Citations to SSO patents have limited distribution in the first few years after the patent is issued, which implies that SSO patents usually have a long life [74]. Due to the selection and marginal effect, SSOs find either compelling technologies or technologies expected to become significant based on the consensus and open technologies built [59].

Patent information can be considered a type of technical problem addressed by engineers over time. The information includes the proposed solution, applied engineering heuristics, and applied technological knowledge [75]. When the flow of knowledge within the patent citation network is identified and the patents belonging to the trajectory can be scrutinized to obtain information regarding the engineering heuristics applied, the citations received in the heuristics enable the detection of the paradigmatic knowledge spillover and externality. In this paper, an attempt is made to explore whether the citations are isomorphic by analyzing three different patent datasets at the technical, organizational, and industrial standard levels. Each patent comprises highly detailed information regarding aspects such as the innovation, technological area to which the innovation belongs, inventors (e.g., their geographical location), and assignees. Moreover, patents have a very wide coverage (in terms of technology fields and types of inventors) Patent data include citations to previous patents and the scientific literature. These citations allow multiple linkages to be traced between inventions, inventors, scientists, firms, and locations. In particular, patent citation data allow us to investigate knowledge spillovers, thereby introducing a method of capturing the enormous heterogeneity in the value of patents. Therefore, the patent characteristics, such as the number of inventors, the number of inventor countries, the number of assignees, the number of assignee countries, the number of patent citations received in five years, the number of cooperative patent classification (CPC) classes, patent family size, the number of patent and nonpatent references, longevity and geographical distance of the forward citation, and the number of claims, obtained from patent documents indicate whether an SEP is significant compared with non-SEPs within the same technology categories.

In this paper, the flow of the forward and backward citations to these patents is tracked. Moreover, the knowledge spillover following disclosure is investigated. Disclosure serves as a proxy for creating a new standard based on several patented technologies. Thus, the methodology used builds on the substantial amount of literature that has found patent citations to be a valid measure of economic and technological development [76]–[78]. The methodology provides the appraisal of the knowledge spillover of patented technology. Moreover, a previous study indicates that disembodied cross-border spillovers are significant [79]. Patenting activities are based on a consensus in the selection of a specification among members of SSOs, which are regarded as organizational borders for knowledge transmitted inward and outward [80].

Three patent datasets are prepared for achieving the research objectives of this paper. The first dataset includes SEPs supported by SSOs as well as non-SEPs within the same CPC fields as the first dataset. The second dataset comprises patents supported by the five major SSOs, namely, SSO patents, as well as non-SEPs within the same CPC fields as the second dataset. The third dataset includes patents likely to be concentrated within one of the most commercially significant standard setting efforts, namely, the 802.16 standard, as well as non-SEPs within the same CPC fields as the third dataset. The value of an SEP is considered a function of the standard's level of adoption. An empirical study is performed to investigate the knowledge spillover and externality from technical, organizational, and industrial standard perspectives. The design of an increasingly concentrated data scope and the integration of the three datasets

TABLE I
THREE DATASETS USED IN THIS PAPER

No.	Dataset	No. of patents
1st Dataset	All SEPs (from all SSOs)	3,796
	Non-SEPs within the same CPC 5 class	319 371
2nd Dataset	SSO patents from five SSOs (ANSI, ETSI, IEEE, ITU, and IETF)	3,497
	SSO patents supported by ANSI	213
	Non-SEPs within the same CPC 5 class as the SSO patents from ANSI	51 846
	SSO patents supported by ETSI	2,127
	Non-SEPs within the same CPC 5 class as the SSO patents from ETSI	149 077
	SSO patents supported by IEEE	475
	Non-SEPs within the same CPC 5 class as the SSO patents from IEEE	87 076
	SSO patents supported by ITU	321
	Non-SEPs within the same CPC 5 class as the SSO patents from ITU	44 594
	SSO patents supported by IETF	343
	Non-SEPs within the same CPC 5 class as the SSO patents from IETF	70 419
3rd Dataset	SEPs for the 802.16 standard	158
	Non-SEPs within the same CPC 5 class	30 792

TABLE II
NUMBER OF SSO PATENTS SUPPORTED BY THE FIVE MAJOR SSOS BETWEEN 1976 AND 2017 IN THE USPTO

SSO	Number of SSO patents	Number of non-SSO patents in the same CPC 5 class
ANSI	213	51 846
ETSI	2,127	149 077
IEEE	475	87 076
IETF	343	70 419
ITU	321	44 594
Total	3,497	403 012

provides a comprehensive view of the knowledge spillover and externality at three different levels. To examine the significance of SEPs and SSO patents and eliminate the bias resulting from the comparison of different technological fields at three levels, this paper focuses on patented technologies categorized within the same class of CPC 5, which was developed by the European Patent Office (EPO) and USPTO. CPC 5 is a hierarchical classification system used primarily to classify patent documents according to the technical fields to which they belong. To eliminate the potential bias resulting from critical differences among the technology fields, non-SEPs within the same technology categories are retrieved for each dataset. A total of 354 063 utility patents are downloaded from the USPTO. The retrieved patents are classified into the following categories: SEPs (3796), non-SEPs (319 371), patents from the five major SSOs (3497), patents of the 802.16 standard (158), and non-SEPs (30 792) within the same technology field of the five-digit CPC. The overall description of the three datasets is provided in Table I.

As per the USPTO database, the total number of patents supported by the five major SSOs and the non-SEPs within the same CPC 5 class is 3497 and 403 012, respectively (see Table I). The patents supported by the five major SSOs account for 90% of all the SSO patents issued by the USPTO. The ETSI supported 2127 patents, the IEEE supported 475 patents, the IETF supported 343 patents, the ITU supported 321 patents, and the ANSI supported 213 patents. Table I presents the summary statistics of two datasets, which comprise SEPs and non-SEPs. The ETSI supported the most number of patents for standards, and the ITU published the least number of patents. The application year of the patents supported by the five SSOs ranges from 1976 to 2017. The overview of the second dataset is provided in Table II.

For analyzing SEP patents aligned with the 802.16 standard, 159 patents are retrieved from the USPTO database. Within the same CPC 5 class, 30 792 non-SEPs are obtained for examining the significance of the patent characteristics of SEPs. An overview of the third dataset is provided in Table III.

B. Method

To identify the significance of the knowledge spillovers and externality involved in technology standardization, the sample of disclosed patents is compared with a set of "control patents" with the same application year and primary technology class (field) as the SEP patents. Although the control patents serve as reference points, these patents are unlikely to be a valid set of "controls" because control patents are statistically indistinguishable from SEPs. In this paper, the control patent datasets

TABLE III
NUMBER OF SEPS ALIGNED WITH THE 802.16 STANDARD ISSUED IN THE USPTO

SEP	Patents	Non-SEP patents within the same CPC 5 class
	158	30 792

are used to address macrochanges in the patenting regime, and the main results are based largely on the variation within the SEP dataset. When comparing SEPs with the control sample, the aim is to compare SEPs with average patents rather than patents that are truly identical (except for disclosure). For organization-level analysis, the patents supported by the five major SSOs are retrieved. Moreover, the significance of the originality and generality of the retrieved patents, which is obtained from the patent characteristics, is compared with that of the non-SEPs from the same technology fields. To further examine the knowledge spillover and externality at the industrial standard level, 158 SEPs and 30 792 non-SEPs from 1989 to 2011 that comply with the IEEE 802.16 standard are retrieved. The IEEE 802.16 MAC protocol, which was approved in 2001, was designed for point-to-multipoint broadband wireless access applications. The standard addresses frequencies from 10 to 66 GHz. This extensive spectrum is currently available worldwide; however, the short wavelengths introduce significant deployment challenges. To achieve the aims of this paper, the Scheffé test is conducted. The Scheffé test can be used for adjusting the significance levels in a linear regression analysis to account for multiple comparisons. This test is particularly used for analysis of variance (ANOVA).

1) Originality of Knowledge Spillovers: The backward citations in a patent indicate the technological antecedents of the patented invention. A patent that contains many citations corresponds to an invention with many antecedents. Technology originality is an index for indicating the antecedents or historical background of a patented technology. The originality index is defined in the same manner; however, it refers to the citations made. By contrast, the generality index refers to the citations received. Basic inventions are argued to be less incremental in nature and thus have few identifiable antecedents. Patents near the beginning of a trajectory are more basic than patents at the middle or end of a trajectory and thus are expected to have few backward citations due to their limited historical background. Furthermore, patents may be partly or completely based on new scientific knowledge. Therefore, a nonpatent reference can indicate the state-of-the-art against which the patent application must be evaluated. The originality of a patent indicates the diversity of cited patents (i.e., the patents cited by the target patent). The originality is based on the distribution (ratio) of cited patents over technological classes [72], [81]. The originality index can also be applied at the country, industry, and assignee levels for illustrating the distribution (ratio) of cited patents over different assignees, industries, and countries. The originality is calculated as follows [82]:

$$\text{Originality}_i = 1 - \sum_{j}^{n_i} s_{ij}^2$$

where s_{ij} denotes the percentage of citations made by patent *i* that belong to patent class *j* out of n_i patent classes.

$$\text{Assignee originality}_i = 1 - \sum_{j}^{n_i} s_{ij}^2.$$

$$\text{Industry originality}_i = 1 - \sum_{j}^{n_i} s_{ij}^2.$$

$$\text{Country originality}_i = 1 - \sum_{j}^{n_i} s_{ij}^2.$$

2) Externality of Knowledge Spillovers: In this paper, the forward citation count, patent family size, geographical reach of patent citations, longevity of patents, and generality index are used as proxies for detecting the externality of knowledge spillovers. Two types of data, namely, Docdb and Inpodoc, are retrieved from the EPO for analyzing the patent family size. Docdb is a simple collection of patent applications covering the same technical content, and Inpodoc is an extended collection of patent applications covering similar technical content. When one specific standard is selected to facilitate a broad market, the patents applied for aligning with the selected standard must be highly relevant to other standard supporting technologies. Therefore, such patented technology is likely to be generic and related to the general purpose technology identified by other members for facilitating the division of standard setting efforts in technology markets [83]. General-purpose technologies are credited with generating the increasing returns that drive endogenous growth [83]. Technology generality is a critical characteristic for selecting a technology standard. The forward citations indicate the influence of a patent. Therefore, a high generality score suggests that the patent has a broad impact, which influences subsequent technologies in a variety of fields [84]. Previous studies have suggested that the number of references to the patent literature and the citations received by a patent are positively related to the skewed allocation of the property value [85]–[89]. Citing patents are regarded as knowledge that can spill across different technology fields, organizations, and countries. Therefore, the information abstracted from citing patents is crucial for measuring the direction and magnitude of knowledge spillovers. In addition to the forward citations received, the size of a patent family, which is measured as the number of jurisdictions in which a patent grant has been sought, and the survival span of patents are also proxies for capturing the externality of knowledge spillovers.

The generality index is used to measure the externality of knowledge spillovers. The generality index indicates the diversity of citing patents (i.e., patents that cite the target patent) and is based on the distribution (ratio) of citing patents over technological classes [81], [90]. The generality index can also be applied

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at the assignee, industry, and country levels for illustrating the distribution (ratio) of citing patents over different organizations, industries, and countries. The generality is calculated as follows [86]:

$$\text{Generality}_i = 1 - \sum_{j}^{n_i} s_{ij}^2$$

where s_{ij} denotes the percentage of citations received by patent i that belong to patent class j out of n_i patent classes.

$$\text{Assignee generality}_i = 1 - \sum_{j}^{n_i} s_{ij}^2.$$

$$\text{Industry generality}_i = 1 - \sum_{j}^{n_i} s_{ij}^2.$$

$$\text{Country generality}_i = 1 - \sum_{j}^{n_i} s_{ij}^2.$$

Two novel indicators, namely, the technological longevity and geographical reach of a patent, are used for analyzing the externality of knowledge spillover. The period of knowledge spillover is the time interval between the citing and cited patents [91]. The longevity index is designed for comparing the lifespan of patented technologies. The longevity index is based on the calculation of the mean and maximum lag (in years) between the earliest patent granted and the latest citations the patent receives. Therefore, the mean lag is the difference between the grant date and the citation date averaged over all the citations of a patent. The increasing effect of geographical distance is associated with strengthened knowledge agglomeration over time. However, the distance effects decrease with the age of patents [91]. The calculation of the geographical distance is based on the location of citing patents in geographic space. Most prior studies on knowledge flows have neglected explicit distance measures and the contributions of geographical distance to the knowledge spillover [37], [92]. Patent documents report the town/city and postal address of each assignee. Existing studies have suggested that patent citations can be used as an "article trail," which allows knowledge spillovers to be measured and captured [16], [93]. Patents can have multiple assignees. The first assignee is usually regarded as the major assignee for the patent application with the highest number of credits. Therefore, the location of patents in geographic space is assigned to the first assignee. The patent characteristics and indicators used in this paper are listed in Table IV.

IV. Results and Discussion

A. ANOVA

The significance of the knowledge spillover of technology standards is examined by analyzing SEPs, non-SEPs, SSO patents, and SEPs aligned with the 802.16 standard from 1976 to 2017. Two knowledge spillover properties are evaluated, namely, the originality and externality of knowledge spillovers. As presented in Table VI, the number of inventor countries, CPC count, number of claims, originality index, country originality, industry originality, and assignee originality of SEPs are considerably higher than those of non-SEPs within the same technology fields. As presented in Table V, the sum of the forward citation distance, the number of patent citations received, patent family size, generality index, country generality, industry generality, assignee generality, mean longevity, and maximum longevity of SEPs are significantly higher than those of non-SEPs. However, compared with non-SEPs, SEPs have fewer assignees, patent references, and nonpatent references.

Table VI presents the ANOVA results for the characteristics of the patents supported by the five major SSOs. The externality of the patents supported by the five SSOs is consistent. For these patents, the sum of the forward citation distance, mean longevity, and maximum longevity are considerably higher than those of the non-SEPs, which indicates that the knowledge spillover of the patents supported by the five SSOs can be transmitted over a larger geographical distance than that of the non-SEPs. Moreover, the patents supported by the five SSOs have a longer lifespan than the non-SEPs. In contrast to the originality indices, the generality indices at the country, industry, and assignee levels are significant for the SSO patents. The originality results indicate that SSO patents have fewer assignees, patent references, and nonpatent references than non-SEPs, which suggests that SSO patents often have a weaker scientific basis, fewer IP owners, and less prior art than non-SEP patents.

The patents supported by ANSI have a significantly higher number of claims and lower number of inventor countries, assignees, assignee countries, patent references, and nonpatent references compared with non-SEPs within the same technology classes. Moreover, these patents have a considerably higher number of forward citations, larger Docdb family size, larger geographical reach of forward citations, longer lifespan, higher generality index, higher country generality, higher industry generality, and higher assignee generality than non-SEPs within the same technology classes. The sum of the forward citation distance of ANSI patents is considerably higher than that of non-SEPs, which indicates that the knowledge spillover of ANSI patents can be transmitted over a longer geographical distance than that of non-SEPs. The patents supported by ETSI have a significantly higher number of CPC classes, claims, inventor countries, and assignee countries than non-SEPs within the same technology classes. However, the ETSI patents have a lower number of assignees, patent references, and nonpatent references compared with the non-SEPs. The patents supported by ETSI have a considerably higher number of forward citations, larger Docdb family size, larger geographical reach of forward citations, longer lifespan, higher generality index, higher country generality, higher industry generality, and higher assignee generality than the non-SEPs within the same technology classes. The sum of the forward citation distance of ETSI patents is considerably higher than that of non-SEPs, which indicates that the knowledge spillover of ETSI patents can be transmitted over a longer geographical distance than that of non-SEPs. The patents supported by IEEE have a considerably higher number of claims and CPC classes than non-SEPs within the same technology classes. However, the IEEE patents

TABLE IV
PATENT INDICATORS OF KNOWLEDGE SPILLOVERS USED IN THIS PAPER

Patent characteristics and indicators		Definition	References
Originality of knowledge spillover			
1	No. of assignees	Average number of assignees per patent	[96]
2	No. of assignee countries	Average number of assignee countries per patent	[97]
3	No. of inventors	Average number of inventors per patent	[98][96]
4	No. of inventor countries	Average number of inventor countries per patent	[99, pp. 1980–2005] [96]
5	No. of CPC classes	Average CPC count per patent	[100]
6	No. of claims	Average claim count per patent	[101]
7	No. of references	Average number of backward patent references per patent	[102]
8	No. of nonpatent references	Average number of non-patent references per patent	[79]
9	Originality index	Herfindahl index for the technological classes of cited patents	[86]
10	Assignee originality	Herfindahl index for the assignee classes of cited patents	[98] [96]
11	Industry originality	Herfindahl index for the industrial classes of cited patents	[98][84] [96]
12	Country originality	Herfindahl index for the inventor-country classes of cited patents	[99, pp. 1980–2005] [96]
Externality of knowledge spillover			
1	No. of forward citations	Average number of forward citations received per citing patent	[103]
2	Generality index	Herfindahl index for the technological classes of citing patents	[86]
3	Assignee generality	Herfindahl index for the assignee classes of citing patents	[98] Su, 2017)
4	Industry generality	Herfindahl index for the industrial classes of citing patents	[98] [84] Su, 2017
5	Country generality	Herfindahl index for the inventor-country classes of citing patents	[99, pp. 1980–2005] [96]
6	Patent family size	Number of documents from different patent offices that cover the same invention	[87][104]
7	Geographical reach of patent citations	Accumulated distance of the first assignees per citing patent	[32][38]
8	Longevity of patents	Mean and maximum lag (in years) between the earliest patent grant and the citations the patent receives	[105][106][107]

have a lower number of assignees and patent references than the non-SEPs. The patents supported by IEEE have a considerably higher number of forward citations, larger Docdb and Inpodoc family size, larger geographical reach of forward citations, longer lifespan, higher generality index, higher country generality, higher industry generality, and higher assignee generality than non-SEPs within the same technology classes. The sum of the forward citation distance of the IEEE patents is significantly higher than that of the non-SEPs, which indicates that the knowledge spillover of IEEE patents can be transmitted

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TABLE V
PATENT CHARACTERISTICS AND ANOVA OF THE SEPS AND NON-SEPS

Patent characteristic	Mean value		ANOVA test		Scheffé test *P* value
	Non-SEPs	SEPs	*F* value	*P* value	I–II
Originality of knowledge spillovers					
No. of inventors	2.60 (1.77)	2.65 (1.72)	2.46	0.12	0.117
No. of inventor countries	1.08 (0.29)	1.10 (0.32)	20.08	0.00*	0.000*
No. of assignees	1.00 (0.29)	0.98 (0.21)	16.42	0.00*	0.000*
No. of assignee countries	0.97 (0.21)	0.97 (0.18)	0.82	0.37	0.365
No. of CPC classes	5.14 (5.52)	6.95 (8.82)	397.70	0.00*	0.000*
No. of claims	18.98 (13.50)	23.47 (19.54)	410.92	0.00*	0.000*
No. of patent references	19.61 (23.85)	17.15 (20.76)	39.90	0.00*	0.000*
No. of nonpatent references	5.81 (14.24)	4.88 (11.21)	15.96	0.00*	0.000*
Originality index	0.63 (0.33)	0.75 (0.25)	452.02	0.00*	0.000*
Assignee originality	0.61 (0.33)	0.71 (0.26)	318.03	0.00*	0.000*
Industry originality	0.34 (0.27)	0.37 (0.25)	43.92	0.00*	0.000*
Country originality	0.29 (0.25)	0.38 (0.24)	430.61	0.00*	0.000*
Externality of knowledge spillovers					
Docdb patent family size	5.04 (12.01)	12.17 (22.74)	1283.81	0.00*	0.000*
Inpodoc patent family size	13.97 (84.45)	31.42 (82.97)	160.27	0.00*	0.000*
No. of forward citations (5 years)	3.80 (7.17)	11.72 (13.56)	4444.76	0.00*	0.000*
Generality index (5 years)	0.32 (0.37)	0.68 (0.30)	3754.85	0.00*	0.000*
Assignee generality (5 years)	0.28 (0.34)	0.63 (0.30)	3918.52	0.00*	0.000*
Industry generality (5 years)	0.17 (0.25)	0.35 (0.25)	1894.32	0.00*	0.000*
Country generality (5 years)	0.16 (0.23)	0.37 (0.26)	3076.98	0.00*	0.000*
Sum of the backward distance	382014.60 (956446.10)	405410.20 (900069.00)	2.19	0.14	0.139
Sum of the forward distance (5 years)	183461.30 (448476.60)	373140.00 (638193.40)	622.31	0.00*	0.000*
Mean longevity	6.02 (3.84)	8.25 (3.24)	1245.88	0.00*	0.000*
Maximum longevity	9.67 (7.02)	14.46 (6.09)	1717.85	0.00*	0.000*

Standard deviations are in parentheses.
*Indicated *P* value < 0.05.

over a longer geographical distance than that of non-SEPs. The patents supported by IETF have a considerably higher number of inventors, inventor countries, claims, nonpatent references, and CPC count and lower number of patent references than non-SEPs within the same technology classes. The patents supported by IETF have a significantly higher number of forward citations, larger Docdb and Inpodoc family size, larger geographical reach of forward citations, longer lifespan, higher generality index, higher country generality, higher industry generality, and higher assignee generality than non-SEPs within the same technology classes. The sum of the forward citation distance of the IETF patents is significantly higher than that of the non-SEPs, which indicates that the knowledge spillover of the IETF patents can be transmitted over a longer geographical distance than that of the non-SEPs. The patents supported by ITU have a significantly higher number of claims and CPC classes and lower number of patent references than non-SEPs within the same technology classes. The patents supported by ITU have a considerably higher number of forward citations, larger distant geographical reach of forward citations, longer lifespan, higher generality index, higher country generality, higher industry generality, and higher assignee generality than the non-SEPs. The sum of the forward citation distance of the ITU patents is significantly larger than that of the non-SEPs, which indicates that the knowledge spillover of ITU patents can be transmitted over a longer geographical distance than that of the non-SEPs.

TABLE VI
SUMMARY OF THE CHARACTERISTICS AND ANOVA RESULTS OF THE PATENTS SUPPORTED BY THE FIVE MAJOR SSOs

	ANSI	ETSI	IEEE	IETF	ITU
Originality					
No. of inventors				SEP	
No. of inventor countries	Non-SEP	SEP		SEP	
No. of assignees	Non-SEP	Non-SEP	Non-SEP		
No. of assignee countries	Non-SEP	SEP			
No. of CPC classes		SEP	SEP	SEP	Non-SEP
No. of claims	SEP	SEP	SEP	SEP	SEP
No. of patent references	Non-SEP	Non-SEP	Non-SEP	Non-SEP	Non-SEP
No. of nonpatent references	Non-SEP	Non-SEP		SEP	
Originality index		SEP	SEP	SEP	
Country originality		SEP	SEP	SEP	
Industry originality		SEP	SEP		
Assignee originality		SEP	SEP	SEP	
Externality					
Docdb patent family size	SEP	SEP	SEP	SEP	
Inpodoc patent family size			SEP	SEP	
No. of forward citations	SEP	SEP	SEP	SEP	SEP
Generality index	SEP	SEP	SEP	SEP	SEP
Country generality	SEP	SEP	SEP	SEP	SEP
Industry generality	SEP	SEP	SEP	SEP	SEP
Assignee generality	SEP	SEP	SEP	SEP	SEP
Sum of the backward distance	Non-SEP				
Sum of the forward distance	SEP	SEP	SEP	SEP	SEP
Mean longevity	SEP	SEP	SEP	SEP	SEP
Maximum longevity	SEP	SEP	SEP	SEP	SEP

Table VII presents the ANOVA results of the characteristics of SEPs designed for the 802.16 supporting standard. The patents designed for the 802.16 standard have a considerably higher number of claims, number of CPC classes, originality index, assignee originality, industry originality, and country originality than non-SEPs within the same technology classes. However, these patents have a lower number of patent references than the non-SEPs. The patents aligned with the 802.16 standard have a significantly higher number of forward citations, larger geographical reach of forward citations, longer lifespan, and higher generality indices at three levels (country, industry, and assignee) compared with the non-SEPs. The sum of the forward citation distance of the patents aligned with the 802.16 standard is considerably higher than that of the non-SEPs, which indicates that the knowledge spillover of these patents can be transmitted over a longer geographical distance than that of the non-SEPs. In this paper, all the USPTO patents between 1976 and 2017 are investigated for exploring the knowledge spillovers of technology standards. In total, 3796 SEPs are retrieved. Within the same CPC 5 class, there exist 319 371 non-SSO patents. These patents form a control sample for examining the significance of SEPs. Furthermore, the SEPs supported by the five major SSOs are retrieved to further scrutinize the significance of SSO patents. The formulas for calculating the originality and externality indices at three levels (country, industry, and assignee) are derived from [104].

As indicated by the ANOVA results, SEPs have a lower number of assignees, patent references, and nonpatent references than non-SEPs. The number of inventor countries, number of CPC classes, number of claims, originality index, country originality, industry originality, and assignee originality of SEPs are significantly higher than those of non-SEPs within the same technology fields. The sum of the forward citation distance, number of patent citations received, patent family sizes, generality index, country generality, industry generality, assignee generality, mean longevity, and maximum longevity of the SEPs are significantly higher than those of the non-SEPs. These results indicate that when knowledge spills are transmitted across boundaries through the Internet, peers within organizations, industries, countries, or neighborhoods are benefitted, which is consistent with the results of previous studies [106]–[108].

B. *Originality of Knowledge Spillovers*

To understand the source and destination of the knowledge spillover of technology standards, this paper integrates the originality indicator proposed by Trajtenberg *et al.* [84] into the data. Moreover, the originality indicator is analyzed according to the distribution of technological classes. The indicator is also analyzed by country, industry, and assignee. The source of knowledge spillovers is investigated from three perspectives (technical, organizational, and industrial standards), which

TABLE VII
CHARACTERISTICS AND ANOVA OF THE PATENTS ALIGNED WITH THE 802.16 STANDARD

Patent characteristic	**Mean value**		**ANOVA test**		**Scheffé test *P* value**
	Non-SEP	**SEP**	***F* value**	***P* value**	**I–II**
Originality of knowledge spillovers					
No. of inventors	2.70 (1.75)	2.79 (1.29)	0.42	0.52	0.518
No. of inventor countries	1.10 (0.33)	1.11 (0.33)	0.20	0.65	0.653
No. of assignees	1.03 (0.28)	0.99 (0.24)	2.14	0.14	0.143
No. of assignee countries	0.99 (0.17)	0.97 (0.18)	2.02	0.15	0.155
No. of CPC classes	5.79 (6.93)	9.52 (10.65)	45.08	0.00*	0.000*
No. of claims	19.37 (13.03)	27.16 (21.74)	55.70	0.00*	0.000*
No. of patent references	18.80 (22.44)	17.47 (20.95)	0.55	0.46*	0.458*
Originality index	0.59 (0.36)	0.76 (0.25)	36.89	0.00*	0.000*
Country originality	0.32 (0.26)	0.40 (0.23)	14.21	0.00*	0.000*
Industry originality	0.29 (0.26)	0.34 (0.23)	4.33	0.04*	0.038*
Assignee originality	0.56 (0.35)	0.71 (0.26)	28.01	0.00*	0.000*
Externality of knowledge spillovers					
Docdb family size	6.13 (10.70)	8.51 (13.68)	7.80	0.01*	0.005*
Inpodoc family size	18.62 (116.66)	42.70 (155.35)	6.67	0.01*	0.010*
No. of forward citations (5 years)	3.67 (6.85)	16.2 (16.11)	514.50	0.00*	0.000*
Generality index (5 years)	0.31 (0.37)	0.76 (0.29)	232.78	0.00*	0.000*
Country generality (5 years)	0.18 (0.25)	0.44 (0.26)	174.08	0.00*	0.000*
Industry generality (5 years)	0.16 (0.24)	0.34 (0.22)	90.14	0.00*	0.000*
Assignee generality (5 years)	0.28 (0.34)	0.69 (0.28)	230.97	0.00*	0.000*
Sum of the backward distance	385246.60 (1087742.00)	369041.10 (438435.30)	0.03	0.85	0.854
Sum of the forward distance (5 years)	205298.30 (425781.70)	525938.00 (633011.80)	84.68	0.00*	0.000*
Mean longevity	5.31 (3.30)	7.53 (2.53)	69.53	0.00*	0.000*
Maximum longevity	8.41 (6.09)	13.21 (4.73)	96.06	0.00*	0.000*

Standard deviations are in parentheses.
*Indicated *P* value < 0.05.

contribute to a holistic understanding of the originality of knowledge spillover.

1) *Technical perspective:* Compared with non-SEPs, SEPs have a significantly higher number of inventor countries, CPC classes, and claims. The originality indicators (based on the analysis of the backward patent citations), namely, the country originality, industry originality, and assignee originality, of SEPs are higher than those of non-SEPs. By contrast, non-SEPs have a higher number of assignees, patent references, and nonpatent references than SEPs.
2) *Organizational perspective:* Compared with non-SEPs, SSO patents generally include a larger number of claims. The industry originality, country originality, and assignee originality of patents supported by the ETSI and the IEEE are higher than those of non-SEPs. The ANSI patents have a significantly higher number of inventor countries, assignees, assignee countries, patent references, and nonpatent references than non-SEPs. The SSO patents supported by the ANSI exhibit a significantly lower degree of industry originality, country originality, and assignee originality than non-SEPs. The average number of claims in the SSO patents supported by the five major SSOs is significantly higher than that in non-SEPs.
3) *Industrial standard perspective:* Compared with non-SEPs, SEPs aligned with the 802.16 standard have a significantly higher CPC class count and claim count. Moreover, the country originality, industry originality, and assignee originality of the SEPs are higher than those of the non-SEPs. However, the non-SEPs comprise a higher number of patent references than the SEPs aligned with the 802.16 standard.

Thus, knowledge spillovers of technology standards originate from diversified inventor countries, diversified technological fields, and broad scopes of patent protection. Technology standards generally converge knowledge from various countries, industries, and assignees. However, if an SEP has few patent and nonpatent references, it implies that the technology standard has limited scientific and technological prior art or antedates. As indicated by the organizational perspective toward technology standards, the knowledge spillover of SSO patents is generated from diversified inventor countries, diversified technological fields, and broad scopes. However, the low number of average backward citations is consistent with the results obtained from the technical perspective. Due to their significant country originality, industry originality, and assignee originality, the technology standards supported by SSOs converge knowledge from various countries and firms but not from industries. Industrial standard-level analysis indicates that knowledge spillovers of the 802.16 standard originate from diversified inventors, inventor countries, and technological fields and broad scopes. The 802.16 standard combines knowledge from various countries but few industries.

C. Externality of Knowledge Spillovers

For examining the externality of technology standards, the generality indicator proposed by Trajtenberg *et al.* [84] is extended to country, industry, and assignee distribution. Three perspectives (technical, organizational, and industrial standard) are used in this paper to examine the externality of knowledge spillovers, which can be used to determine the generality and subsequent benefits or cost of a technology standard.

1) *Technical perspective:* Compared with non-SEPs, SEPs have a considerably higher number of patent citations and larger patent family size. All the generality indicators based on the calculation of the forward citation, namely, the country, industry, and assignee generality, are significant.
2) *Organizational perspective:* Compared with non-SEPs, SSO patents generally have a significantly higher number of patent citations and larger patent family size. The country, industry, and assignee originality are significant. The results obtained for the generality of knowledge spillovers at the organizational level are consistent with results obtained from the technical analysis.
3) *Industrial standard perspective:* Compared with non-SEPs, SEPs aligned with the 802.16 standard have a significantly higher number of patent citations and larger patent family size. The country, industry, and assignee generality of the SEPs aligned with the 802.16 standard are higher than those of non-SEPs. The results for generality of knowledge spillovers at the industrial standard level are consistent with the results obtained from the technical and organizational analysis.

D. Geographical Reach and Longevity

The existence of path dependence within a technological paradigm results in knowledge externalities that contribute to geographic concentration [109]. In addition to path dependence, social connection is a crucial determinant for colocation between the cited and citing patents [110]. However, the geographic reach of patents by matching geographic area between cited and citing patents relates to the way patents are assigned to locations. To examine the externality of a technology standard, the geographical assignment, geographical reach, and longevity of SEPs, SSO patents, and non-SEPs are analyzed for determining whether these variables are significant from technical, organizational, and industrial standard perspectives.

1) *Technical perspective:* Compared with non-SEPs, SEPs have a significantly higher sum of the forward citation distance. However, the sum of the backward citation distance of non-SEPs is significantly higher than that of SEPs.
2) *Organizational perspective:* Compared with non-SEPs, SSO patents have a significantly higher sum of the forward citation distance. However, the sum of the backward citation distance of non-SEPs is significantly higher than that of the SSO patents.
3) *Industrial standard perspective:* Compared with non-SEPs, SSO patents aligned with the 802.16 standard have a significantly higher sum of the forward citation distance. The results for the externality of knowledge spillovers at the industrial standard level are consistent with the results obtained from the technical and organizational analysis.

In summary, knowledge spillovers of a technology standard can attain a large geographical reach and transcend various types of borders in a wide time window. However, the geographical reach of backward citations in patents supported by technology standards indicates that the knowledge flow and spillovers of technology standards originate from adjacent areas.

V. Conclusion

Patents are regarded as a valuable source for tracing the dynamics of technological progress [111], [112]. A novel set of U.S. patents on standard setting efforts was used in this paper. This paper provided a critical reassessment of the recent literature on knowledge spillovers and externality. This paper provided three contributions to existing research streams. First, it offered a comprehensive perspective of knowledge spillovers resulting from technology standardization. Previous studies have mainly emphasized the causes of technological emergence [113], [114]. Second, this paper articulated the characteristic patterns of knowledge externality that occurs during and after technology standardization. With the growth in the knowledge foundation over time, knowledge spillovers allow a large number of differentiated products to be introduced without a continual increase in R&D resources. Knowledge that spills across organizational, industrial, and national borders may enable the application of the dominant design (standard) in the entire industry. Knowledge spillover can also cause a gradual shift toward a new generation or paradigm. Therefore, knowledge spillovers can serve as engines for creating a new technological trajectory or paradigm by providing access to new knowledge. To explore knowledge spillovers empirically, three datasets were used for ANOVA, which indicated the significance of SEPs, non-SEPs, and SSO patents. The results of this paper indicated that on an average, SEPs have a low number of assignees, patent references, and nonpatent references, which suggests that the patented technology standard usually originates from adjacent technological fields with few antecedents and a weak scientific basis. For instance, the knowledge spillover of the SEPs supported by the 802.16 standard originates from fewer industries than that of the non-SEPs within the same technology fields. This finding is consistent with the characteristics of technology standards, which are often not the most advanced or cutting-edge technologies. Standards are generally adopted under pressure or due to their compatibility advantages, which benefit manufacturers, distributors, and consumers [107].

A. Managerial Implication

There usually exists a long-time interval between scientific discoveries and industrial applications, which allows knowledge to be transmitted far away from the university or firm that produced it. This paper indicated that knowledge spillovers of technology standards could transcend diversified fields and have considerable geographical reach and longevity. The results obtained in this paper suggested that SEPs had a significant value of knowledge spillover in terms of the originality and externality. The results can also help policymakers justify their efforts in enhancing knowledge flow and inducing knowledge spillover across boundaries during the standard setting process. The key science policy issue now relates to beginning new paradigms and redirecting existing ones. When a government's budget for R&D is limited and has to be focused on promising technologies, policymakers must decide which standard to support and which paradigm to redirect in existing innovation systems. This paper identified the role of knowledge spillovers and externalities, which emerged as critical determinants in shaping new technological development. This paper also offered R&D managers the strategic options to be focused on promising technologies during the standard setting process in order to establish its technology as a standard, which include entering into strategic alliances, adopting an appropriate positioning strategy, licensing, and diversifying into the production of complementary products. Furthermore, knowing key stakeholders within an industrial system and conversely to be known is critical for fostering effective cooperation across the entire value chain where necessary.

B. Limitations

This paper used SEP data to examine the knowledge spillover and externality of technology standards. However, the complete knowledge spillover cannot be obtained from patent data because knowledge may spill through other methods, such as face-to-face interactions. Knowledge spillovers may be influenced by factors that cannot be captured using patent-based indicators. Moreover, there exists limited understanding regarding the extent to which SEPs represent the wide universe of inventions because no systematic data regarding unpatented inventions exists. Therefore, further studies are required to more thoroughly understand knowledge externalities.

C. Future Research

Technology originality is an index for illustrating the extent to which antecedents or historical background of a patented technology. The originality index is defined in the same way; however, it refers to citations made, different from citations received for the generality index. Since the originality and generality indices can also be applied to assignee, industry, and country levels for illustrating the distribution (ratio) of cited/citing patents over different assignees, industries, and countries, it is still needed for further studies to operationalize variables and metrics. Moreover, qualitative research complementary to current studies can provide in-depth and flexible understanding of knowledge spillovers. Therefore, interview-based research can also be performed in future studies.

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