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The Primary Actors of Technology Standardization in the Manufacturing Industry

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ABSTRACT To date, discussions on standards and standards-related market issues have mainly been focused on market influence, such as a company's performance, trade, and technological innovation. Despite the fact that many studies have been conducted with a focus on technology standards, the ways in which primary actors of standards affect the market are yet to be fully investigated in extant studies. In this study, we investigate the primary actors in technology standardization by carrying out a systematic review and constructing a conceptual framework and concept maps of primary actors. Based on our analysis, we categorize primary actors, according to their roles and timing of engagement in standardization, as follows: Technology producers, standard-setters, regulators, and technology users. We illustrate each actor's detailed actions, motives, and difficulties with concept maps that are structured based on the SAO/P model, in order to elucidate why primary actors participate in standardization and how they act to achieve their goals or resolve difficulties. Based on our findings, we derive implications in terms of the strategic management of standardization activities in the manufacturing industry.

INDEX TERMS Technology standards, standardization, technology management, concept map, competitive strategy.

I. INTRODUCTION

Standards are used in a wide variety of areas, including product standards and service standards, to enhance lives by establishing uniform criteria for goods and services [1], [2]. Traditionally, standards have been studied from a multidisciplinary perspective. For example, studies on standards have been spread over various fields, such as Economics, Business Management, International Studies, and other areas where the influence of standards is typically emphasized, including technological change and innovation in industry, global trade flow, and even sustainable development in developing countries, as standards are closely related to capitalism and the market economy [3]–[10].

However, at present, the strategic value of standards has attracted attention from scholars in business-related areas, due to their applicability as an effective tool to achieve competitive advantage in the market [1], [11]–[14]. Scholars have focused on the influence of standards in the market, such as examining the bilateral interplay of standards and elements associated with standards, including a company's performance, competitive strategy, and global trade [11], [12], [15]–[20]. This is particularly relevant to product standards, which is the main focus of this study. These standards have been associated to a number of aspects, including innovation, environmental impact, safety, and energy efficiency, that can influence the market in various ways [21], [22]. In terms of the strategic management of companies, standards are not simply constraints that need to be complied with; they have strategic value that companies need to leverage, by exploring all aspects of standards to improve their competitiveness in the marketplace [21].

Despite there being several articles on technology standards, there is little knowledge on how companies can manage and leverage technology standards from a technology management perspective, as most articles have focused on the economic aspect, such as their impact on trade [2], [23]–[29]. For this reason, the way in which companies manage and leverage standards still has substantial room for exploration. In association with this, some articles have attempted to elucidate the relationships among actors in standardization by focusing on how actors influence and interact with

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each other [30]–[32]. According to existing studies, five actors are frequently mentioned when discussing technology standardization: Users, manufacturing companies, complementary goods suppliers, standard-setting organizations, and governments [31]–[36]. Extant studies have discussed the relationships among these actors in technology standardization [31], [32], [34]–[36]. Markard and Erlinghagen [31] used the five groups of actors to describe the interplay in the smart meter technology industry. However, they did not explicitly define the concept of actors in their study. Wiegmann *et al.* [32], who studied multi-mode standardization based on the existing literature, also used the term 'actor' to describe players in standardization.

In the context of these studies, the term 'actor' is used to denote participants who play a central role in technology standardization. These studies have attempted to explain the industry or business environment in connection with standards based on the main subject [30]–[32]. Hence, studies on the technology management aspect of technology standards in the market—such as primary actors, their actions, and the motives of their actions, in terms of standards-related issues—are needed to broaden our understanding of standards by filling the research gaps in the standards-related research field.

In this study, we attempt to understand the interests of primary actors based on existing discussions, by using a concept map and a Systematic Literature Review (SLR). By studying the complicated interests of primary actors, we expect to discover meaningful implications for companies, specifically strategic insights focusing on technology standards and standardization.

Using the concept of primary actors, who have interests and participate in standardization and standard-related activities, we synthesize current discussions on standards and standardization by understanding how standards affect the market and how companies can leverage the advantages of standards. Based on this, we derived three research questions:

- RQ 1: Who are the primary actors and what are the relationships that exist among them?
- RQ 2: What is the purpose of their actions, in terms of the goals they want to accomplish and the difficulties they face?
- RQ 3: How can primary actors utilize standards and standardization to achieve or sustain a competitive advantage in the market?

To answer these questions, we used a SLR as the basis for our analysis, as this structure has been used in several exploratory studies to build frameworks, as well as to organize and integrate research themes based on extant studies [37]–[43]. Considering that several studies have used SLR to discover new opportunities or to better synthesize the results of extant studies, we expect to fill in some of the gaps in extant studies on technology standards by applying SLR [44]–[46]. As the continuous development of technology through R&D is not an absolute solution for the current fierce competition being experienced in the market, it is important to understand the nature of standards, in order to properly assess the corresponding industrial change. Understanding the nature of standards can help companies to prepare standardization strategies and, thus, maintain a competitive edge in the market.

This paper is organized as follows: The second section presents the theoretical background based on existing discussions on standards with a focus on major actors (i.e., companies, standard-setting organizations, and users). In the third section, we introduce the research framework and the details of research method, including the data collection and data analysis. The fourth section presents a conceptual framework, which shows the overview of primary actors in technology standardization, and concepts maps of primary actors. Finally, the implications and limitations of this study will be discussed in the last section.

II. THEORETICAL BACKGROUND

Standardization is generally defined as an activity or process of establishing a set of requirements guiding the prerequisite of a given good or service, with the aim to diffuse it in the market, expecting that they will be repeatedly used during a certain period of time by the players in a given field [47], [48]. According to International Organization for Standardization (ISO), a standard is a document that is established through the consensus of relevant experts and approved by a recognized body that provides guidance on the performance and design of products, processes, services, and systems [47], [49]. In terms of standards and standardization, there exists no well-defined categorization for actors of standardization, although actors such as companies, Standard-Setting Organizations (SSOs), and users are often mentioned in the related literature [1], [50]–[52]. Kauffman and Tsai [50] categorized actors involved in standardization processes according to the cascading effect of each actor's participation, such as company-level, industry-level, and society-level. As such, in this study, we discuss the three most-frequently mentioned actors, according to the cascading effect of their participation in the standardization process.

A. COMPANIES (COMPANY-LEVEL)

In the case of companies, they tend to focus on standards and standardization processes that are closely related to their core business [53]–[55]. The core value of standards is to set technical specifications, such as quality, performance, and safety requirements, that products should fulfill in order to enter the market; therefore, technology standards compliance is necessary for companies to be able to compete in the market [1], [13], [14], [56], [57]. Particularly, compliance with technology standards can enhance business performance by guaranteeing product quality to consumers [11], [12], [14], [58]–[61].

Companies also benefit from participating in standardization processes by reflecting their company-level specific interests in a certain standard, while also suggesting that their technology serves as a standard in the market [28], [30], [62]–[70]. According to Chiesa, Manzini, and Toletti [65], companies previously implemented an ex-post standardization strategy that corresponded with standards; however, they currently use an ex-ante standardization strategy by taking pre-emptive actions with regard to standardization. This indicates that standards can also serve as an effective tool to strengthen a company's competitive position in the market by leveraging various factors associated with standards, such as network effects and Standard Essential Patents (SEPs) [17], [71]–[81]. In terms of SEPs, their importance in the ICT (Information and Communication Technology) sector is to drive companies to focus more on IPR when designing and implementing their business strategy [82]–[84]. Pohlmann, Neuhäusler, and Blind [79] stressed that it is important to link standardization and patent strategies, in order to maximize the positive influence of essential patents. Patenting of the company's own technology gives it a chance to gain additional profits from licensing patents and licensing technology, which has a positive influence by helping to create market dominance [82]. Therefore, managing essential patents in connection with standardization activities is crucial across manufacturing businesses in the ICT sector, as owning patents can give companies a competitive edge [78], [80].

For these reasons, companies sometimes organize standard alliances, which are coalitions among companies in similar or related industries, to pre-empt the market by reflecting their interests in standards [85], [86]. This has been supported by van de Kaa and Greeven [54], who studied LED standardization cases in developing countries. Their analysis result showed that developing countries in Asia actively participated in standardization more, in order to attain an advantageous position in the market.

B. STANDARD-SETTING ORGANIZATIONS (INDUSTRY-LEVEL)

In the case of SSOs, they develop standards that provide a guarantee to consumers: that they will only receive products or services that have reached that set standard [87]. The standard-setting process differs, depending on the SSO; however, standards development typically involves five stages: Submission of a proposal to the SSO; preparation of a draft; comments and ballot; approval; and publication [1], [48], [88]–[90]. SSOs include various entities, such as national, regional, and international SSOs, standard alliances (industry consortia), and governmental administrative agencies [49], [57].

In general, national standards bodies are the sole member of ISO, as ISO allows only one member per country [91]. National standards bodies develop and publish national standards; for example, the American National Standards Institute (ANSI) in the United States, Deutsches Institut für Normung (DIN) in Germany, and the Bureau of Indian Standards (BIS) in India [92]. Not all national standards bodies are based on the public sector; some of them are based on the private sector and others are based on a combination of the two sectors. For example, the Korean Agency for Technology and Standards (KATS) is a governmental agency under the Ministry of Trade, Industry, and Energy of South Korea, and ANSI is a non-profit organization with members from both public and private sectors.

Regional standards organizations also exist, such as the European Committee for Standardization (Comité Européen de Normalisation Europäisches Komitee für Normung; CEN), the Gulf Cooperation Council Standardization Organization (GSO), and the African Organization for Standardization (ARSO). Regional standards organizations provide a forum for standards setting at the regional level, and support regional regulations and policies through the development of regional standards [49].

International standards organizations, such as ISO, International Electrotechnical Commission (IEC), and International Telecommunication Union (ITU), develop international standards [1], [56], [49]. International standards organizations are composed of national standards bodies and are generally founded on the basis of one member per country [91]. Industry consortia, which consist of private companies in a specific industry sector, also develop and publish technology standards [57].

Standard alliances consist of core companies who have the resources for standardization, as well as companies who may want to get involved in the standardization process [85]. As core companies have access to ample resources, including R&D resources, financial resources, and so on, they control the initiative of standard alliances, and can strongly influence the standardization process and political direction regarding standard alliances [85], [86]. As discussed by Keil [86], standard alliances influence the market in quite a simple way, which can be described as follows: as companies in standard alliances obtain increased membership bases immediately after their technology achieves an initial lead in the installed base, the adoption of that technology will consequently become more attractive to participants in the market. Standard alliances help a certain standard to become dominant in the market, by leveraging the network effect based on the size of the alliance membership [86]. Therefore, from a macro perspective, standards are perceived as a consequence of global competition among countries and companies, with the aim of being a winner in the standards game and gaining a competitive advantage in the market [93].

C. USERS (SOCIETY-LEVEL)

As stakeholders in standardization, users consist of consumers and clients of technology producers; that is, users include those companies that use technology standards and end-users of the resultant products [50]. Network effects and installed base have often been mentioned when discussing the role and influence of users in standardization [94]–[97].

One user's decision to adopt a given technology standard indirectly influences the future adoption decisions of other users, by forming a large installed base through the accumulation of users [94], [95]. The combination of a large user base and the wide availability of complementary products accelerates adoption by users [96], [97]. In particular, a large installed base attracts users who have risk-averse inclination [97]. Network effects are closely related to those who have a competitive edge in the market. Once a standard has been set in the market, the companies that took the lead in standardization tends to dominate the industry, by obtaining network or lock-in effects through a dominant design [71], [72], [75], [98]. Particularly in network-based technology markets, network effects increase user switching costs, which eventually increases the bargaining power of manufacturers [99]. This is one of the main reasons why companies actively participate in standardization activities, as more companies have realized the importance of network effects in gaining a competitive advantage in the market [73], [76]. For instance, according to Lee and Mendelson [76], active participation in standards is important among companies in the IT industry, due to the high importance of compatibility.

As sponsors of technology standards, users contribute to the standardization process by participating in standardization and providing a real-world perspective [88], [100]. Unlike with large users, the participation of small users has clear limitations, due to resource deficiencies, such as human and financial resources [88]. For this reason, it is appropriate for small users to participate in standardization through trade associations or by forming user coalitions [88].

Existing standards research has highlighted and discussed the roles and influences of the participation of actors in standardization activities from different perspectives. Although existing studies have described the roles and influences of actors in standardization, they were not the focus of research and, therefore, a comprehensive overview on primary actors in standardization is still lacking. For manufacturing companies, it is important to understand the standardization mechanism to fully exploit standardization activities for their own benefit.

III. RESEARCH FRAMEWORK AND METHOD

A. INTRODUCTION OF RESEARCH FRAMEWORK AND METHOD

In this study, we propose the use of a hybrid approach between a concept map and the SAO/P model, in order to highlight the primary actors and their motives and activities. The concept map is a qualitative visualization method which illustrates a certain theme or topic at a glance, by structuring the concepts and sub-concepts involved in a top-down diagram [101]. A concept map is a particularly powerful tool, as it clearly demonstrates the overall relationships among concepts and sub-concepts in a single diagram, thus making them easy to understand [101], [102]. Considering the unique features of concept maps, we decided to adopt the concept map style of Novak and Gowin [103], which displays the elements in a hierarchical order by connecting them with lines to indicate their relationships. We deemed this style to be appropriate for visualizing the extant studies on certain topics, in order to improve our understanding [101], [104], [105].

To identify primary actors and extract ingredients for constructing concept maps, we used SLR to analyze technology standards research, with a focus on technology management in companies. SLR is a qualitative research method which extracts findings from multiple studies, based on a specific research domain [37], [106]. SLR was first introduced in the medical field in the 1970s; however, it has been used in various fields to summarize and integrate the current understanding of specific research themes [44], [46]. Recently, many researchers have adopted SLR for their studies, in order to aggregate research findings from extant studies [38]–[43]. SLR is particularly effective when conducting exploratory research, as it helps researchers understand a particular field of research, based on the extant studies in that field [39], [40], [42]. In this study, we investigate primary actors of standardization and explore their behavioral aspect, such as their actions and motives. Therefore, we deemed that SLR was best suited for our research objective. As has been demonstrated in various studies using SLR, it can be adopted and used in diverse research across various academic disciplines.

Referencing previous studies, we constructed a research framework (see Fig. 1) through a process consisting of five steps: Setting the screening criteria, data collection, screening, qualitative coding, and data analysis [37]–[43]. The first step involves setting the research questions and the screening criteria. In this step, researchers define what they want to discover by using SLR and determine the screening criteria for SLR, in order to narrow down the retrieved articles and target only articles that are appropriate for the study. Data collection is the second step of SLR, which consists of keyword selection, source selection, and data retrieval. The primary data for SLR in our study was retrieved from the Web of Science (WoS), a well-known online subscription-based scientific indexing service, and implementation of snowball sampling in order to include relevant articles that are not covered by WoS. We retrieved articles, books, and working papers related to our research question by searching for keywords that matched the extant studies [40], [42], [43]. We applied phrase searching by separating search keywords with commas. This allowed us to retrieve documents with an exact phrase; that is, retrieving documents containing at least one of the given keywords. We included the term ''technology'', in order to extract articles related to technological fields, as the keyword ''standard'' is used in various fields, such as standard deviation. We set the search period to range from 1990 to 2020, in order to ensure that we gathered as many standards-related articles as possible. Obtaining abundant primary data is important in this research process, as it sets the stage for the thorough analysis of the primary actors. As indicated in Fig. 1, we gathered 1,657 articles from WoS and snowball sampling for data screening.

The primary data was used as a basis for the third step, as the acquired primary data consisted of unrefined and

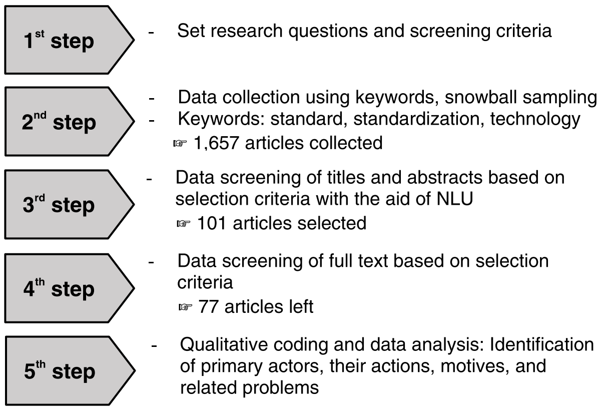

FIGURE 1. Research framework for systematic literature review on the primary actors of technology standardization.

unsorted documents which required a screening process. In the third and fourth steps, researchers screened the primary data based on certain criteria, in order to refine the documents to those that are specifically relevant to the research theme [40], [42], [43]. The screening process is undertaken based on certain inclusion/exclusion criteria, which are defined by the researchers to ensure that the selected articles focus on the specific research topic to properly reflect the research objectives.

The first step in screening involves examining the titles and abstracts of the collected articles. Recently, the utilization of natural language understanding (NLU) in artificial intelligence has increased in various fields, such as education, clinical science, and so on. This increase is due to the useful features of NLU, which include information extraction and time efficiency [107], [108]. We used Watson NLU only during the first step of screening. As a supporting tool, NLU allows one to analyze the literature from various sources, in order to avoid researcher bias during article selection, in addition to avoiding rejection decisions and accelerating the screening process. Watson NLU provides analysis results for the content involving items such as sentiment, keywords, categories, and concepts. Using NLU analysis result, we screened primary articles based on the researcher's judgment, according to the article selection criteria to select or reject articles. Through this process, we narrowed down the initial set of 1,657 articles to 101 articles. In the second step of screening, we made a decision on whether to select or reject articles based on a full text review. We did not use NLU in the second step of the screening, as NLU cannot fully consider the context of an article. After the second step of screening, we were left with 77 articles for analysis.

The fifth step involves qualitative coding and data analysis, including a descriptive analysis on the basis of the number of articles by publication year, academic discipline, and so on, as well as a thematic analysis with a focus on the object of research (e.g., primary actors in technology standardization and managerial or academic implications for manufacturing companies) [40]. Qualitative coding extracts the essence of a text by assigning codes to words, phrases, or paragraphs [109]. Qualitative coding can be described as a process of understanding and interpreting qualitative data by a researcher, as the coding depends substantially on how researchers code the data [110]. According to Saldaña [106], there exist a number of qualitative coding methods from which the researchers should choose from, based on the best fit for their study.

In this study, we coded data using descriptive coding, which consists of summarizing the topic of interest in qualitative data into words or short phrases [106]. As descriptive coding involves extracting core topics from data, it helps researchers to summarize and interpret the data. In consideration of the research questions, we coded target articles to extract three things: Primary actors (RQ 1); the motives of their actions and difficulties that they are facing (RQ 2); and benefits for actors who participate in standardization (RQ 3).

Qualitative coding was conducted with the help of CAQDAS (Computer-assisted Qualitative Data Analysis Software), particularly 'ATLAS.ti', which is useful for social science research and provides a user-friendly UI [111]. Coding data with CAQDAS helps us to conduct qualitative coding more systematically and effectively, as it provides efficient tools, such as code groups, networks, and so on [111]. To verify the reliability of the coding results, we verified the inter-code reliability in the first stage of the qualitative coding procedure.

After qualitative coding, we classified codes into categories according to the primary actors identified from the coding result, as well as their roles and actions in exploring RQ 1 (Who are the primary actors and what relationships exist among them?) and RQ 2 (What is the purpose of their actions in terms of the goals they want to accomplish and the difficulties they face?). The traditional SAO model, which is constituted of Subject (S), Action (A), and Object (O), is generally used for patent specification analysis [112]–[115]. The SAO model aims to analyze text data into a subject–action–object structure, by identifying the key concepts and relationships underlying the data [112]. According to extant studies, the SAO structure helps researchers to extract keywords and relationships from the data, as the SAO structure abstracts a large amount of text into a simple structure, where an action links two keywords [113], [114].

The SAO/P model proposed in this study, which is based on the SAO model, is used to organize concept maps based on the subjects (i.e., actors) in technology standardization. In general, the O in the SAO structure indicates the purpose of a subject's action [114]–[116]; however, when the SAO structure is used in patent analysis, then O represents the problems that needs to be solved by S, while S refers to the solutions [114]–[116]. Considering the possibility of utilizing the SAO structure in various ways, in this modification of the traditional SAO model, we divide O (motive of action/result of action) and P (problem to be solved by actor's action/difficulty related to action) to differentiate the roles depending on the context, such as the purpose of a subject's action or difficulties that need to be solved.

TABLE 1. Top 10 target journals.

Journal Title	Number of Articles
Technovation	5
Technological Forecasting and Social Change	5
Research Policy	4
Technology Analysis & Strategic Management	4
IEEE Communications Magazine	3
Information Technology & Management	3
International Journal of Technology Management	3
R&D Management	3
Sustainability	3
Telecommunications Policy	3

Compared to the traditional SAO model, the SAO/P model has the advantage of showing the underlying reasons for an actor's action more specifically, by classifying codes into objectives and problems. With this modification of the traditional SAO model, the SAO/P model can respond to RQ 3 (How can primary actors utilize standards and standardization to achieve or sustain a competitive advantage in the market?). As the SAO/P model is limited to showing the summarized text data in the SAO/P structure, we applied a concept map based on the SAO/P structure to overcome this limitation, such that we can comprehensively describe the aspects of the subject, according to the actors involved [103].

We expect that using this hybrid approach can improve the analysis process, by making it more systematic and enhancing its readability by hierarchically organizing actors and their activities based on the SAO/P model. In addition, the integration of concept maps and the SAO/P model allows researchers to create concept maps based on a solid foundation. By reflecting the SAO/P structure in concept maps, this hybrid approach triggers researchers to consider the purpose that underlies the qualitative data, rather than excessively focusing on the language structure.

B. DESCRIPTIVE ANALYSIS

Before we handle the analysis, we examined the descriptive characteristics of the 77 articles selected, including the target journal, publication timing of the article, and research methods. Specifically, the descriptive analysis includes three topics: The target journal, annual publication pattern of research, and research methodology (qualitative or quantitative). The purpose of descriptive analysis is to examine the general aspects of the SLR target articles, such that we can fully understand the flow of interests in technology standards and standardization.

According to this descriptive analysis, articles tend to be published in journals associated with technology management or innovation. Specifically, Technovation and Technology Forecasting and Social Change were the most common target journals. As described in TABLE 1, as relevant articles were published in journals in various fields, we inferred that articles that discuss technology standards and standardization tend to have interdisciplinary characteristics.

TABLE 2 shows the distribution of the publication and timing of the 77 articles that were subject to our SLR.

TABLE 2. Publication timing of articles.

Publication Year	Number of Articles
1992	1
1994	1
1998	3
2000	1
2001	3
2002	4
2003	3
2004	4
2006	1
2007	2
2008	2
2010	2
2011	4
2012	6
2013	1
2014	2
2015	3
2016	10
2017	6
2018	4
2019	7
2020	7

According to TABLE 2, the number of articles focusing on standards started to increase in the early 2000s and reached a peak in 2016. Despite the ups and downs of this pattern, we observed that there has been continued interest in technology standards since the early 2000s.

According to TABLE 3, a number of relevant articles employed qualitative analysis, especially case studies, which were the most frequently used method among the various research methods. Considering that studies on standards have mostly focused on how technology standardization is achieved and its effects on the market, conducting a qualitative analysis of the articles that focus on standards might be the most logical action for researchers who want to identify the primary actors in the field of standardization, based on the findings of existing discussions.

IV. RESEARCH FINDINGS

Section IV consists of two parts: A conceptual framework of the primary actors of technology standardization and an actor-focused analysis. In the first part of this section, we suggest a conceptual framework for primary actors of standardization, based on the systematic review result. The conceptual framework provides an overview of the primary actors and the point at which they engage in technology standardization, according to three stages of technology standards; that is, technology development, standard-setting, and standards implementation and regulation. Subsequently, details of the actions, objects, and problems related to the primary actors are presented using concept maps.

A. CONCEPTUAL FRAMEWORK

Based on the systematic review results, we identified the primary actors of technology standardization and constructed a conceptual framework (see Fig. 2). Referring to the stakeholder dynamics as per Kauffman and Tsai [50],

TABLE 3. Research methodology.

Category	Detailed Methods	Frequency
Qualitative Analysis	Case study	23
	Narrative literature review	17
	In-depth interview	1
	Action research	1
	Scorecard method	1
	Survey	1
	D–S–N model	1
	Entropy theory	1
	Sum	**46**
Quantitative Analysis	Regression	7
	Network analysis	3
	Structure equation model	3
	Logistic regression	2
	Equilibrium analysis	2
	Panel analysis	3
	Multiple step regression	1
	Agent-based computational model	1
	Best worst method	1
	Descriptive statistics	1
	Innovation adoption curve	1
	Entropy theory	1
	Polynomial distributed lag model	1
	Portfolio analysis	1
	Scenario analysis	1
	Hausman–Taylor estimation	1
	Sum	**30**
Mixed Method	Scenario analysis + Case study	1
	Sum	**1**

we categorized the primary actors based on their roles and timing of engagement in technology standardization as follows: Technology producers, standard-setters and relevant participants in the standardization process, technology users, and regulators. Technology producers are innovators who develop new technologies, such as companies, universities, and research institutes [50]. In this study, we limit technology producers to companies, considering our research focus (i.e., technology management of manufacturing companies) and the resultant systematic literature review result. Standard-setters consist of various types of SSOs according to the scope of works—namely, national, international, or regional standards—as well as standard alliances that aim to develop and promote industrial standards based on specific technologies [50], [117]. Relevant participants of SSOs include experts from companies, academicians, certification bodies, industry associations, and lobby groups. Technology users consist of consumers and users of the technology produced by technology producers [50], [88]. Regulators include governments, who design and implement standard-related policies, and certification bodies who perform actual works related to certification, such as testing and the issuance of compliance certificates [57], [118].

Based on the SLR result, we constructed the conceptual framework of the relationship of primary actors, according to their roles in technology standardization (see Fig. 2). We marked four categories of primary actors in gray and solid arrows, showing each actor's participation in the standardization process. A dotted arrow indicates the influence of one actor on the other (indicated by the direction of the arrow); for example, the influences of governments and certification bodies on manufacturing companies are indicated by dotted arrows in Fig. 2.

As technology producers, companies participate in the standardization processes by working in groups of SSOs [51]. SSOs operate working groups, which are in charge of a certain technology area, consisting of experts from various sectors, such as manufacturing companies, academia, certification bodies, and public authorities [51], [94]. Participating in a working group provides some clear benefits to stakeholders of technology standardization; for example, stakeholders can join a community of experts who share knowledge, including know-how and skills, which can eventually build the company's reputation [51]. In terms of technology standardization, the participation of a company is highly dependent upon its ability to recognize and understand the value of technology standards and the resources available [119]. Companies that understand the benefits of technology standards actively participate in technology standardization, in order to increase their market share and to gain a competitive position in the market [4], [85]. Companies that participate in standardization tend to invest in R&D, which may help them to influence standardization, as well as to concentrate on standardization activities that are related to their core business [51], [120].

According to Jakobs *et al.* [129], company experts regard themselves as the representatives of their company, rather than seeing themselves as user representatives, when participating in working groups of SSOs. For this reason, they tend to endorse specific technical requirements that are favorable to their affiliated organization [51], [88]. Not only companies but also various stakeholders, who have direct and indirect roles in technology standards, participate in standardization process, such as lobbying groups, certification bodies, NGOs, and users [50], [89]. However, unbalanced stakeholder representation may result from participation barriers among stakeholders or the existence of a dominant stakeholder [52]. This implies that facilitating the participation of various stakeholders in the standardization process does not guarantee a sufficient actual user representation. Cases such as the Dual EC DRBG, which is an algorithm that can compute pseudorandom numbers, have indicated that standards can be deliberately manipulated by stakeholders during the standardization process [121].

Regulators such as governments and certification bodies also engage in standard-setting, as policy implementors and experts, respectively [96], [118], [122]. As indicated by the dotted line in Fig. 2, regulators not only participate in standardization processes, but also influence the adherence of companies to technology standards, by setting regulatory measures which establish technical barriers, in order to protect domestic industries and sustain technological and market dominance [118].

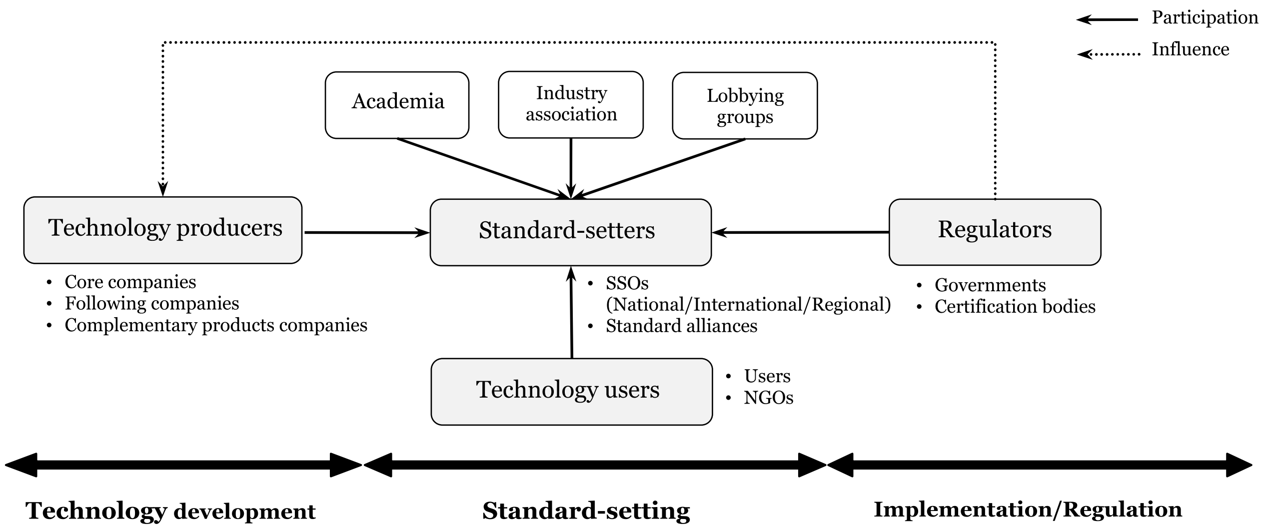

FIGURE 2. Conceptual framework of the relationships among primary actors.

B. CONCEPT MAPS OF PRIMARY ACTORS IN TECHNOLOGY STANDARDIZATION

Based on the qualitative coding results, we constructed concept maps of primary actors in standardization, based on the SAO/P model. In this part, we discuss the detailed motives, actions, and difficulties that primary actors face, through the use of concept maps. Our study can be differentiated from other studies in that it explores the motives and interests of each actor, based on an examination of the current understandings of primary actors in standardization. This analysis is also important as extant studies have focused more on the influences of actors regarding standardization, with less emphasis on the various interests and reasons to adopt standardization [32], [56], [85], [123].

Two types of arrows are used in the concept map: one is a solid arrow and the other is a dotted arrow. Solid arrows show a direct connection between codes; for example, the solid arrow linking core companies (S) to promoting standardization (A) means that the subject implements the action in the direction indicated by the arrow. Regarding the objectives and problems, the direction of an arrow shows which code triggers the other. For example, the arrows linking objectives- or problems-related polygons to actions indicate that such objectives or problems are the cause of actions, and vice versa. A dotted arrow indicates an indirect contribution of one code to the other. For example, following companies and complementary products companies support the standardization-related activities of core companies.

Fig. 3 shows a concept map of technology producers, including core companies, following companies, and complementary products companies. Extant studies have discussed the participation and general activities of manufacturing companies in the standardization process [32], [86], [99], [124]. As shown in Fig. 3, primary actors were classified based on their roles which, in this case, consisted of core companies, following companies, and complementary products companies. Following companies and complementary products companies support the standardization-leading core companies by adopting existing standards and developing complements, respectively, as indicated by the dotted arrows in Fig. 3 [31], [86].

As shown in Fig. 3, there are seven actions that companies take, in relation to standardization: Promoting standardization, licensing patents, sponsoring alliances, participating in standardization, monitoring technology strategies, adopting existing standards, and developing complements. Primary actors take various actions to achieve either their objectives or to overcome problems related to standards. After qualitative coding, we identified several objectives and problems. As shown in Fig. 3, there were eight identified objectives: a strong competitive position, de facto standards, dominant design, gaining a first mover advantage, achieving technological dominance, knowledge sharing, exploring strategic opportunities, and the proper allocation of resources. Two objectives—de facto standards and dominant design—were linked to promoting standardization.

We intentionally differentiated between these two concepts, in order to highlight the detailed strategic motives of companies. Several studies have shown that dominant design and de facto standards are generally used interchangeably, as these two concepts are closely related to each other [125]–[127]. A dominant design is a persistent design that is widely adopted by various industries and which meets the requirements of most segments of consumers for most companies in the market [125], [127]. De facto standards arise from market competition between standards which are supported by various subjects, such as a single company, a group of companies, or standard alliances/consortiums, consisting of companies with common interests [125]. Narayanan and O'Conner [127] stated that standards are an important element of dominant designs, but not all dominant designs achieve competitive advantage; however, those that establish a standard often reap a competitive advantage.

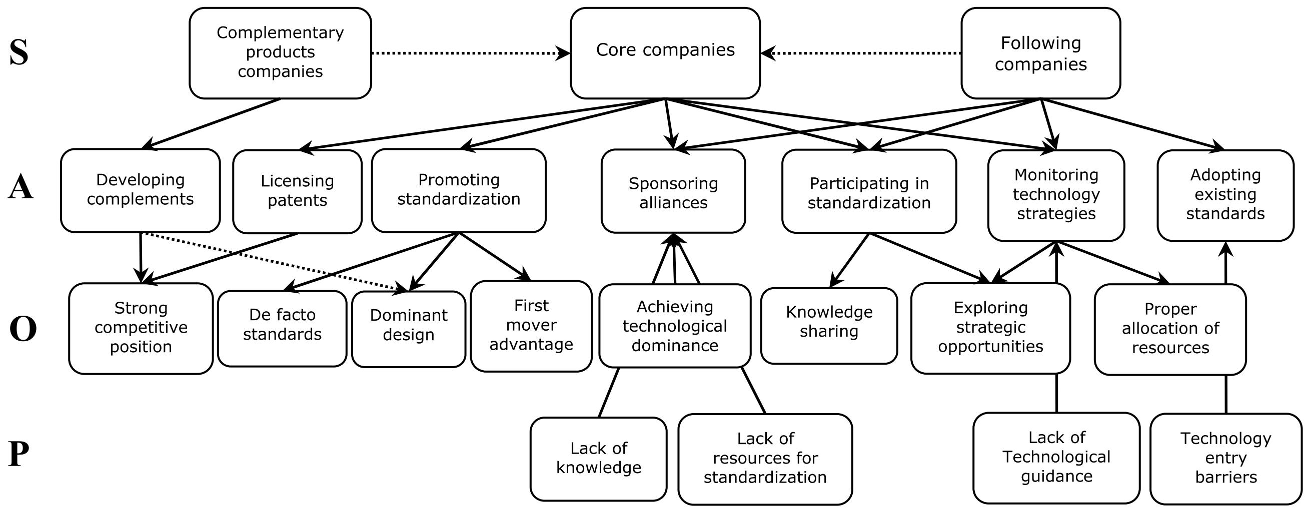

FIGURE 3. Concept map of technology producers.

Based on the discussions from extant studies, we distinguished these two objectives from an operational standpoint [125]–[127]. The operational definition of a de facto standard is a standard which naturally becomes the standard in the market, and is dominant as a result [125]–[127]. In contrast, the operational definition of a dominant design is slightly different from that of a de facto standard, in terms of the focus: the 'design' aspect [125], [126]. A dominant design is a product architecture that commands a huge market share, and one that another manufacturing company must strive to acquire in order to gain a competitive advantage [125], [126].

There are four problems in Fig. 3: Lack of knowledge, lack of resources for standardization, lack of technological guidance, and technology entry barriers. The relationships among actions, objectives, and problems facing primary actors are discussed below.

Core companies promote standardization to acquire the first mover advantage by establishing de facto standards or dominant designs [65], [76], [85], [128]. By participating in standardization, they share and acquire knowledge while exploring strategic opportunities [51], [129]. Core companies sponsor standard alliances in order to increase their chances of achieving technological dominance in the market [130]. As indicated in Fig. 3, they also license patents to strengthen their competitive position. Further, they monitor technological strategies to find strategic opportunities and to properly allocate internal or external resources for R&D, while also obtaining technological guidance through monitoring the results [71], [85].

Following companies also monitor technology strategies with the same objectives as core companies. While core companies perform direct actions, following companies are passive in standardization by adopting existing standards. According to Fig. 3, following companies experience four challenges in relation to standards: A lack of knowledge, a lack of resources for standardization, a lack of technological guidance, and technology entry barriers. Like core companies, following companies also sponsor standard alliances; however, the intention of their action is different from that of core companies. In comparison with core companies, following companies sponsor standard alliances to address deficiencies, such as a lack of knowledge and lack of resources for standardization, as participating in alliances provides opportunities to access external knowledge and resources [51], [53]–[55], [75], [85], [88], [117], [130]. They monitor technology strategies to attain technological guidance for their business and to explore strategic opportunities [89], [129]. Moreover, they adopt existing standards, such that they can overcome technology entry barriers [66], [71].

The action of complementary products companies is closely related to the benefits of core companies. According to Rosen [124], complementary products companies tend to develop complements for core companies, due to their large share in the market, and they do this with the aim of strengthening their competitive position. Regarding the influence of complementary products, Bonardi and Durand [131] indicated that the diversity of complements available gives users a push toward choosing the products of core companies, which are made more attractive than other products by featuring various complements. The availability of complementary products generates an indirect network effect, subsequently influencing the emergence of a dominant design [94], [97], [131]. Based on the SLR results, the supplementing role of complementary products companies is significant, compared to those of other actors.

Fig. 4 shows a concept map of standard-setters, consisting of SSOs and standard alliances. In terms of SSOs, it consists of three actions; namely, de jure standardization, providing a benchmark, and facilitating the participation of various stakeholders. SSOs conduct de jure standardization to develop new standards and to substitute or revise existing standards [1]. Through de jure standardization, SSOs can overcome

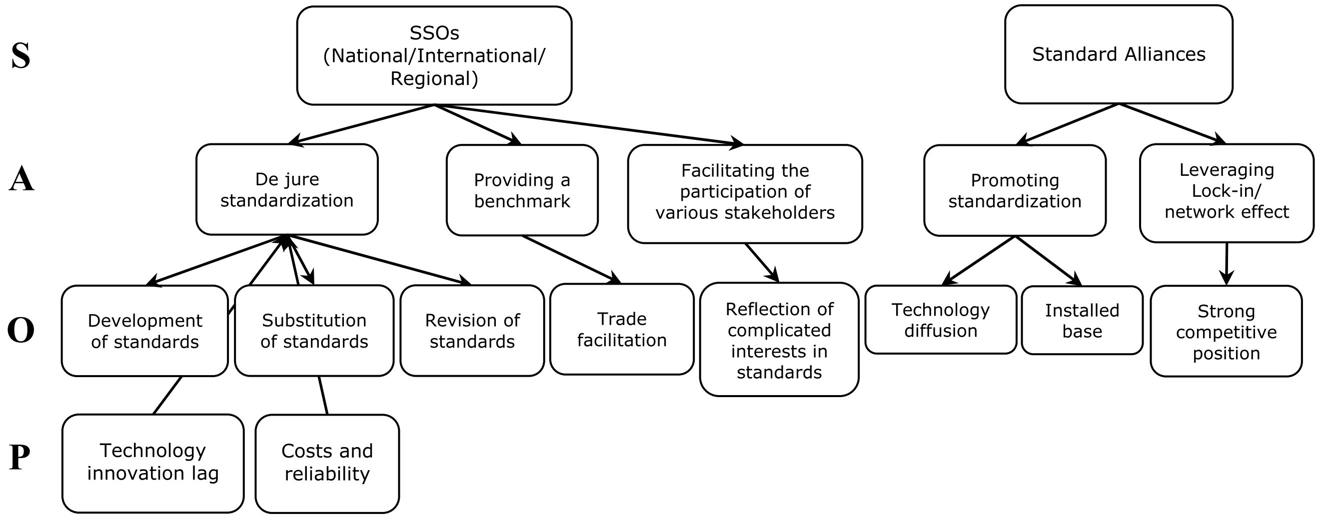

FIGURE 4. **Concept map of standard-setters.**

problems related to standardization, such as technology innovation lag, costs, and reliability issues [71], [124], [128]. Setting de jure standards can foster technology diffusion and reduce the technology innovation lag, as de jure standards tend to diffuse faster in the market [71], [95], [128]. SSOs provide a benchmark for participants in the market by setting standards to facilitate trade [139]. They also facilitate the participation of various stakeholders, in order to reflect on the complicated interests of stakeholders, with respect to standards [17], [85], [140].

In terms of standard alliances, there are two actions involved, namely, promoting standardization and leveraging lock-in/network effects. Standard alliances promote standardization to diffuse technology, which the standard alliance supports, and to build an installed base. By promoting standardization, standard alliances help to diffuse technology through cooperation with participating companies in alliances [72], [85], [97], [124], [128], [131]. Standard alliances also contribute to building of an installed base by indirectly forcing other parties who did not join the alliance to select certain technology for adoption [65], [86], [117].

Similar to the objectives of manufacturing companies in Fig. 3, standard alliances aim to attain market dominance through standardization activities. As a part of supporting standardization activities, standard alliances leverage lock-in/network effects to gain a strong competitive position [28], [65], [75], [76], [86], [128], [133]. This has been supported by extant studies, which have depicted standard alliances as wielding a strong influence over the market [65], [75], [85]. As described by Chiesa *et al.* [65], standard alliances indirectly force other parties who did not join the alliance to select certain technologies for adoption. In the end, there is an opportunity cost associated with not having been part of the decision-making process of the technology in use or choosing the wrong technology, such that companies need to make a decision on which technology the will apply for their products. For this reason, companies have a clear incentive to participate in standard alliances in the early stages of the standardization process.

There are two actors—governments and certification bodies—in the concept map of regulators. Governments implement three actions—intervening in standardization, government-driven standardization, and monitoring standardization activities—while certification bodies take one action; namely, operating certification schemes.

The most salient point is that governments promote government-driven standardization, in contrast to standardization driven by manufacturing companies and standard alliances. Governments conduct government-driven standardization to establish de jure standards, to harmonize national standards with international standards, and to promote innovation and boost industry competitiveness [85], [122], [132]. Countries overcome standards-related issues in areas such as cost and reliability through government-driven standardization. They also resolve the inconvenience of inadequate standardization by intervening with the leverage afforded by their governmental authority, while promoting innovation and boosting industry competitiveness. Moreover, they monitor standardization activities to take pre-emptive actions related to removing technology entry barriers.

In terms of certification bodies, they operate certification schemes, which offer written assurance that a product, service, system, or process conforms to specific requirements under the relevant standard [57], [64]. As certification schemes are operated based on standards, operating certification schemes promote established standards, while also promoting technology diffusion [95].

Figure 6 shows two actors: Users (including consumers and companies who use technology standards) and NGOs. Specifically, the concept map of technology users is differentiated from the other concept maps that were earlier

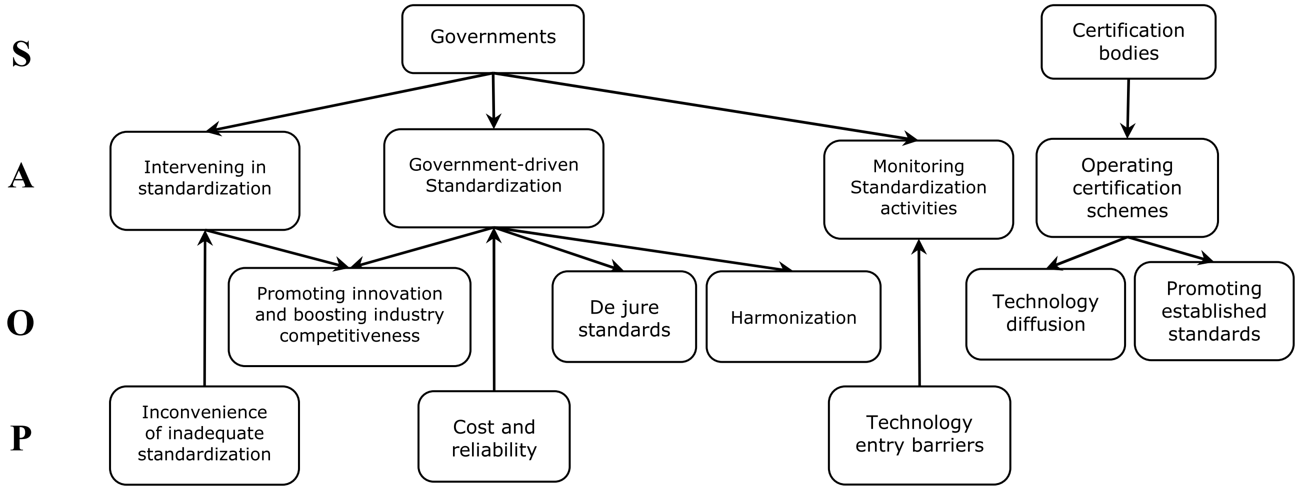

FIGURE 5. Concept map of regulators.

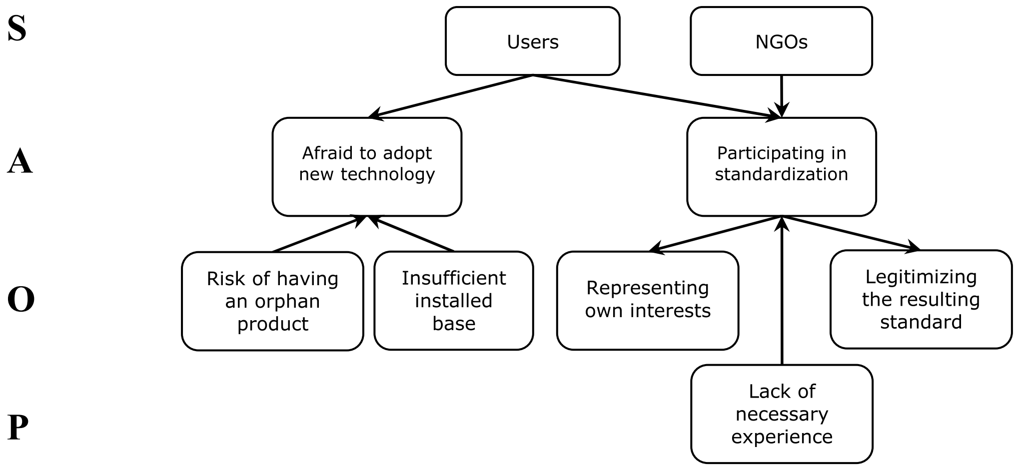

FIGURE 6. Concept map of technology users.

discussed through its characteristics. The users are the end-users of standards, meaning that they influence standardization by making decisions as to whether or not to accept products that comply with a certain standard. For this reason, the actions of users are closely related to the resultant feedback toward standards and how they view standardization activities. Detailed discussions on the actions of technology users and the associated problems are provided below.

As shown in Fig. 6, there are two actions related to users: 'afraid to adopt new technology' and 'participating in standardization'. The former action is a result of standard-related risks based on the adoption decisions of users, which are indicated as problems in Fig. 6. The latter action represents the influence of users in standardization. In a number of the highlighted studies, the key pre-requisite of de facto standards is public acceptance of a product or technology in the market, because the choices of users influence the technology or product that will become the de facto standard [72], [76], [99], [124].

According to Fig. 6, the former action is associated to two motives (i.e., the risks of having an orphan product and that of having an insufficient installed base). This kind of user behavior has been explained in several studies, with a focus on the relationship between technology standardization and its inherent network effect [124], [133]–[135]. According to Rosen [124], users hesitate to adopt a newly introduced standard in the market, as products based on newly developed standards barely have any complementary products. A few studies have referred this to as 'adopter's fear,' which results from the fear of having an orphan product that may soon stop receiving support from the market [124], [133].

When a sufficient installed base is yet to be established in the market, market inertia emerges, which influences the choice regarding whether to adopt a standard or not [65], [124], [134], [135]. Considering the risk of buying a product that does not have a sufficient installed base, it is reasonable to expect users to adopt technology that suits their needs and which has a sufficient installed base [65], [68], [74], [133]. As discussed in the studies by

Lin and Huang [120] and Clements [135], the superiority of the technology standard itself and having a sufficient installed base also have significant influences on the adoption of standards by users.

This kind of user attitude will eventually lead to market inertia, which hinders technology adoption in the market [70]. Eventually, user hesitation in adopting a newly introduced standard develops, and market inertia may result in the settlement of a standard with inferior technology [28], [68]. As mentioned by Rosen [124], user choices influence manufacturers both positively and negatively; for example, setting a standard reduces the costs incurred by an individual manufacturer, in exchange for reduced product diversity.

Both actors share the action 'participating in standardization', which is connected to two objects (representing own interests, legitimizing the resulting standard) and one problem (lack of necessary experience). Both actors participate in standardization to represent their own interests; for instance, companies participate in standardization activities of SSOs, such as WGs, to express their interests, while consumers and NGOs also participate, but the influence is relatively weaker than that of large companies [51], [88], [94]. In the case of companies, they tend to actively participate in standardization activities related to their core business [51]. Moreover, users implicitly influence the R&D decisions of manufacturing companies, as the choice of users has a significant impact on the competitiveness of a company's product [83], [136]. The participation of technology users can legitimize the resulting standard, as users can contribute to standardization by providing meaningful real-world requirements [21], [31], [64], [88], [100], [137]; however, it is challenging to achieve actual user representation, due to the lack of necessary experience of users who participate in the standardization process to provide meaningful suggestions regarding the technical requirements [52], [88].

Based on the conceptual framework and concept maps, we obtained answers for RQs 1 and 2. RQ 3 will be discussed, in connection with business implications to companies, in Section VI.

First, we identified primary actors in standardization (RQ 1). In the technology development phase, manufacturing companies, such as core companies, play key roles as technology producers. During the standard-setting phase, SSOs and standard alliances (i.e., standard-setters) lead standardization activities, and various stakeholders, such as academicians, industry association, and lobby groups (i.e., participants), users, and NGOs (i.e., technology users) participate in standardization. Governments and certification bodies (i.e., regulators) play central roles in the implementation/regulation phase.

Secondly, motives and difficulties facing primary actors regarding standardization activities were examined through concept maps (RQ 2). In terms of technology producers, core companies benefit from the support of following companies and complementary products companies, which constitute adopter layers for the successful adoption of standards in the market [31], [85], [138]. As standard alliances provide support to manufacturing companies, who want to lead the standardization effort, manufacturing companies sometimes exercise their influence by forming or sponsoring standard alliances, in order to intensify their influence on the standardization process [85], [86], [124].

In terms of standard-setters, both SSOs and standard alliances lead standardization; however, they demonstrate similar but different objectives for standardization. The objectives of SSOs are more aligned with public interest than those of standard alliances; for instance, SSOs focus more on the public aspects of standards, as compared to manufacturing companies and standard alliances, who concentrate on their own special interests rather than public interests. In regards to the problems stated in Fig. 4, they are closely related to the public functions of standards, such as setting a universal standard for products. Extant studies have highlighted the positive influence of setting universal standards, as they facilitate the application of current technology in the market while lowering costs and increasing reliability, as higher costs and decreased reliability are believed to primarily result from the absence of de jure standards [34], [124].

In terms of regulators, governments engage in standardization to maximize the societal benefits that can be achieved through standardization. For example, governments provide feedback on the standardization process, in order to make sure that standardization moves in the right direction to achieve objectives, such as preventing inadequate standardization, harmonization with international standards, and monitoring standards of other countries through channels, such as the WTO [28], [32], [34], [124], [136]. Meanwhile, certification bodies ensure that manufacturing companies follow standards by imposing certification schemes. By doing so, certification bodies contribute to the diffusion of technology, which is set in the standard subject to the certification scheme.

In terms of technology users, users and NGOs tend to participate in standardization to reflect their interests on standards. Considering that technology users are the end-users of products based on the set standards, leveraging user feedback can legitimize the resulting standard and maximize the impact of the standard on the market [65], [99].

V. CONCLUSION AND LIMITATIONS

In this study, we conducted SLR to discover the primary actors in standardization, based on existing discussions covered in the previous literature. We identified primary actors and illustrated the conceptual framework of the relationship among them, as shown in Fig. 2. In particular, we unveiled the roles of primary actors, according to three phases: Technology development, standard-setting, and implementation/regulation. This approach provides a clear overview on the relationship among primary actors, how they interact with each other, and who holds the central role in each phase, thus differentiating our study from extant studies. We constructed concept maps to describe the details of actions, motives, and difficulties which primary actors face, based on the SAO/P model. Four concept maps were presented, according to the categories of primary actors, including technology producers, standard-setters, regulators, and technology users. Based on the analysis results, we discussed business implications related to the technology management of manufacturers at three levels: Company-level, industry-level, and society-level.

At the company-level, companies need to understand market conditions, such as the availability of complementary products, in order to exploit standardization to their own advantage. Successful standardization of concerned technology not only requires acceptance by users but also requires support from other companies in the market. Regarding the acceptance of users, core companies must secure a certain number of adopters to eliminate user hostility towards a given standard. Considering the concept map of technology producers, support from other companies can be achieved in two ways: leveraging the support of following companies and exploiting indirect network effects, produced by complementary products companies. In the case of support from other companies in the market, following companies play a critical role in mitigating fear among users over the introduction of a new standard in the market [65]. In the case of complementary products, the availability and compatibility of complementary products influence consumer decisions on whether to adopt a certain product or technology which, subsequently, results in indirect network effects [94]. Considering this, it is important for core companies to secure a certain number of companies who will support them during the standardization process and help users to accept the standard. Therefore, it is important for companies who want to standardize their core technology to prepare the ground for successful standardization, by exploiting following companies and complementary products companies.

At the industry-level, manufacturing companies can leverage governmental authority to their own advantage in both domestic and global markets. In general, people believe that governments control standardization activities [32], [34], [139]. According to the concept map of regulators, the role of governments in standardization is not limited to simply controlling standardization activities. Regarding the technical barriers to trade, the government supports manufacturing companies by monitoring standardization activities in the relevant field of interests in the domestic industry. The government can ease manufacturer's difficulties related to responding to technical barriers set by standards through official enquiry channels, such as the TBT enquiry points of WTO members. For this reason, manufacturers need to not only participate in standardization activities, but also leverage governmental authority to ensure that they can effectively exploit all available means to compete globally. In the case of newly developed technologies, companies, who share common interests and want to promote a certain technology or pioneer it in the market, they can achieve their goals through joining or establishing standard alliances.

At the society-level, a government's role in promoting technology standardization is prominent in the interplay among various primary actors. Governments act as an initiator and a sponsor for technology standardization projects, by initiating products and formulating policies and activities to develop and diffuse standards. A government's proactive actions toward technology standardization reflect current societal trends of neo-techno-nationalism, which represents the expanded commitment of a government to national technology and innovation policy with a focus on national interests. This provides practical implications to emerging countries which are eager to catch up to leading countries. Strong governmental support for technology standardization through setting goals and implementing policies can contribute to the facilitation of a certain technological field in two ways; that is, promoting innovation of companies by lowering accompanying risks of R&D and synergizing public–private partnerships by making companies adhere to the government's scientific and technological policies, which helps companies to align their business strategies with national policies.

Although we identified primary actors, as well as their motives and influences, in standardization and reconstructed these factors based on the synthesis of extant discussions, there were several limitations and unsolved issues in this study. First, we inevitably missed some articles which are relevant to the primary actors of standardization, as the range of data collection was limited to ISI (Institute for Scientific Information)-listed journals. Therefore, a further study, which encompass a wider range of literature, is needed to enrich our understanding of the primary actors in standardization. Second, we identified several primary actors based on qualitative coding and constructed a conceptual framework. As we primarily discussed the primary actors of standardization in the electronics industry, further studies with a focus on the primary actors of standardization in other industries are needed. Third, while we identified several primary actors that have not attracted much attention in previous standards-related research, there may be more actors which we failed to identify in this study. Hence, follow-up research is necessary, in order to expand our understanding on the primary actors of standardization; that is, a study that fills in the remaining gaps left by this study and discovers the missing actors. Fourth, we briefly discussed the interplay among actors; however, our discussion was limited to actor-specific influences on standards. For this reason, the overall influence based on the interplay of these factors on the market and how various actors influence each other need to be investigated further, in order to elucidate the symbiotic relationships between actors. We hope that this study will enhance understanding of the primary actors of standardization, including providing a better understanding of motives, the strategic importance of standardization, the behaviors of participants, and how they influence each other.

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