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Research Article

Evolution of Enterprise Competitiveness in Multiplex Networks of Standards: A Case Study of the Communication Industry in China

Fangyu Chen and Yongchang Wei

Institute of Operations Management and System Engineering, School of Business Administration, Zhongnan University of Economics and Law, Wuhan 430073, China

Correspondence should be addressed to Yongchang Wei; ivanwilts306@163.com

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Competing to set industry standards is a strategic option to a variety of industries. This paper aims to investigate the role of standard drafting in the evolution of enterprises' competitiveness in multiplex networks of standards. Specifically, network-based measurements are deliberately designed to evaluate the enterprises participation, contribution, and collaboration in drafting standards. By demonstrating the development of the standard system in China's communication industry, the effectiveness of our measurement system is verified. Accompanied by empirical observation, the data analysis shows that the relevant governmental agencies dominate the whole standard system; basic-technology providers acquire greater competitiveness through participating in the standards drafting than the other kinds of enterprises. Finally, the corresponding managerial suggestions are offered.

1. Introduction

Many studies have confirmed the important roles of standards in supporting technological innovation [1–4]. In addition, it is widely accepted in China's business environments that third-tier enterprises manufacture products, their second-tier counterparts forge brands, but leading first-tier enterprises set industrial standards. Thus, we gauge enterprise can gain competitiveness through determining not only the extent to which a given company is involved in drafting standards, but also the significance of such standards. However, there is no literature in ascertaining how to evaluate the enterprises' involvement in standard setting. Fortunately, standards encompass the information such as cited standards, implementation date, and drafters. Two implications follow here. Firstly, to assess the significance of the standards, we may analyse the mutual referencing between standards in a manner analogous to analysing the networks of patents and of literatures [5–9]. Secondly, through examining the standard-drafting by drafters and the collaboration between drafters, we may underline their involvement to the entire standards system. Such analyses, coupled with experiential observation of the drafters' position in the industry, enable us to determine whether enterprises can improve their competitiveness through involvement in drafting industrial standards.

Referencing to a given set of standards reflects the recognition and inheritance of the knowledge in the literature thus referenced. Referencing to standards, citing papers, and citing patents all can demonstrate the relevance of the knowledge, but each has different characteristics. The citation of papers encompasses not only the authors' recognition and inheritance of their predecessors' knowledge, but possibly also critiques of such knowledge; there may additionally be such "referencing noise" [10, 11] as misquotation, referential bias, and intentional self-citation. The citation of patents refers to the adoption of relevant technological predecessors (known as the "prior art") by applicants of new patents, but similar "referencing noise" exists [8, 12]. This may be exemplified by Company A's filing for a new patent based on examining another patent owned by a competitor. The Company A may tend to avoid citing the examined patent and instead seek other bodies' literature, in order to minimize the risks of copyright infringement or failure in patent filing. Such a propensity will culminate in the lack of citation between two technically most related patents. In this regard, the decision by a standardization organization in referencing a given set of standards implies its selection of the standards from its peers. In the standards-drafting process, the standards technical committee (TC) makes a coordinated, unified, and systematic demonstration of the referential relationship of the standards, thus effectively circumventing the aforesaid problem. The citation of a given set of standards by another set most directly and measurably reflects its adoption and recognition: the higher frequency of a standard being cited illustrates its wider adoption and recognition, which in turn demonstrates both its higher status in the system and the greater contribution of the drafter to establishing the standards system. Co-authorship of standards reflects the collective contributions of multiple drafters to composing them. As with papers and patents, co-authorship of standards reflects collaboration between authors; such co-authorship also implies that the drafters' interests in this area have been agreed by consensus. Greater involvement in drafting and co-authorship translates into greater potential benefits for the drafters through establishing standards, thereby improving their competitiveness. Against this backdrop, despite rich findings on networks of patents and of papers, research into citation networks of standards and the accompanying co-authorships is still lacking.

Challenges exist in identifying key standards and in measuring the drafters' impact on formulating standards. The first concerns the dynamism of the standards system. For scholarly papers, they will upon publication become permanently available in the network of citations. For patents, despite their terms of legal protection, they nonetheless will upon expiry of such terms enter into the public domain. For standards, they are assigned a defined life cycle: from their implementation to their substitution or abolition, and finally to their removal from the system altogether. In the meantime, the drafters constantly undergo organizational changes such as mergers and reorganizations. In sum, the structure and function of the whole standards system evolve continuously. The second challenge concerns the heterogeneity of elements constituting the standards system. On the one hand, the system consists of two different elements: the standards and the drafters. On the other hand, the relationship between the elements is threefold, as it includes citation between standards, drafting between standards and drafters, and the co-authorship between drafters. These challenges have hindered the modelling and analysis of citation and co-authorship networks of standards.

Rapid development in network science has yielded rich theoretical grounds and methods to the research into the aforesaid problem [13–15]. Therefore, through employing the network theory, this paper constructs a dynamic multiplex network model that considers the interactions between the standards and drafters, with focuses on the dynamism and heterogeneity of standards systems. With the communication industry in China as an example, this proposed model is used for: analysing the evolution of standards systems; determining the significance of standards and the contribution of drafters to constructing such systems; demonstrating whether enterprises can improve their competitiveness through involvement in formulating standards; elucidating the different roles of the government and enterprises in formulating standards; and providing corresponding managerial advice on establishing standards systems and on improving enterprises competitiveness.

The academic contributions of this paper follow hereafter. It proposes a general dynamic multiplex standards network model, which can be used for analysing the structural evolution of standards systems in other different industries. Secondly, based on the aforesaid model, a set of measurements is designed for evaluating enterprises' involvement in standards setting, including the extents of such aspects as participation, contribution, cooperation, co-authorship. Thirdly, the paper showcases the development of the standards system in China's communication industry in recent decades from the perspectives of time and of technology, and verifies the effectiveness of the measurement system. Lastly, critical conclusions are drawn based on the results of data analysis—such as the relevant governmental agencies predominating the whole network, and the basic-technology providers acquiring greater competitiveness through participating in the formulating standards than the terminal-equipment manufacturers; the corresponding managerial suggestions are offered.

The rest of this article is organized as follows. Section 2 provides an literature review on the citation networks, co-authorship networks, and standards and enterprises competitiveness. Section 3 not only introduces the evaluative metrics for the standard network selected in this paper and evaluative measurement designs for the drafters involvement, but also outlines the construction of dynamic multiplex standard networks. Section 4, with China's communication industry as an example, not only charts the industry's developmental course through the time and technology mode, but also attests to the rationality of the network model and of the related indicators for evaluation. Some managerial suggestions are also yielded. Finally, conclusions are provided in Section 5.

2. Literature Review

This paper elucidates the dynamic multiplex network (formed by the citation of standards and by the co-authorship between drafters) in the communication industry. Our aims are threefold: to identify the key standards; to assess the drafters' involvement, and to chart the industry's developmental course through analysing the evolution of the network. The literature relevant to this study mainly concerns analysing networks of citations and of co-authorship and the relationship between enterprises' competitiveness and standards. The following is a review of these three areas:

2.1. Analysis of Citation Networks. The citation networks embody the literature—including papers, patents, standards, etc.—and the interconnected referencing. The increasing profusion of the literature in publication not only enriches data in such networks, but also complicates their structures. Through studying the structure and evolution of citation networks, we can effectively evaluate the importance of academic research results, predict the developmental direction of science and technology, and reveal correlations between bodies of knowledge.

Early research into the citation of papers was limited to only simple indicators. For instance, Garfield [16] first suggested evaluating papers based on the frequency of citations. In addition, in 1976, the US Institute for Scientific Information in its Journal Citation Reports proposed evaluating journals based on impact factors [17]. However, a frequently-cited paper may not necessarily be an influential one. In October 2014, Nature published two consecutive papers on the phenomenon of highly-cited papers [18, 19]: the authors found that the most highly-cited papers were not necessarily the most influential or important papers—the papers of many Nobel laureates had not entered the list of such papers. PageRank, an algorithm invented by Google to evaluate the importance of web pages, has been suggested to evaluate the significance of papers [20]. With the development of the complex network theory, some structural metrics have been used widely to evaluate the significance of papers, such as the degree centrality and betweenness centrality [6, 5, 21].

The publication of scientific articles reflect the trend of development in science, whereas the filing of patents, being an important carrier of technology, forms a requisite source of information for reference in technological innovation of enterprises. For patent citation networks, analysis of the evolution of their structure and function forms the basis underlying the evaluation, selection, and prediction for patent technologies; in addition, such analysis enables research into the transfer and diffusion of knowledge between technical organizations and fields [22–25]. Against this background, Narin [26] pioneered the application of the analysis of paper-citing to patents, thus paving the path for the new field of quantifying patent literature. In their analysis of the trend of patent citation and the mode of knowledge flow, Hu and Jaffe [27] found that the flow of technical knowledge between entities was positively correlated to technological proximity and to geographical proximity. Choe et al. [7], based on data of patent citation, studied the flow of knowledge among organizations and the structural characteristics of the network. Although patents are closely linked to corporate innovation, it is noteworthy that not all technologies can be patented, given factors such as the degree of their innovation and strategic decisions of the enterprise [8, 9, 12, 28, 29].

2.2. Analysis of the Co-Authorship Networks. In the citation networks, each literature originates from one or more authors; accordingly, the citation and drafting of the literature can be further mapped into the co-authorships and communications between authors, thereby forming co-authorship networks. Network analysis has been applied to evaluating the statuses of scholars, academic groups, and research institutions in the academic circles [15, 30]. Such application exerts a critical influence on decision-making such as recruiting talents and allocating resources. Price [31] published the first study on the co-authorship networks, thereby pioneering the research into this hitherto uncharted area. Subsequently, scholars have studied at the microscopic (individuals), mesoscopic (institutions) and macroscopic (countries) levels [30, 32, 33] into technological cooperation in areas as diverse as sociology, medicine, mathematics, intelligence and information science, materials science, etc. [6, 15, 34–37]. In establishing a network of research co-authorship covering physics, biomedicine, and computer science, Newman [13] has reported numerous findings: that the network had a "small-world" phenomenon [14]; that the network in each field contains a huge subgroup; and that the networks of different disciplines possess different characteristics. Hou et al. [35] investigated the structural characteristics of the co-authorship networks at a more microscopic level, including the network density and centrality, areas of cooperation between different sub-networks, and the centres of cooperation. White et al. [38], through examining the contact mode and social distance between co-authors, not only analysed the role of team cooperation in scientific production, but also offered insights into the formation of academic teams and schools of thought. In recent years, considerable attention has been paid to research into networks of cross-disciplinary co-authorship [39–41].

2.3. Enterprise Competitiveness and Standards. Competi tiveness is a complex and multi-facet concept that has not come to one broadly accepted, which is closely related to one enterprise's profitability, productivity and market share. The existing research has focused on the impact of different factors on w, or on the comprehensive evaluation of it through a system of indicators. Numerous factors affect enterprises competitiveness: in addition to existing technical advantages [42–46], some of the literature has focused on the mode of employment [47], prices of energy [48], free-trade agreements [49], captive finance [50], venture capital [51], and intellectual capital [52]. A contentious subject concerns whether environmental protection exerts positive or negative influences on enterprises competitiveness [53–56]. Cheng and Yiu [57] proposed four recommendations, including strengthening intellectual-property protection and implementing educational reforms, to enhance the competitiveness of Chinese enterprises. Goncalves et al. [58] proposed a model for assessing the competitiveness of small-and-medium-sized (SMEs) based on integrating cognitive mapping and the measuring attractiveness by a categorical-based evaluation technique (MACBETH). Despite their managerial suggestions on augmenting enterprises competitiveness, these studies have mostly been static and included few sample enterprises, leading to difficulty in reaching dynamic and universal conclusions.

Additionally, they have overlooked the role of standardization in promoting innovation and enhancing competitiveness [42, 59]. A common thread linking dominant design, appropriability and complementarity is the presence of standards [60]. Standards play a special role in shaping industry architecture, in part because they facilitate specialization and modularization [61]. For instance, if a company wants to get into the cell phone business, it can now buy the relevant chips sets from a company like Qualcomm. In these settings, rents flow to the suppliers of specialized chips that create lock-in via compatibility or control over standards [62]. Competition to own the standard (or the dominant design) becomes, in some ways, competition for the market [59]. Furthermore, standards setting bodies are usually willing to forms cooperation networks to access additional technology and market knowledge, to create a minimum (critical) size for a project, and to share innovation costs and risks [63]. Therefore, this paper argues that enterprises' competitiveness is closely related to the involvement of enterprises in drafting critical standards and the co-authorship in such drafting [6].

In summary, despite rich findings on citation networks of patents and papers, research into standard citations and the accompanying co-authorships is still lacking. Additionally, in the existing research into enterprises competitiveness, little consideration has been given to how the involvement in standards-drafting may boost competitiveness. As aforesaid, industrial standards are often the fruition of complete consultation and repeated practice of the relevant TC, which are associated with an excellent systematic nature, coordination, and practicality. Standards' citations and the co-authorships reflect the inheritance and development of experience, technology and knowledge in a field. Collectively, these considerations motivate us to undertake this research.

3. Theoretical Framework

3.1. Dynamic Multiplex Network Model. Given the heterogeneity and dynamic nature of the standards system, this paper considers a dynamic multiplex network with two layers: the *standard citation layer* that reflects the citation relationship between standards, and the *drafter cooperation layer* that reflects the cooperation in drafting. The former comprises m standards, while the latter comprises n drafters, which could be governmental agencies, enterprises, etc. In this study, we only focus on enterprises' involvement because we empirically observed that enterprises dominantly affect the communications industry. Consequently, the entire standard network, which includes two kinds of node sets and three kinds of edge sets, is represented by:

$$\mathcal{G} = \left\{\mathcal{N}_s^t, \mathcal{N}_d^t, \mathcal{E}_{citation}^t, \mathcal{E}_{drafting}^t, \mathcal{E}_{co-authorship}^t\right\}, \quad t \in T = \{t_0, t_1, \ldots, t_k, \ldots\}, \tag{1}$$

where $\mathcal{N}_s^t = \{s_1^t, s_2^t, \ldots, s_m^t\}$ denotes the node set of valid standards at time t; $\mathcal{N}_d^t = \{d_1^t, d_2^t, \ldots, d_n^t\}$ denotes the node set of drafters corresponding to those valid standards at time t; $\mathcal{E}_{citation}^t = \left\{\left\langle s_i^t, s_j^t\right\rangle \middle| s_i^t, s_j^t \in \mathcal{N}_s^t, i \neq j\right\}$ denotes the edge set of citations; $\mathcal{E}_{drafting}^t = \left\{\left\langle s_i^t, d_j^t\right\rangle \middle| s_i^t \in \mathcal{N}_s^t, d_j^t \in \mathcal{N}_d^t\right\}$ denotes the edge set of drafting relationships; $\mathcal{E}_{co-authorship}^t = \left\{\left\langle d_i^t, d_j^t\right\rangle \middle| d_i^t, d_j^t \in \mathcal{N}_d^t\right\}$ denotes the edge set of co-authorships. If the standard s_i^t is cited by the standard s_j^t, then $\left\langle s_i^t, s_j^t\right\rangle \in \mathcal{E}_{citation}^t$. Between the *standard citation layer* and *drafter cooperation layer*, if the standard s_i^t is drafted by the drafter d_j^t, then $\left\langle s_i^t, d_j^t\right\rangle \in \mathcal{E}_{drafting}^t$; if the standard s_k^t is drafted jointly by the drafters d_i^t and d_j^t, then $\left\langle d_i^t, d_j^t\right\rangle \in \mathcal{E}_{co-authorship}^t$. Apparently, the network is heterogeneous because it is composed of nodes and edges with distinct characteristics. Moreover, the network is dynamic because both node sets and edge sets only cover the standards and drafters that are valid at time t, leading to constant structural evolution.

Elements in the three kinds of edge sets can be defined by the matrix that characterizes the three kinds of relationships. Since the citation relationship is irreversible, the edges in $\mathcal{E}_{citation}^t$ are directed. Thus, the citation relationship between standards is characterized by an asymmetrical matrix $\mathbf{A}^t = \left[a_{ij}^t\right]_{m\times m}$, wherein:

$$a_{ij}^t = \begin{cases} 1, & \text{if standard } s_i^t \text{ is cited by standard } s_j^t; \\ 0, & \text{otherwise.} \end{cases} \tag{2}$$

Accordingly, the drafting relationship between m standards and n drafters is directed, which constitutes a matrix $\mathbf{B}^t = \left[b_{ij}^t\right]_{m\times n}$, wherein:

$$b_{ij}^t = \begin{cases} 1, & \text{if standard } s_i^t \text{ is drafted by drafter } d_j^t; \\ 0, & \text{otherwise.} \end{cases} \tag{3}$$

Given the possibility of their multiple occurrences, co-authorships between drafters can be expressed by a weighted matrix $\mathbf{C}^t = \left[c_{ij}^t\right]_{n\times n}$, where the weight of the co-authorship between drafters d_i^t and d_j^t, c_{ij}^t is represented by

$$c_{ij}^t = \sum_{k=1}^{m} b_{ki}^t b_{kj}^t. \tag{4}$$

When $b_{ki}^t = 1$ and $b_{kj}^t = 1$, it is implied that drafters d_i^t and d_j^t have jointly drafted the standard s_k^t. Thus, the c_{ij}^t is determined by the number of standards that are jointly drafted by d_i^t and d_j^t.

Based on the above definitions, the dynamic multiplex network model can be constructed, as shown in Figure 1.

3.2. Metrics of Dynamic Multiplex Standard Network. Prior to evaluating drafters' involvement, we will firstly evaluate the significance of each standard with the out-degree of standards in the standard citation layer, which is represented by,

$$D_o\left(s_i^t\right) = \sum_{j=1}^{m} a_{ij}^t. \tag{5}$$

We select the out-degree to for two reasons. Firstly, although a lot of topological metrics, e.g., betweenness centrality and clustering coefficient, are available in measuring the significance of nodes, the most direct one is the out-degree of standards [13, 15], which is the frequency of citations. Actually, the citation count is the most frequently used metric in bibliometric analysis [16]. Secondly, this study aims at evaluating the drafters' involvement; the computational simplicity of out-degree facilitates the real application.

As aforesaid, competitiveness of an enterprise is closely related to its involvement in standards setting. Moreover, this involvement is an abstractive concept, which is intrinsically

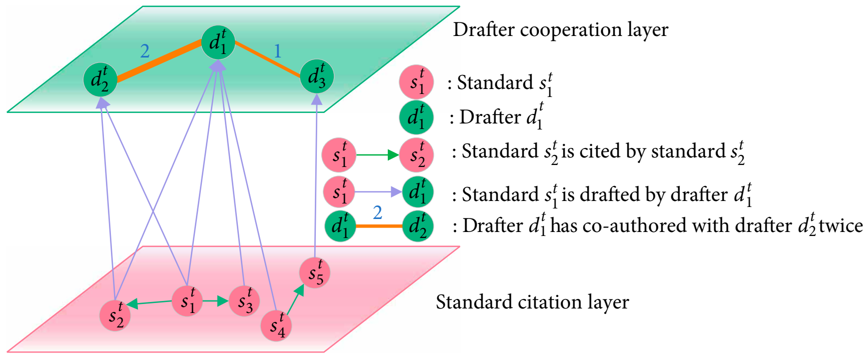


Figure 1: An illustration of dynamic standards network at time t.

multi-dimensional. Based on our network model, we can evaluate each enterprise's involvement with a measurement system with four dimensions: *participation degree*, *contribution degree*, *cooperation degree*, and *co-authorship degree*. Firstly, we can measure the significance of each enterprise by the number of its drafted standards, namely, *participation degree*. However, the *participation degree* disregards the quality or significance of standards, which motivates us to design the measurement of *contribution degree* by considering each standard's significance based on *participation degree*, as measured by the out-degree defined in (1). Secondly, cooperation between institutions also plays an essential role in promoting information exchange and knowledge communication. In this study, each enterprise's performance on cooperation is quantified by two aspects: cooperation width and cooperation depth, correspond to *cooperation degree*, and *co-authorship degree*, respectively. *Cooperation degree* of a drafter is determined by the number of its partners in drafting standards jointly, while *co-authorship degree* of each drafter is mainly determined by the number of cooperation times quantified by c_{ij}^t. The four measurements are subsequently defined as follows:

(1) *Participation degree*

The *participation degree* indicates the number of all standards whose drafting the drafter, d_j^t, has participated in, as defined by

$$D_p\left(d_j^t\right) = \sum_{i=1}^{m} b_{ij}^t. \tag{6}$$

A greater *participation degree* of the drafter, d_j^t, suggests a greater number of standards drafted by it.

(2) *Contribution degree*

The *contribution degree* indicates the number of citations of all drafted standards by the drafter, d_j^t, as defined by

$$D_{con}\left(d_j^t\right) = \sum_{i=1}^{m}\left(b_{ij}^t \sum_{k=1}^{m} a_{ki}^t\right). \tag{7}$$

A greater *contribution degree* of the drafter, d_j^t, suggests the greater impact of those standards drafted by it on other standards.

(3) *Cooperation degree*

The *cooperation degree* indicates the number of drafters with whom the drafter, d_j^t, has cooperated, at time t, as defined by

$$D_{coo}\left(d_j^t\right) = \left|\mathscr{C}_j^{\prime t}\right|, \tag{8}$$

where $C_j^{\prime t} = \left\{c_{ji}^t \neq 0 \,\middle|\, i = 1, 2, \ldots, n\right\}$. A greater *cooperation degree* associated with the drafter, d_j^t, suggests its greater number of collaborators.

(4) *Co-authorship degree*

The *co-authorship degree* of the drafter d_j^t represents the number of all the co-authorship times with other drafters, as defined by

$$D_{coa}\left(d_j^t\right) = \sum_{i=1}^{n} c_{ji}^t. \tag{9}$$

A greater *co-authorship degree* associated with the drafter, d_j^t, suggests its greater willingness to adopt co-authorship in standards-drafting.

Finally, we select the numbers of nodes and of edges of the network as the network-level indicators to describe the dynamic evolution of the entire standards system. The number of nodes reflects the scale of the network. To distinguish between different types of nodes, we compute the numbers of standards, indicated as $m = \left|\mathscr{N}_s^t\right|$, and of drafters, indicated as $n = \left|\mathscr{N}_d^t\right|$, at time t. The number of standards nodes will rise because of the implementation of standards and decline because of their abolition, whereas the number of drafters' nodes will rise because of the participation of their new counterparts in standards-setting and decline because of institutional restructuring or mergers. On the other hand, the number of edges reflects the number of connections between nodes; for the standards network, computations are made at time t according to the edges of citation, of drafting, and of co-authorship, as determined by the formulas $\left|\mathscr{E}_{citation}^t\right|$, $\left|\mathscr{E}_{drafting}^t\right|$, and $\left|\mathscr{E}_{co-authorship}^t\right|$.

3.3. Establishing and Evaluating the Standards Network. After the architecture of the network and evaluation measurements are designed, the corresponding standard network can be generated based on our data collected from publicized web sites. The process is illustrated in Figure 2, which offers two

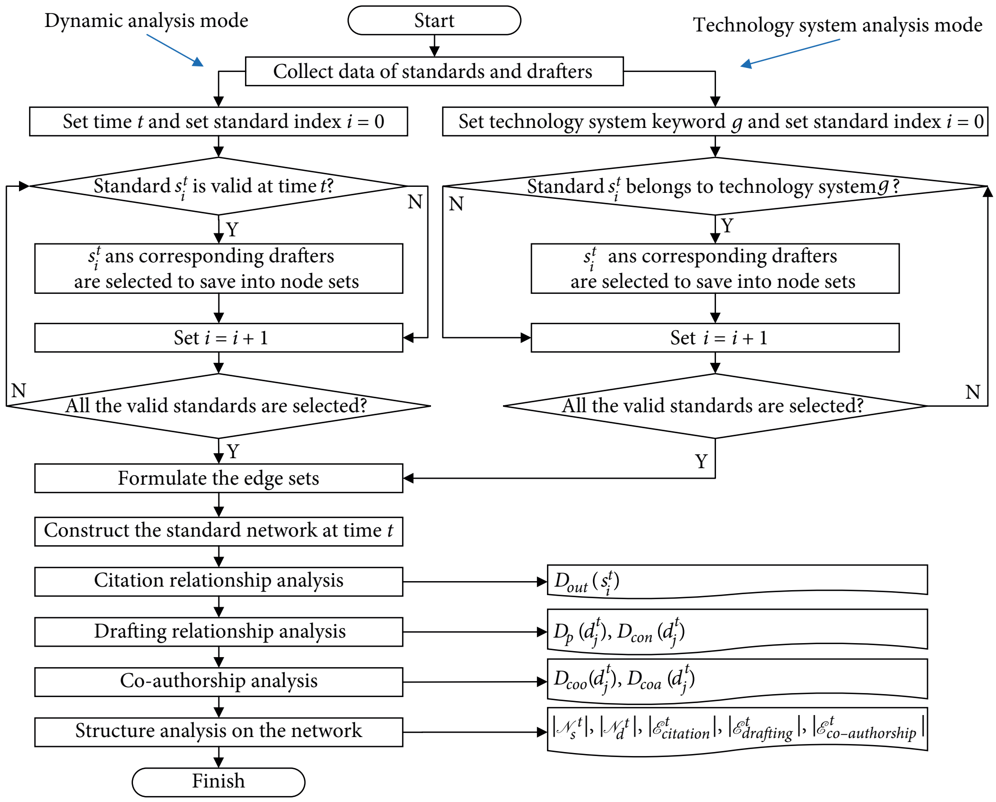


FIGURE 2: Flowchart depicting the construction of network and computation of indicators.

analysis modes: dynamic analysis mode and technology system analysis mode. The dynamic analysis mode begins with the screening of data of the standards and drafters at a pre-set time; only the standards in use and their corresponding drafters are retained. The technology system analysis mode screens the data by a specific keyword of technology, such as GSM, and retains the related standards and drafters. Firstly, considering the standards nodes and the citation relationship between them, we can determine the out-degree of the standards. Secondly, considering the drafting relationship between the standards and drafters, we can compute not only the drafters' *participation degree*, but also the *contribution degree*. Thirdly, considering the cooperative relationship between the drafters, we can compute the drafters' *cooperation degree* and *co-authorship degree*. Finally, the overall characteristics of the standards network at time t is analysed.

4. Case Study

4.1. Sources of Data and Processing. Taking China's communications industry as the case study, this paper considers that, in a given domain, the standards may cite their counterparts from other areas or international standards during their drafting process, and may also in turn be cited by standards in other domains; accordingly, there is a need to limit the scope of the standards thus considered. The China Communications Standards Association is the main nonprofit corporate body in communication technology that governs standardization and standards-formulation in China's communications industry, under which are 10 technical committees and 5 ad-hoc task forces. The standards under its management are largely categorized as telecommunications according to the Chinese classification, for which the prefixes are mostly "YD". Therefore, we limit the standards in our study to those under the purview of the Association. Through web crawlers, we have acquired a list of all the standards up to June 2018 from the website of the Association. Given possible missing information in registration, we then cross-compared multiple other standards' service websites based on the list. This enabled us to obtain attributes of the standards such as their name, technical field, keywords, implementation date, expiration date, reference standards, substitution standards, drafters, etc. Finally, our efforts yielded 4,642 valid standards signals (to which corresponding codes were assigned). Through collation of the drafters' signals on mergers and reorganizations, we filtered 1,036 drafters' signals (to which corresponding codes were assigned), alongside 8,266 reference signals, 10,754 co-authorship signals and 17,620 drafting signals.

To outline the dynamic evolution of the standards network, we partitioned the development of China's communications industry into five stages (before 1997, 1998–2002, 2003–2007, 2008–2012, and after 2013), thereby forming five time points: 1997, 2002, 2007, 2012, and 2017. The rationale underlying such partitioning was that China's communication standards system was not yet mature before 1997; this was followed by five-year intervals, with the more significant years being 2002, 2008, and 2013, which respectively corresponded

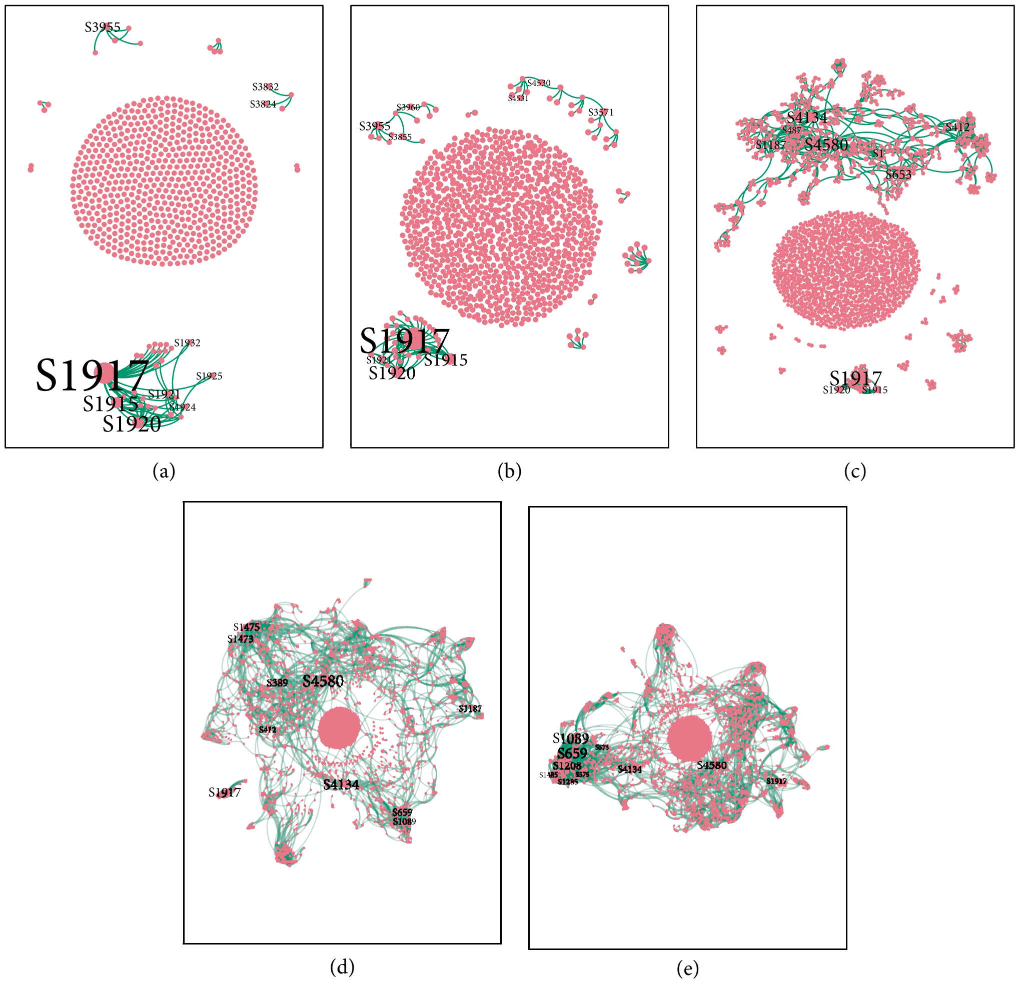


Figure 3: The sub-networks of citation in different stages. (a) 1997, (b) 2002, (c) 2007, (d) 2012, (e) 2017.

to the commercial application of 2G, 3G, and 4G technology in China's mobile-communications industry. The partitioning charts the evolution of the standards system in tandem with the development of the industry. In addition, apart from mobile communications, the standards system encompasses optical-fiber communications, construction of telecommunication infrastructures, and standards of other areas. To analyse the different mobile-communication technologies in China's establishment of standards system, we determine from the standards system a list of the relevant technical standards (a network of six standards sub-system)—GSM, CDMA, WCDMA, TD-SCDMA, CDMA2000, and LTE—and the accompanying indicators.

4.2. Findings

4.2.1. Dynamic Analysis of the Overall Network.

(1) 1997: In 1993, China began testing the commercial application of second-generation communication technology. Prior to this, most mobile communications in China used FDMA-based analog communication technology, and more users were using landlines.

To delineate the structural characteristics of different relationships in the standard network, three sub-networks—each of which respectively considers only the citation relationship, drafting relationship, and co-authorship—can be constructed. They can be defined by:

$$\begin{aligned} &\mathscr{G}_{citation} = \left\{\mathscr{N}_s^t, \mathscr{N}_d^t, \mathscr{E}_{citation}^t\right\}, \mathscr{G}_{citation} \subseteq \mathscr{G}, \\ &\mathscr{G}_{drafting} = \left\{\mathscr{N}_s^t, \mathscr{N}_d^t, \mathscr{E}_{drafting}^t\right\}, \mathscr{G}_{drafting} \subseteq \mathscr{G}, \\ &\text{and} \quad \mathscr{G}_{co\text{-}authorship} = \left\{\mathscr{N}_d^t, \mathscr{E}_{co\text{-}authorship}^t\right\}, \mathscr{G}_{co\text{-}authorship} \subseteq \mathscr{G}. \end{aligned} \tag{10}$$

In sub-network of citation (Figure 3(a)), the S1917 represents the most important standard, as shown in Table 1. This standard stipulates specifications for components used in the construction of overhead communication lines. This implies that China's main means of communication has not yet transitioned to the digital mobile communications as of 1997. In the end of 1997, the number of fixed-line users reaching 110 million, while mobile phone users have just exceeded 10 million. For information on the standards referred to herein, please refer to Appendix A. In the sub-networks of drafting relationship (Figure 4(a)) and of co-authorship (Figure 5(a)), we can evaluate the *participation degree*, *contribution degree*, *cooperation degree*, and *co-authorship degree* of each drafter. As the standards-citation is insufficient, only eight drafters have valid values in *contribution degree*. As shown in Table 1, the majority of the top ten are research institutes and

Table 1: The top ten standards and drafters in high indicators till 1997.

	Out degree		Participation degree		Contribution degree		Cooperation degree		Co-authorship degree	
Rank	s_i^t	$D_o(s_i^t)$	d_j^t	$D_p(d_j^t)$	d_j^t	$D_{con}(d_j^t)$	d_j^t	$D_{coo}(d_j^t)$	d_j^t	$D_{coa}(d_j^t)$
1	S1917	28	D3	179	D10	62	D3	9	D10	63
2	S1920	11	D10	83	D501	60	D10	7	D501	58
3	S1915	10	D4	52	D502	60	D334	4	D502	58
4	S3955	4	D1021	48	D1021	5	D4	4	D3	17
5	S1921	3	D135	43	D3	5	D1035	3	D135	5
6	S1925	1	D1031	35	D381	1	D501	2	D334	4
7	S1924	1	D16	32	D15	1	D502	2	D4	4
8	S1932	1	D501	29			D96	2	D96	4
9	S3832	1	D502	29			D1021	2	D1035	3
10	S3824	1	D1027	18			D115	2	D1021	3

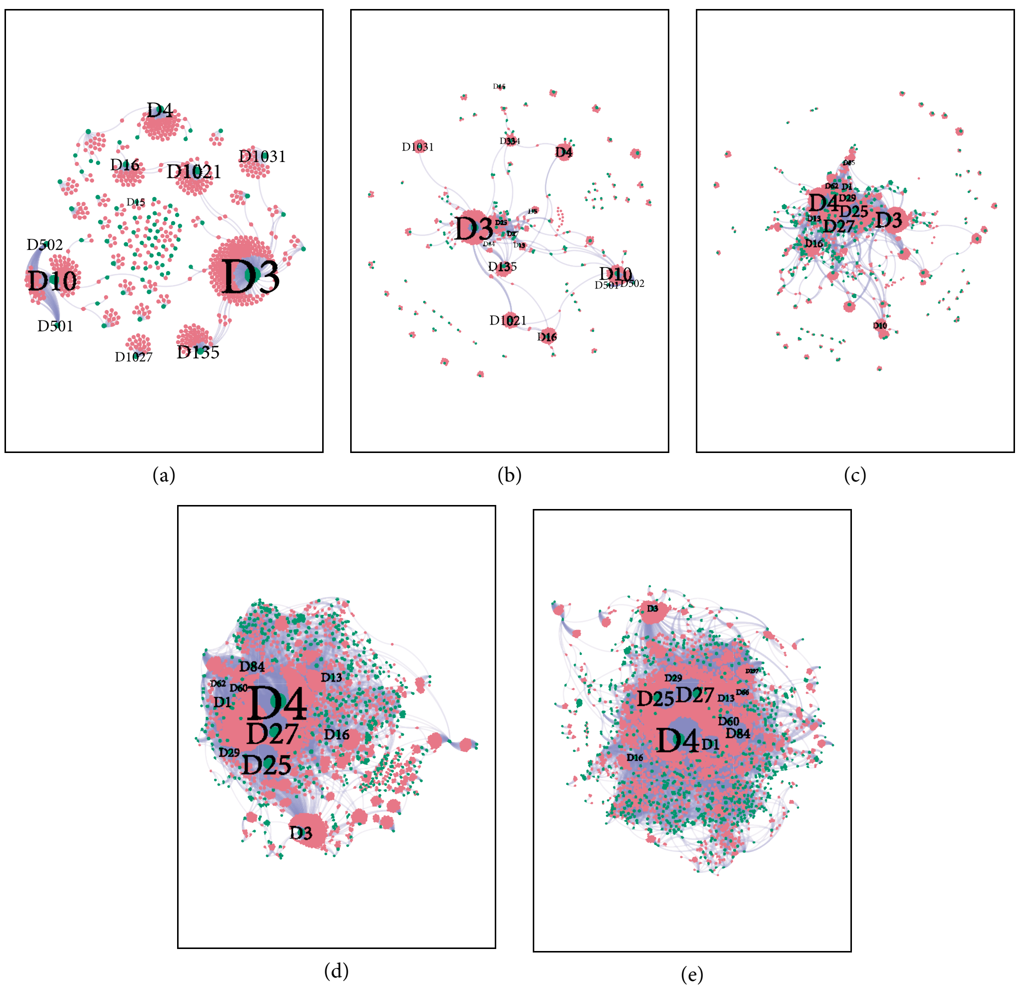
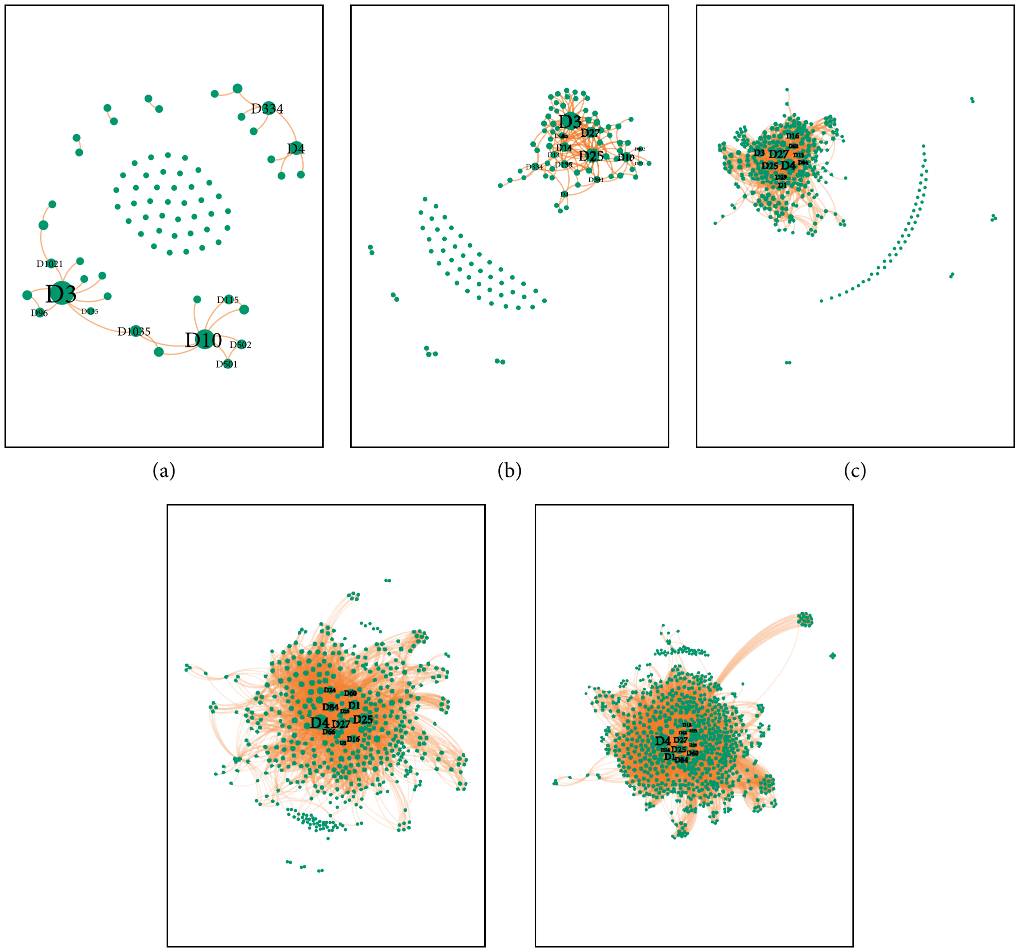


Figure 4: The sub-networks of drafting in different stages. (a) 1997, (b) 2002, (c) 2007, (d) 2012, (e) 2017.

manufacturers of communication equipment affiliated with the Ministry of Industry and Information Technology (MIIT). This suggests that, in the period leading up to 1997, standardization in China's communications industry had been dominated by governmental agencies, with relatively low participation of enterprises. For the main drafters' and their corresponding details, please refer to Appendix B. In this first stage, 658 standards were collated, alongside 74 drafters, 75 pairs of citation relationships, 33 pairs of co-authorships, and 749 pairs of drafting relationships, all of which constituted the overall network shown in Figure 6(a).

(2) 2002: The year 1998 witnessed the commercial application of 2G digital mobile-communications technology. In 2001, the use of analog mobile phones was completely phased

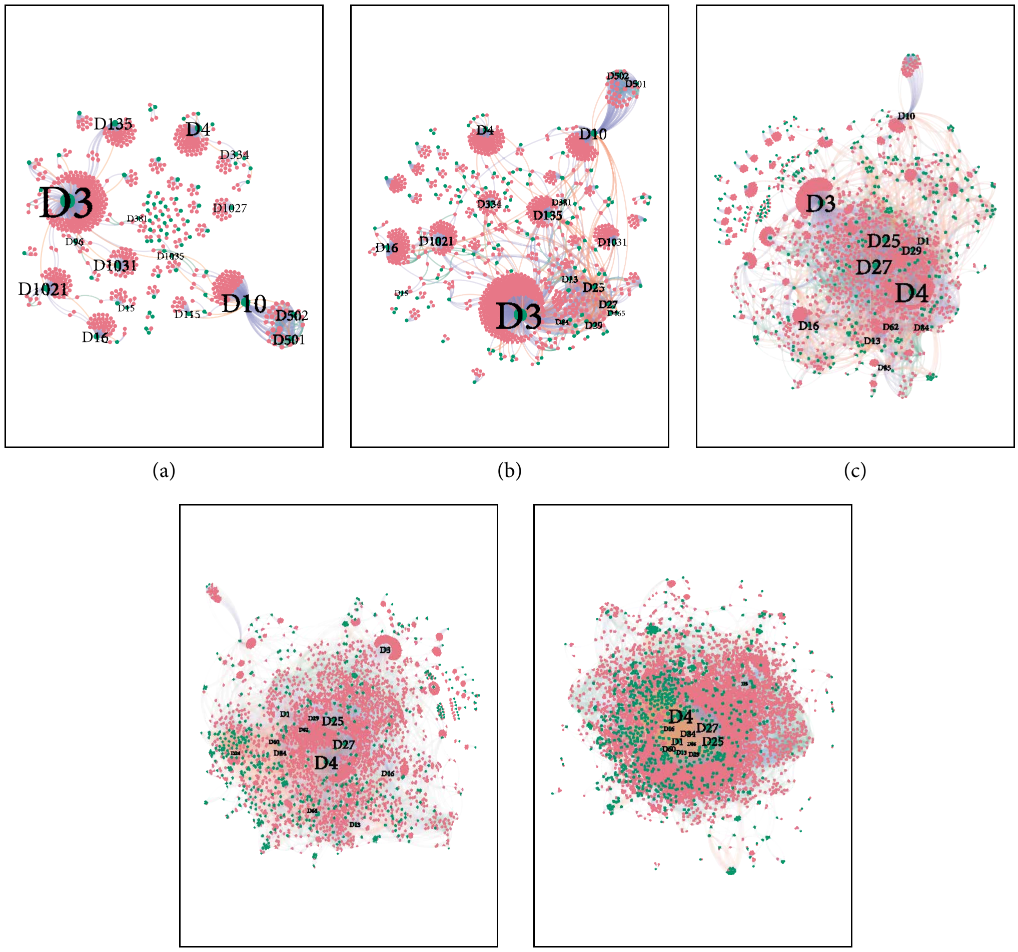


(a) (b) (c) (d) (e)

FIGURE 5: The sub-networks of co-authorship in different stages. (a) 1997, (b) 2002, (c) 2007, (d) 2012, (e) 2017.

out of the market. In the next year, China's mobile-phone numbers rose from 10 digits to 11, mobile-phone users reached 150 million, and fixed-line users persisted at 200 million. In the sub-network of citation (Figure 3(b)), S1917 remained as the standard with the greatest out-degree in the entire citation network, as likewise indicated in Table 2. Given the little difference between mobile-phone users and fixed-line users, despite the expanded volume in the standards system, the standards relating to fixed-line users remained as the core of the system. In the sub-networks of drafting (Figure 4(b)) and of co-authorship (Figure 5(b)), the greatest change was the beginning of a more pronounced increase in the proportion of enterprises among the drafters, especially Huawei and ZTE, as suggested in Table 2. Although the number of standards whose drafting involved them was not superior to that of the government, the two companies had performed well in cooperating with the relevant governmental agencies. In 2002, 1033 standards nodes were collected, alongside 122 drafters, 114 pairs of citation relationships, 167 pairs of co-authorships, and 1286 pairs of drafting relationships, all of which constituted the overall network shown in Figure 6(b). Within 1998–2002, the numbers of standards and drafters almost doubled, in tandem with evident development in the standards system. Of note, the standards in China's communications industry were still predominantly driven by governmental agencies. Despite rising enterprises participation, standards whose drafting involved enterprises had yet to become the core standards in the system.

(3) 2007: From 2003 to 2007, the 2G digital communication technology continued to expand the market. In October 2003, the number of mobile-phone subscribers reached 260 million, exceeding the number of fixed-line subscribers, while that of Internet users rose from 59.1 million in 2003 to 160 million in 2007. In sub network of citation (Figure 3(c)), although S1917 remained as the standard with the greatest out-degree of the entire citation network (as shown in Table 3), standards in other domains such as the Internet, telephones, optical-fiber communications, and mobile phones began to enter lists of highly-cited standards. This shows that, in the communications industry, the changes in the focus of the establishment of the standards system were consistent with the industrial structure changes. The 11th Five-Year plan outlines the need to build a next-generation communication network with independent intellectual property rights. In the sub-networks of drafting



(a) (b) (c) (d) (e)

FIGURE 6: The overall networks in different stages. (a) 1997, (b) 2002, (c) 2007, (d) 2012, (e) 2017.

TABLE 2: The top ten standards and drafters in high indicators till 2002.

Rank	Out degree		Participation degree		Contribution degree		Cooperation degree		Co-authorship degree	
	s_i^t	$D_o(s_i^t)$	d_j^t	$D_p(d_j^t)$	d_j^t	$D_{con}(d_j^t)$	d_j^t	$D_{coo}(d_j^t)$	d_j^t	$D_{coa}(d_j^t)$
1	S1917	28	D3	363	D10	64	D3	40	D3	145
2	S1920	11	D10	96	D502	60	D25	28	D25	110
3	S1915	10	D4	76	D501	60	D27	18	D27	77
4	S3955	5	D16	67	D3	20	D10	15	D10	71
5	S1921	3	D1021	65	D1021	13	D29	14	D29	67
6	S3571	3	D135	64	D16	9	D135	11	D501	58
7	S3855	2	D25	47	D15	3	D334	10	D502	58
8	S3960	2	D1031	40	D13	2	D381	8	D135	23
9	S4530	2	D334	33	D5	2	D13	8	D13	16
10	S4531	1	D27	29	D84	1	D4	7	D465	15

relationship (Figure 4(c)) and of co-authorship (Figure 5(c)), the proportion of enterprises among the drafters continued to rise, as shown in Table 3. The number of standards drafted by Huawei and ZTE had become on a par with that by governmental agencies, with concomitantly significant contributions. Given the emerging segmentation in the industry, other enterprises such as Datang Telecom Technology and Fiberhome Technologies, had started to assume more important positions in the standards system. At this stage, 1,975 standards nodes were collected, alongside 303 drafters, 1,130 pairs of citation relationships, 1,185 pairs of co-authorships, and 4,070 pairs of drafting relationships, all of which constituted the overall

Table 3: The top ten standards and drafters in high indicators till 2007.

Rank	Out degree s_i^t	$D_o(s_i^t)$	Participation degree d_j^t	$D_p(d_j^t)$	Contribution degree d_j^t	$D_{con}(d_j^t)$	Cooperation degree d_j^t	$D_{coo}(d_j^t)$	Co-authorship degree d_j^t	$D_{coa}(d_j^t)$
1	S1917	28	D4	577	D3	433	D4	110	D4	1174
2	S4580	22	D3	503	D25	349	D27	101	D27	1174
3	S4134	20	D27	389	D4	335	D25	80	D25	1005
4	S653	15	D25	347	D27	296	D3	74	D29	640
5	S1187	13	D29	185	D29	174	D29	64	D1	417
6	S412	13	D16	159	D62	96	D16	59	D3	385
7	S1	12	D1	97	D10	80	D1	52	D62	302
8	S1920	11	D10	97	D16	73	D13	42	D16	271
9	S1915	10	D13	93	D13	65	D84	39	D13	265
10	S487	9	D62	83	D85	63	D62	35	D84	235

Table 4: The top ten standards and drafters in high indicators till 2012.

Rank	Out degree s_i^t	$D_o(s_i^t)$	Participation degree d_j^t	$D_p(d_j^t)$	Contribution degree d_j^t	$D_{con}(d_j^t)$	Cooperation degree d_j^t	$D_{coo}(d_j^t)$	Co-authorship degree d_j^t	$D_{coa}(d_j^t)$
1	S4580	36	D4	1480	D4	1511	D4	297	D4	4481
2	S4134	31	D27	869	D27	1085	D25	204	D27	3359
3	S1917	28	D25	815	D25	905	D27	186	D25	2985
4	S1473	22	D3	474	D3	653	D1	171	D29	1794
5	S1475	22	D29	452	D29	426	D84	159	D84	1705
6	S389	22	D1	333	D84	412	D29	130	D1	1695
7	S659	21	D84	329	D13	377	D16	111	D16	1044
8	S1089	19	D16	320	D1	367	D60	110	D13	941
9	S1187	19	D13	241	D16	305	D66	109	D60	875
10	S412	17	D60	178	D62	292	D24	96	D66	743

network shown in Figure 6(c). Over this five-year period, both the numbers of standards and drafters again nearly doubled, and even showed a nearly ten-fold growth in citation relationships and in co-authorships. Based on the volume, the standards system had exhibited manifest development. The citation, co-authorship, and drafting relationships between the standards and drafters had grown closer. Enterprises participation improved further still, yielding results that occupied higher core positions in the standards system.

(4) 2012: In 2008, China Telecommunications Corporation, China Mobile, and China Unicom launched 3G commercial services based on CDMA2000, TD-SCDMA, and WCDMA respectively. Over the next five years, 3G-based smartphones began to gradually replace feature phones. Internet access services had also demonstrated rapid growth: the numbers of Internet users in China surpassed their counterparts in the United States (US) in 2008 and outnumbered the total US population in 2009. In the sub-network of citation (Figure 3(d)), the majority of the highly-cited standards were related to industries that had rapidly developed over the five years such as Internet access and mobile phones, as likewise indicated in Table 4. In the sub-networks of drafting (Figure 4(d)) and of co-authorship (Figure 5(d)), as likewise indicated in Table 4, influences exerted by research-and-development enterprises such as ZTE Corporation and Huawei in the standards system had gradually stabilised, while communication service providers, such as China Mobile, had also begun to engage in drafting standards. This was mainly because commercial applications of communications technology required the corresponding service-oriented technical standards to be in place; thus, setting such standards was obligatory for service providers. Therefore, from 2008 to 2012, service providers not only became increasingly deeply involved in the standards-formulating in China's communications industry, but also began to occupy higher core positions. At this stage, 3,057 standards nodes were collected, alongside 506 drafters, 3,084 pairs of citation relationships, 3,453 pairs of co-authorships, and 9,016 pairs of drafting relationships, all of which constituted the overall network as shown in Figure 6(d).

(5) 2017: The year 2013 witnessed China's entry into the 4G commercial era. In the sub-network of citation (Figure 3(e)), as shown in Table 5, given the proliferation of smartphones, the standards of the associated functions (such as batteries) and components were highly cited in the network. In the sub-networks of drafting (Figure 4(e)) and of co-authorship (Figure 5(e)), as shown in Table 5, it is evident

Table 5: The top ten standards and drafters in high indicators till 2017.

Rank	Out degree s_i^t	Out degree $D_o(s_i^t)$	Participation degree d_j^t	Participation degree $D_p(d_j^t)$	Contribution degree d_j^t	Contribution degree $D_{con}(d_j^t)$	Cooperation degree d_j^t	Cooperation degree $D_{coo}(d_j^t)$	Co-authorship degree d_j^t	Co-authorship degree $D_{coa}(d_j^t)$
1	S659	53	D4	2426	D4	2616	D4	553	D4	9991
2	S1089	52	D27	1428	D27	1752	D1	365	D27	7262
3	S4580	41	D25	1366	D25	1339	D25	341	D25	6747
4	S1208	39	D1	871	D84	931	D27	314	D1	4972
5	S4134	32	D84	795	D13	885	D84	301	D84	4831
6	S1917	26	D29	713	D1	759	D60	258	D29	3759
7	S1285	26	D60	653	D29	722	D29	190	D60	3746
8	S1485	24	D13	470	D3	645	D16	172	D13	2916
9	S575	21	D16	437	D66	527	D24	168	D66	2035
10	S573	21	D3	407	D297	465	D66	146	D16	1928

that the status of various types of enterprises in the entire network has stabilized. In this 3G era, given these drafters' successive considerable investments in establishing the standards system and their leading roles in the relevant domains, the 4G era has rightly come to determine those standards. It is expected that this situation will persist for long in the coming 5G era. At this stage, 4,132 standards nodes were collected, alongside 775 drafters, 4,324 pairs of citation relationships, 7,347 pairs of co-authorships, and 16,691 pairs of drafting relationships, all of which constituted the overall network shown in Figure 6(e). As 4G is still in the commercial phase, its related standards are still multiplying. No upsurge was observed in the numbers of standards and drafters relative to the 3G era; however, co-authorships notably doubled, suggesting that, in the development of 4G-related standards, co-authorship has grown to be the drafters' default option.

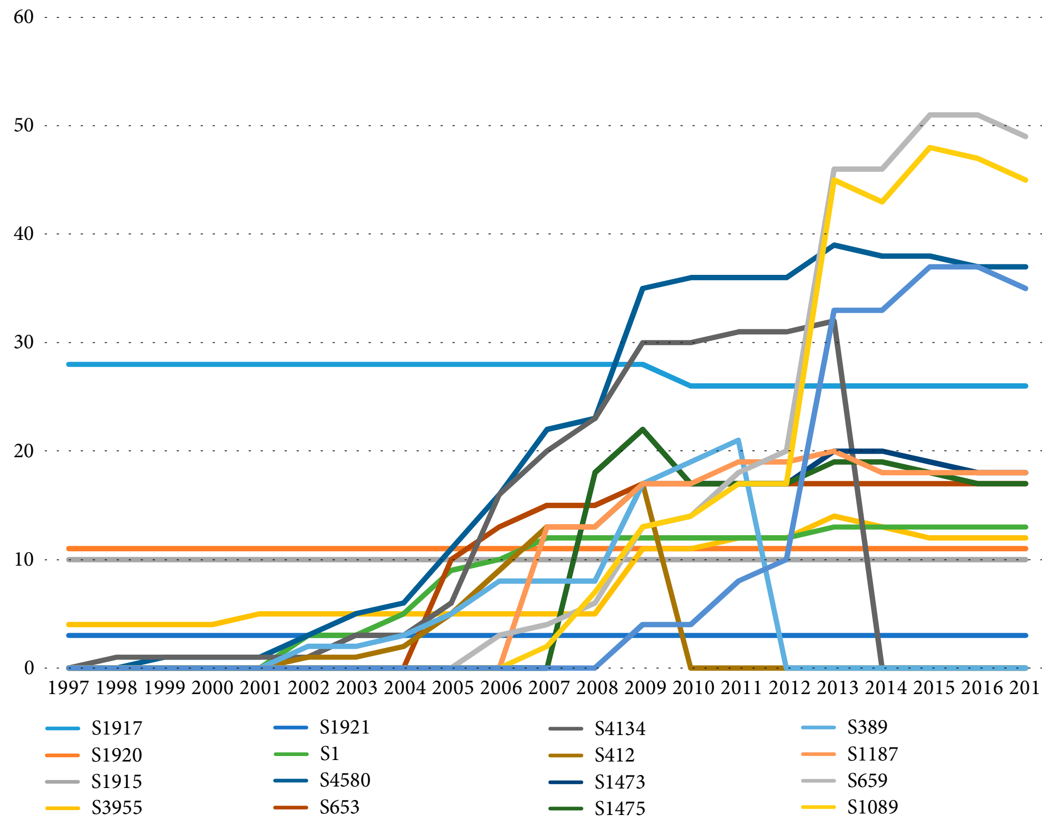
The time series of the highly-cited standards (Figure 7(a)) reveals two findings. The abolition of standards leads to a diminished out-degree of the standards; conversely, the upgrading of communication technology leads to an augmented out-degree of those standards associated with the new technologies. Depicted in Figures 7(b)–7(e) are the time-series characterising the *participation degree*, *contribution degree*, *cooperation degree*, and *co-authorship degree*. Herein, in establishing the standards system, the core drafters fluctuated with the development of communication technology. This cemented the superior positions of Huawei, ZTE Corporation, the three communication service providers (China Telecommunications Corporation, China Mobile, and China Unicom), and other drafters. In the meantime, although the Telecommunications Research Institute (as the governmental representative of the MIIT) has led the drafting, the role of enterprises in the development of China's communications industry has grown progressively critical. As judged from the dynamic change of the network metrics (Figure 7(f)), the scale of the network of communication standards exhibit a yearly increasing trend and is closely connected with the upgrading of communication technology. This is especially so between 2012 and 2013, when the numerous implemented new standards laid the cornerstone for the launch of 4G and its related technologies. This this same stage also saw the evident accelerated growth of the network metrics. This phenomenon was likewise noted during the promotion of 3G between 2008 and 2009.

4.2.2. Analysis of Standard Networks for Technology Systems. The dynamic analysis of the overall network of standards offers insights into the whole development of China's communications industry. However, technological systems comprising the industry's standards are too multitudinous. To investigate the relationship between the establishment of standards system for a specific technology and enterprises' involvement, we disregarded the time factor; instead, we used specific technical terminologies as keywords. We then selected from the system a series of technical standards related to the mobile-phone communication technology for analysis, as follows.

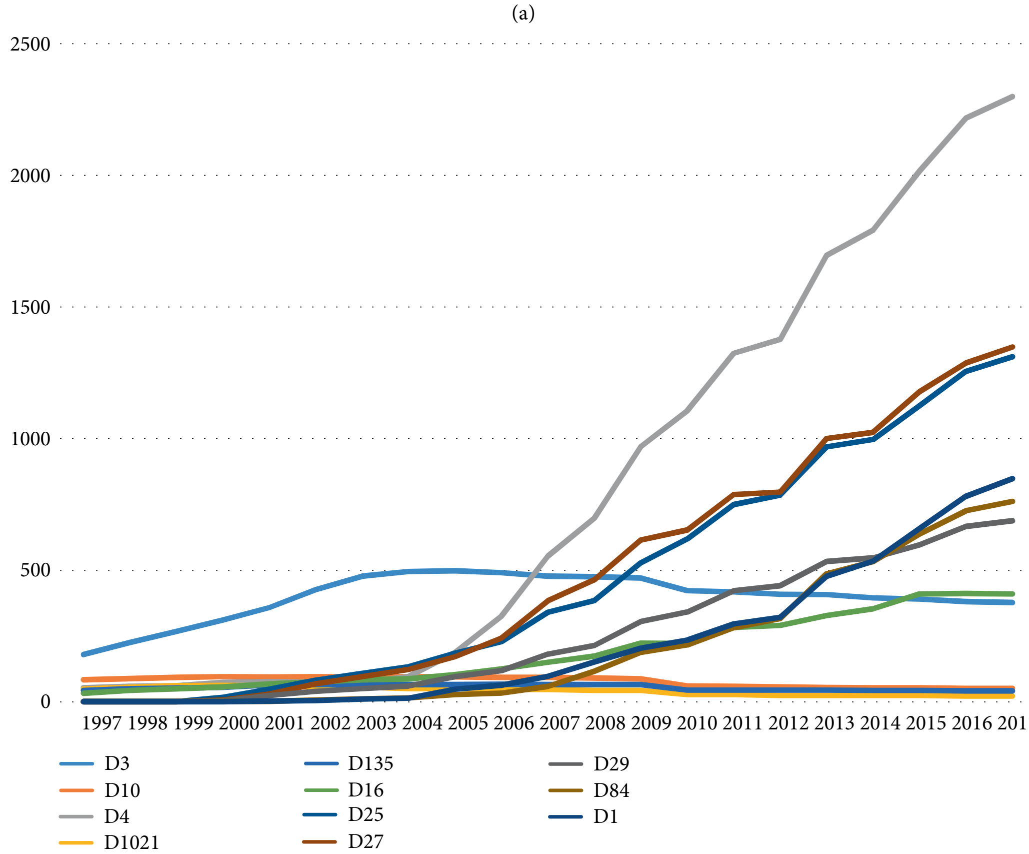
(1) Global System for Mobile Communications (GSM).

The GSM, a technological standard originating in Europe, belongs to the 2G mobile-communications technology. It was introduced and adopted in China in the 1990s. At present, China Mobile and China Unicom each earns the world's largest GSM-based mobile communications network.

The network comprises 79 standards nodes, 33 drafters, 63 pairs of citation relationship, 189 pairs of co-authorships, and 440 pairs of drafting relationships, all of which constitute the overall network shown in Figure 8(a). As shown in Table 6, the Telecommunications Research Institute (under the MIIT), Huawei, ZTE Corporation, and Datang have assumed dominant roles in establishing the standards system. In addition, enterprises holding the dominant market share in the GSM era, such as Samsung and Nokia, have likewise contributed to establishing the system. Two other types of enterprises are those responsible for GSM operations (i.e. China Mobile and China Unicom) and those manufacturing GSM terminal chips such as MediaTek and Spreadtrum Communications. As a whole, the GSM standards system is characterised by decreasing metrics such as *contribution degree*, with the MIIT as the leading contributor, followed by the basic-technology providers, service providers, and terminal-equipment manufacturers (in that order).

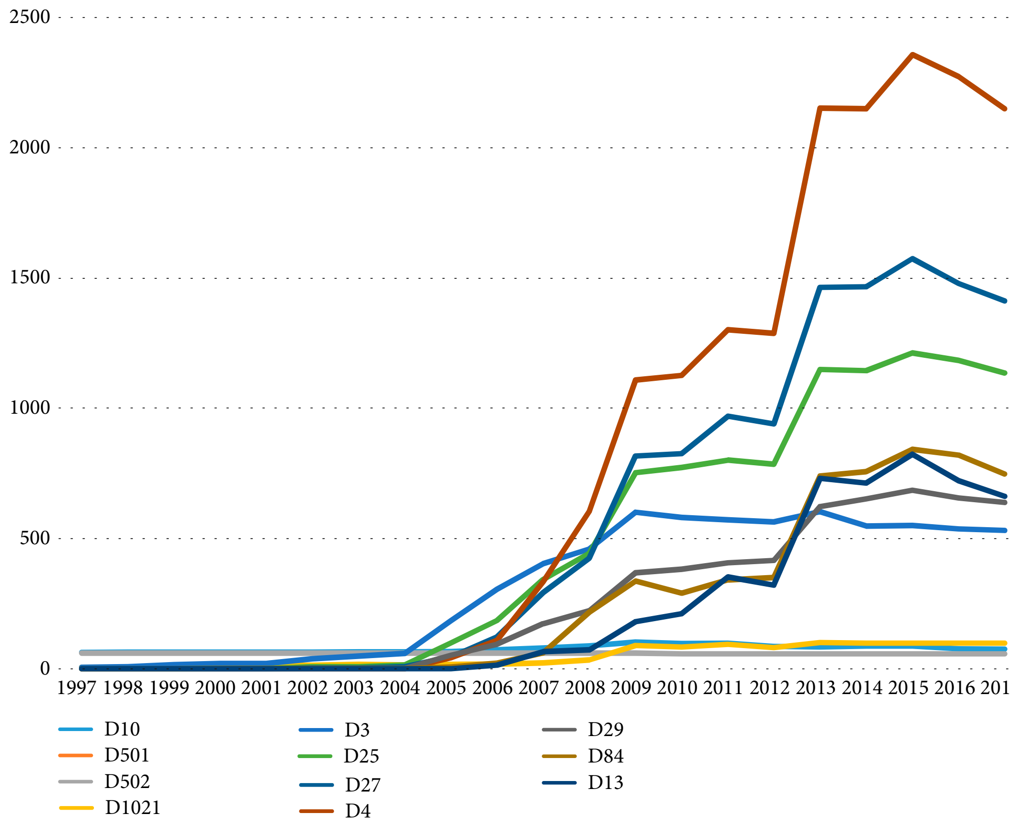


(a)

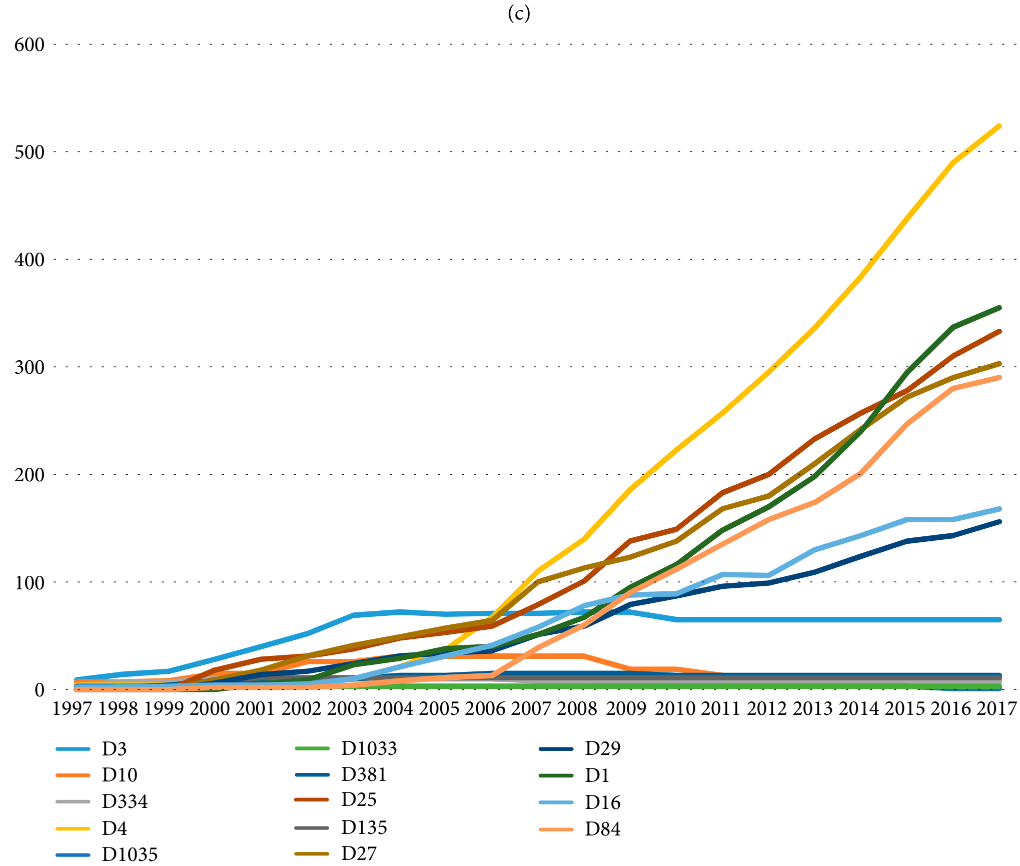


(b)

Figure 7: Continued.

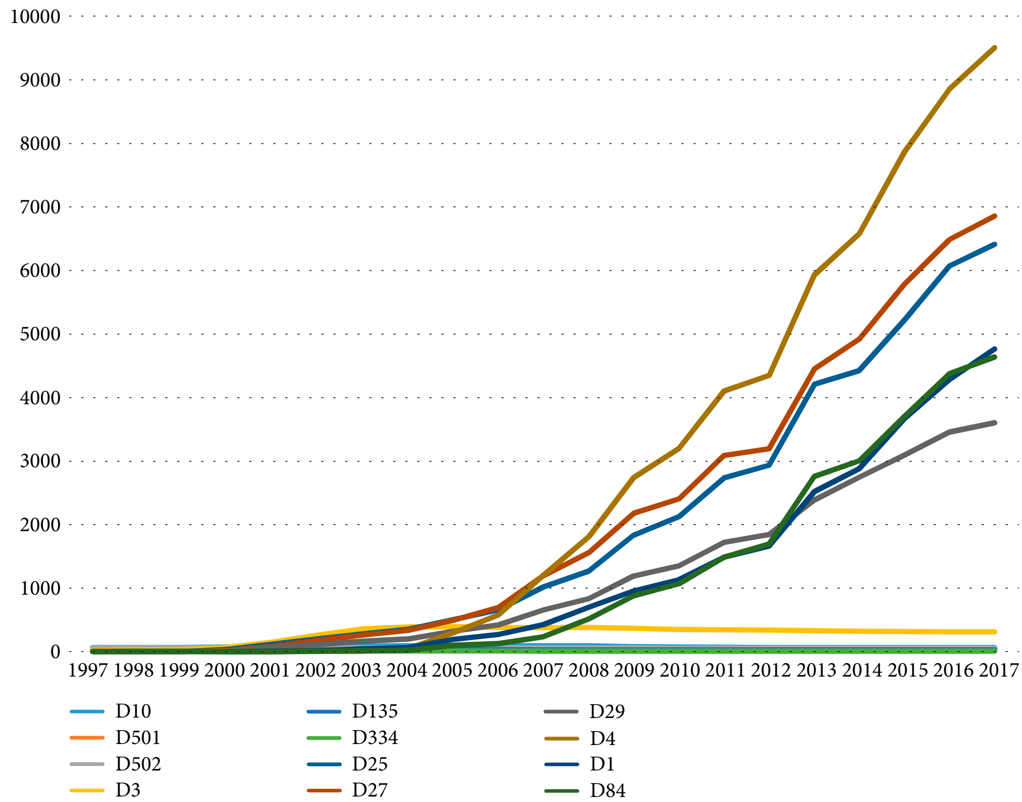


(c)

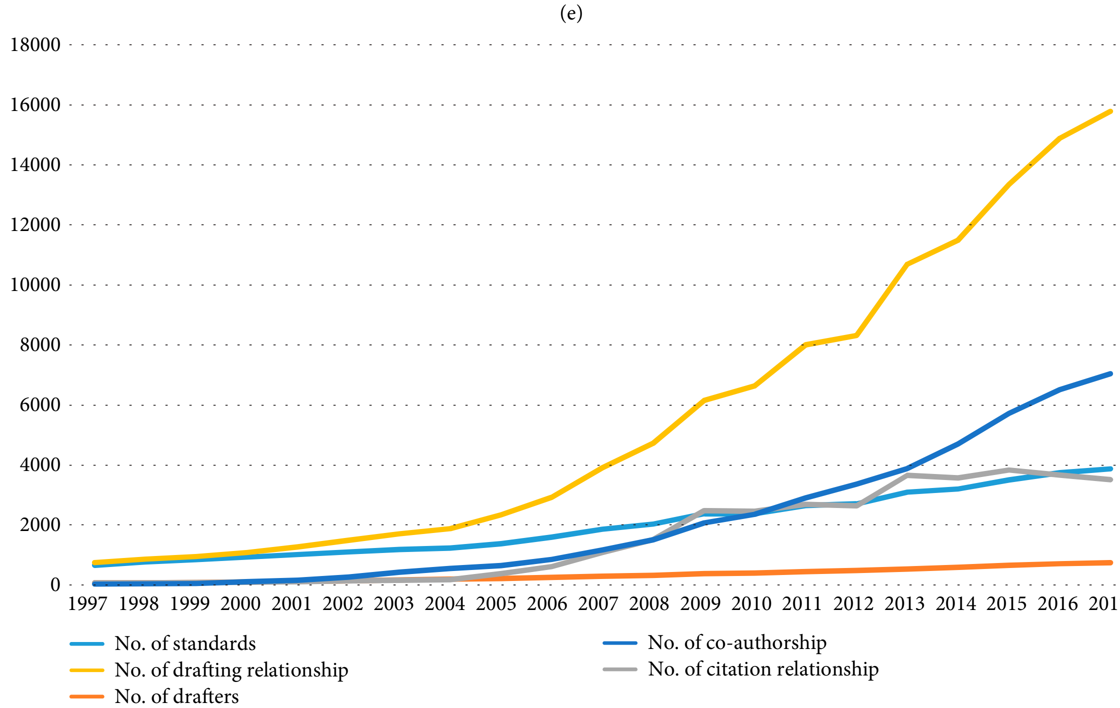


(d)

FIGURE 7: Continued.



(e)



(f)

FIGURE 7: Dynamic changes in metrics communications standards network. Dynamic changes in (a) most highly-cited standards, (b) drafters with the greatest participation degree, (c) drafters with the greatest contribution degree, (d) drafters with the greatest cooperation degree, (e) drafters with the greatest co-authorship degree, and (f) the network metrics.

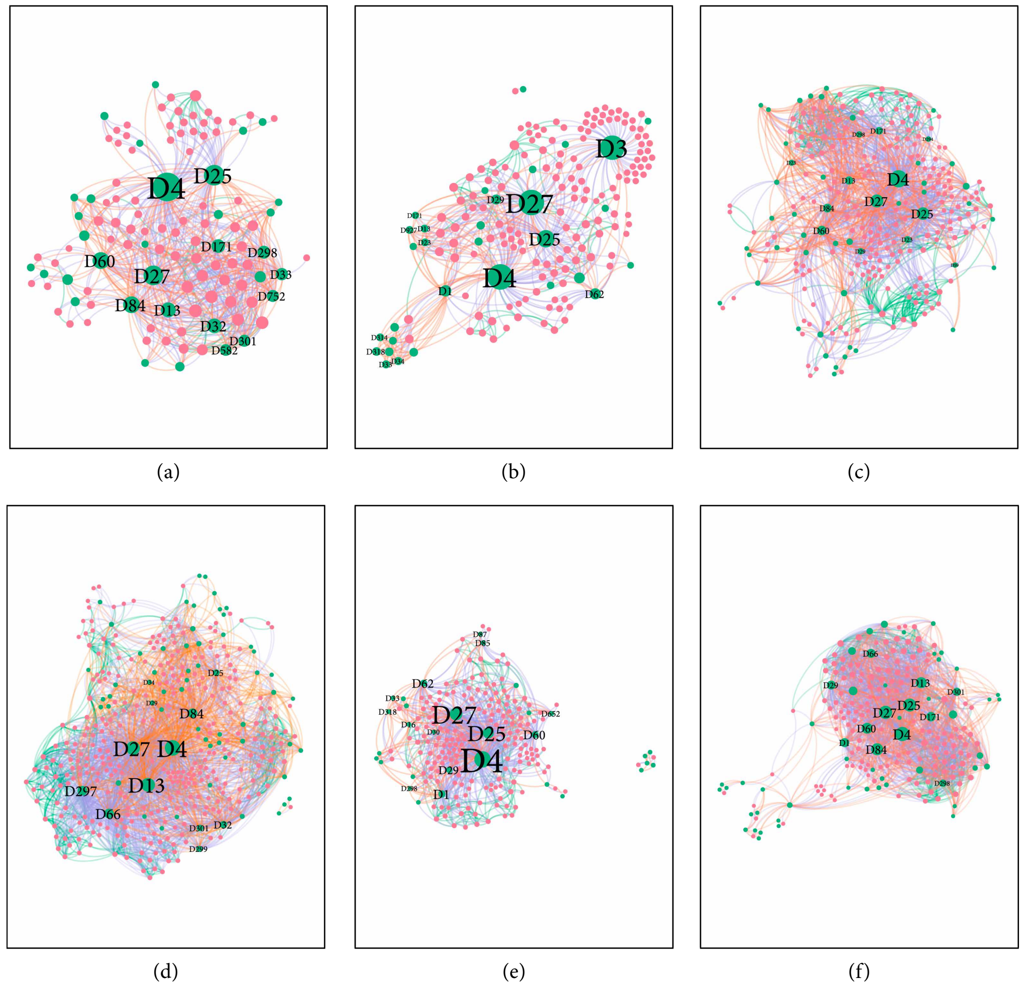


Figure 8: The standard networks of different mobile communication technology. (a) GSM, (b) CDMA, (c) WCDMA, (d) TD–SCDMA, (e) CDMA2000, (f) LTE.

Table 6: The top ten drafters with high indicators in GSM system.

Rank	Participation degree		Contribution degree		Cooperation degree		Co-authorship degree	
	d_j^t	$D_p(d_j^t)$	d_j^t	$D_{con}(d_j^t)$	d_j^t	$D_{coo}(d_j^t)$	d_j^t	$D_{coa}(d_j^t)$
1	D4	66	D4	59	D4	27	D4	274
2	D25	41	D27	37	D60	25	D27	264
3	D27	38	D25	34	D27	24	D32	228
4	D84	29	D32	26	D25	22	D13	211
5	D60	27	D13	25	D84	22	D25	198
6	D13	25	D84	22	D13	21	D84	198
7	D32	25	D582	19	D171	18	D171	185
8	D171	22	D301	19	D32	18	D752	185
9	D298	20	D33	13	D298	16	D33	179
10	D33	18	D171	13	D33	15	D298	175

(2) Code Division Multiple Access (CDMA).

The CDMA is a technological standard originating in the US and, similar to GSM, belongs to the 2G mobile-communications technology. In 2001, it was adopted by China Unicom for launching mobile-communications services; in 2008, the network in its entirety was acquired by China Telecom.

The network comprises 147 standards nodes, 31 drafters, 74 pairs of citation relationships, 129 pairs of co-authorships, and 334 pairs of drafting relationships, all of which constitute the overall network shown in Figure 8(b). As shown in Table 7, as is the case with GSM, apart from dominant institutions (such as the Telecommunications Research Institute of the

Table 7: The top ten drafters with high indicators in CDMA system.

	Participation degree		Contribution degree		Cooperation degree		Co-authorship degree	
Rank	d_j^t	$D_p(d_j^t)$	d_j^t	$D_{con}(d_j^t)$	d_j^t	$D_{coo}(d_j^t)$	d_j^t	$D_{coa}(d_j^t)$
1	D4	67	D4	54	D4	22	D27	156
2	D27	65	D27	44	D1	20	D4	140
3	D3	62	D25	22	D27	20	D25	123
4	D25	36	D29	17	D29	19	D29	99
5	D29	25	D3	16	D25	17	D1	63
6	D1	14	D1	9	D3	9	D3	39
7	D62	14	D13	4	D314	9	D13	29
8	D13	6	D23	4	D318	9	D23	26
9	D23	6	D62	4	D33	9	D171	23
10	D927	4	D5	3	D34	9	D31	23

Table 8: The top ten drafters with high indicators in WCDMA system.

	Participation degree		Contribution degree		Cooperation degree		Co-authorship degree	
Rank	d_j^t	$D_p(d_j^t)$	d_j^t	$D_{con}(d_j^t)$	d_j^t	$D_{coo}(d_j^t)$	d_j^t	$D_{coa}(d_j^t)$
1	D4	163	D4	291	D4	43	D4	611
2	D27	105	D27	146	D27	38	D27	478
3	D25	99	D25	127	D25	35	D25	475
4	D60	64	D84	86	D84	35	D60	323
5	D84	51	D13	84	D60	33	D29	255
6	D29	51	D171	60	D29	29	D84	254
7	D13	42	D29	50	D13	27	D171	229
8	D171	41	D298	41	D171	24	D13	185
9	D23	29	D294	36	D33	22	D23	173
10	D298	23	D59	34	D298	21	D298	167

Table 9: The top ten drafters with high indicators in TD-SCDMA system.

	Participation degree		Contribution degree		Cooperation degree		Co-authorship degree	
Rank	d_j^t	$D_p(d_j^t)$	d_j^t	$D_{con}(d_j^t)$	d_j^t	$D_{coo}(d_j^t)$	d_j^t	$D_{coa}(d_j^t)$
1	D4	281	D4	545	D4	59	D4	1298
2	D13	238	D13	526	D27	50	D27	1258
3	D27	236	D27	471	D84	49	D13	1191
4	D297	138	D297	324	D13	42	D84	753
5	D66	129	D66	314	D25	36	D297	744
6	D84	127	D84	173	D66	34	D66	731
7	D32	81	D32	161	D29	34	D32	560
8	D25	58	D301	116	D34	28	D301	404
9	D301	50	D299	112	D301	28	D25	361
10	D299	47	D25	60	D297	28	D299	317

MIIT, Huawei, ZTE Corporation, and Datang), China Unicom and China Telecommunications Corporation, which are in charge of CDMA operations, and CDMA-solution providers such as Bell and Ericsson, also predominate the standards system. As a whole, the CDMA standards system resemble its GSM counterpart in terms of characteristics.

(3) Wideband Code Division Multiple Access (WCDMA). Among the 3G technologies worldwide, WCDMA—a 3G wireless communications technology based on the upgrading of GSM—not only has the greatest subscription, but also represents the most successful technical and commercial applications. After China Telecommunications Corporation acquired the CDMA network built by China Unicom in 2008, the latter, upon its restructuring in 2009, began to provide 3G mobile-communications business services based on WCDMA.

The network comprises 197 standards nodes, 54 drafters, 312 pairs of citation relationships, 343 pairs of co-authorships, and 915 pairs of drafting relationships, all of which constitute

Table 10: The top ten drafters with high indicators in CDMA2000 system.

	Participation degree		Contribution degree		Cooperation degree		Co-authorship degree	
Rank	d_j^t	$D_p(d_j^t)$	d_j^t	$D_{con}(d_j^t)$	d_j^t	$D_{coo}(d_j^t)$	d_j^t	$D_{coa}(d_j^t)$
1	D4	162	D4	180	D4	22	D4	337
2	D27	110	D27	115	D27	20	D27	302
3	D25	90	D25	82	D25	15	D25	266
4	D1	40	D62	36	D1	13	D29	114
5	D29	39	D1	34	D62	12	D1	106
6	D60	35	D29	22	D29	12	D60	77
7	D62	28	D60	21	D16	11	D62	58
8	D85	11	D85	11	D318	11	D85	21
9	D652	9	D30	9	D33	8	D16	15
10	D87	6	D652	4	D60	8	D298	15

Table 11: The top ten drafters with high indicators in LTE system.

	Participation degree		Contribution degree		Cooperation degree		Co-authorship degree	
Rank	d_j^t	$D_p(d_j^t)$	d_j^t	$D_{con}(d_j^t)$	d_j^t	$D_{coo}(d_j^t)$	d_j^t	$D_{coa}(d_j^t)$
1	D4	127	D4	336	D4	42	D4	1153
2	D27	114	D27	292	D27	38	D25	1142
3	D25	110	D25	287	D25	36	D27	1091
4	D84	101	D84	270	D84	35	D84	938
5	D13	90	D60	261	D13	34	D13	903
6	D60	86	D13	226	D60	31	D60	857
7	D171	70	D171	209	D301	29	D171	826
8	D29	64	D32	205	D66	28	D23	693
9	D1	62	D301	202	D298	27	D29	691
10	D66	61	D29	198	D1	27	D66	656

Table 12: Comparison of network indicators between different communications-technology systems.

	$\lvert\mathcal{N}_s^t\rvert$	$\lvert\mathcal{N}_d^t\rvert$	Proportion of enterprise drafters	$\lvert\mathcal{E}_{citation}^t\rvert$	$\lvert\mathcal{E}_{co-authorship}^t\rvert$	$\lvert\mathcal{E}_{drafting}^t\rvert$
GSM	79	33	84.85%	63	189	440
CDMA	147	31	80.65%	74	129	334
WCDMA	197	54	90.74%	312	343	915
TD-SCDMA	318	67	92.54%	571	493	1752
CDMA2000	181	31	87.10%	193	111	574
LTE	144	57	80.70%	336	416	1431

the overall network shown in Figure 8(c). As shown in Table 8, similarities are noted in the characteristics of WCDMA in the 2G standards system. However, interestingly, given the application of dual-mode mobile phones, China Mobile (responsible for the commercial applications of TD-SCDMA technology) has contributed to the WCDMA standards system to an extent comparable to China Unicom.

(4) Time Division-Synchronous Code Division Multiple Access (TD-SCDMA).

Relative to the other two prime 3G standards (WCDMA and CDMA2000), the TD-SCDMA started late. The historic date of June 29th, 1998 marked the proposal of this standard by China's former Ministry of Posts and Telecommunications through the Research Institute of Telecommunications Science and Technology (the predecessor of modern-day Datang Telecom Technology Co., Ltd.) to the International Telecommunication Union (the initial standards research institute was Siemens). In February 2008, China Mobile began taking charge of constructing the TD-SCDMA communications network.

The network comprises 318 standard nodes, 67 drafters, 571 pairs of citation relationships, 493 pairs of co-authorships, and 1,752 pairs of drafting relationships, all of which constitute the overall network shown in Figure 8(d). As shown in Table 9, enterprises responsible for the domestic research and development of TD-SCDMA (among which a representative is Datang Telecom) and China Mobile, responsible for commercial applications, have contributed the most to the entire standards system, surpassing both nonlocal enterprises and joint ventures.

(5) Code Division Multiple Access 2000 (CDMA2000).

The CDMA2000, an extension of the CDMA standard among the 2G standards, is incompatible with the WCDMA, a 3G standard. In 2009, China Telecommunications Corporation launched a 3G mobile-communications service based on CDMA2000.

The system comprises 181 standards nodes, 31 drafters, 193 pairs of citation relationships, 111 pairs of co-authorships, and 574 pairs of drafting relationships, all of which constitute the overall network shown in Figure 8(e). As shown in Table 10, the drafters' distribution in the CDMA2000 standards system is approximately the same as that in other standards systems, but it is noteworthy that Beijing University of Posts and Telecommunications—the only academic institution in the top ten—is also in the system. Its presence there suggests that the standards-formulating in the CDMA2000 outperforms other standards systems in the translation of scientific research results.

(6) Long-Term Evolution (LTE)

The LTE is a global standard based on the OFDMA technology and developed by the 3rd-Generation Partnership Project (3GPP) Organizational Partners. It encompasses two modes: the Frequency Division Duplex (FDD) and the Time Division Duplex (TDD). The MIIT issued TDD-LTE business licenses to China Mobile, China Telecommunications Corporation, and China Unicom on December 4th, 2013, and then issued FDD-LTE business licenses to the latter companies on February 27, 2015. These historic dates marked the complete entry of China's communications industry into the 4G era. Given the 90% similarities between the two modes, and the stipulations common to both modes during standards-formulation, we do not distinguish between them when analysing the LTE standards system.

The system comprises 144 standard nodes, 57 drafters, 336 pairs of citation relationships, 416 pairs of co-authorships, and 1,431 pairs of drafting relationships, all of which can constitute the overall network shown in Figure 8(f). As shown in Table 11, the drafters' distribution in the LTE standards system is approximately the same as that in other standard systems; however, China Telecom, as the operator-in-charge in the system, has not invested as much as China Mobile and Chinese Unicom in establishing it.

For metrics in the standards systems of the different mobile-communications technologies, horizontal comparison can be performed, as shown in Table 12.

In different communications-technology standard systems, the TD-SCDMA is the optimal based on the metrics, mainly because the standard has been promoted chiefly by China: the standards are in greater need of China's drafters to formulating and improving the entire system. At the same time, with the expansion of China's communications market and the development of communications technology, enterprises in the industry have also begun to pay attention to the importance of standards and thereby channelled more efforts into establishing the standards system. Governmental agencies manage and guide the whole standards system only through the formulation of a minority of standards, with enterprises assuming the dominant role.

4.3. Discussions and Management Implications. The development of China's communications industry is evident from changes in the scale of the standards network; at the same time, technological changes in the industry are also reflected by changes in the core standards. Based on the indicators of the network, the drafters have performed mostly consistent in our measurements, including *participation degree*, *contribution degree*, *cooperation degree*, and *co-authorship degree*. This implies that the indicators proposed in this paper can quantify the drafters' contributions to constructing the standards system. As judged from different periods and the network characteristics of different technological systems, the standards system in China's communications industry has always been led by governmental agencies. Thereafter, for enterprise drafters, basic-technology providers play the most significant role in drafting standards, followed by service providers, while the involvement of terminal-equipment manufacturers is insufficient. This is closely related to the Chinese enterprises competitiveness in the segmentation of China's communications industry. As for basic technology, Huawei, ZTE Corporation, and other enterprises hold the dominant market shares, with correspondingly important roles in the standards system.

Conversely, as for the purveying of terminal-equipment such as mobile phones, no obvious correlation has existed between market shares owned by manufacturers and their positions in the system. This is mainly because market shares of terminal-equipment are influenced more by product designs, marketing, and pricing strategies. However, this does not mean that the terminal-equipment manufacturers need not participate in establishing the standards system. For example, Huawei, as a basic-technology provider, is also engaged in research and development of mobile phones; with its currently most sizeable sales in China's market of mobile-phone terminals, it has exhibited relatively great participation in setting the standards of such terminals. In addition, despite their lack of past contributions, enterprises with substantial shares of the mobile-phone market have been developing standards since 2017: Vivo, Xiaomi, and OPPO have, respectively, been engaged in drafting 1, 2, and 7 standards.

More interestingly, as for the provision of services, the service providers' contributions to developing technical standards related to the mode of their communications services are somewhat related to their market shares. In the 3G era, China Mobile, China Unicom, and China Telecommunications Corporation have respectively been responsible for the operations of the TD-SCDMA, WCDMA,

CDMA2000 communications networks. The three standards systems have exhibited diminution in the scale of the network (in that order), while the significance of the three enterprises in their own standards systems has also declined (in that order). Up to the commercial launch of the 4G technology, the numbers of their 3G users also dwindled in 2012 (likewise in that order). For service providers, notwithstanding their lack of direct involvement in the research and development of technologies, the development of the relevant standards will affect the quality of services offered to clients. Thus, for basic-technology providers, service providers, and terminal-equipment manufacturers, the extent of their contributions to the standards system influences their competitiveness in their domains, and this influence is correlated to the contributions of these three types of enterprises in the whole standards system. Compared with service providers and terminal-equipment manufacturers, basic-technology providers ought to be more involved in constructing standards systems.

China's communications industry has metamorphosed from a minor follower in the past to the major formulator of technical standards in the present. This change in role is attributed to not only the governmental steering of the direction of development through standards-setting, but also, more importantly, to active enterprises participation in the standards-setting. With the development of technology, enterprises in the standards system have started to assume progressively elevated positions. As world-class enterprises in the communications industry, ZTE Corporation and Huawei have exhibited performances second only to the MIIT in the entire standards system, reflecting the magnitude of their contributions to developing China's communications industry. The international standards for 5G mobile-communications technology are still in their nascent formulation, in which the participation of Huawei—the representative of Chinese enterprises—may be seen as the fruition of its aforesaid contribution.

5. Conclusions

The managerial aphorism that leading first-tier enterprises set industrial standards deserves academic explorations. To verify whether evidence suffices to support this widely-circulated view in the China's management field, this paper establishes a dynamic multiplex network that considers not only citation between standards but also co-authorship between drafting institutions. Taking the period from the introduction of the standards to their abolition as their life cycle, the model further observes the interaction between the standards, in order to ascertain whether augmenting investments in standards-formulating boosts enterprises competitiveness. To quantitatively evaluate the drafters' involvement in establishing the standards system, we selected relevant indexes in the network theory. More importantly, we also designed a series of evaluative measurements—including the *participation degree*, *contribution degree*, *cooperation degree*, and *co-authorship degree*-based on the characteristics of the system. In the case study (with China's communications industry as the case study), we combined the standard citation network and drafter co-authorship network in the industry, based on collecting data on the standards and the drafting institutions. Subsequently, we performed a dynamic analysis of the development of the standards system in China's communications industry, based on two dimensions: the era and the specific technical mode. The results show that the development of the standards system mirrors that of China's communications industry: in constructing the standards system, the situation in which governmental agencies acted as the main body is noted to have changed into another in which such agencies acted as the leader and the enterprises acted as the main body. Over time, it can be observed that early participation in standards-drafting enables enterprises to acquire advantages in the subsequent competition in the industry. Such a change has exerted a more catalytic effect on basic-technology providers than on service providers and terminal-equipment manufacturers. From the perspective of market segmentation, basic-technology providers enjoy a greater market share than terminal-equipment manufacturers in China's communication market. The aphorism "first-class enterprises set the standards" has indeed been verified to some extent.

In addition to their suitability for the communications industry, models and indicators established herein may be extended to other industrial standards or to other network systems with citation and drafting relationships, so as to provide an instructive angle for observation. Admittedly, findings on China's communications industry based on the models have their limitations. We have restricted the standards to those within the purview of the China Communications Standards Association and not considered references to other industries or international standards.

For future research, one question warrants more investigation: whether the participation, contribution, cooperation and co-authorship in establishing standards systems can improve enterprises competitiveness in other industries and international standards. If, for certain areas of segmentation, such improvement is not apparent, research should then focus on the presence of other factors. Likewise, the quantitative evaluation of such improvement in competitiveness is worth studying. In addition, our observation of the standards system in China's communications industry has revealed the leading role of governmental agencies. Against this background, two emergent questions are the most challenging for future research: (1) whether such governmental leadership likewise exists in other industries and even other countries; and (2) whether it exerts a favourable or adverse effect on the development of the industry and on the cultivation of enterprises competitiveness.

Appendix

A. Standard Information (Figure 9)

s_i^t	Standard No	Standard name
S1	GF 001-9001	Technical specification for domestic network No. 7 signalling
S389	YD/T 1082-2000	Technical requirements for the protection against overvoltages and overcurrents and the suitability in basic environment on access network equipment
S412	YD/T 1098-2001	Test Specification for Low-End Router
S487	YD/T 1156-2001	Test Specification for High-End Router
S573	YD/T 1214-2006	Technical requirement of 900/1800 MHz TDMA Digital Cellular Mobile Telecommunication Network General Packet Radio Service (GPRS) Equipment: Mobile Stations
S575	YD/T 1215-2006	Testing Methods of 900/1800 MHz TDMA Digital Cellular Mobile Telecommunication Network General Packet Radio Service (GPRS) Equipment: Mobile Stations
S653	YD/T 1261-2003	The technical specification of CAMEL3: CAMEL Application Part (CAP) for 900/1800 MHz TDMA digital cellular mobile telecommunication network
S659	YD/T 1268-2003	The safety specification and test method for lithium batteries and charger
S1089	YD/T 1539-2006	Technical Requirements and Testing Methods for Reliability of Mobile Telecommunication Handset
S1187	YD/T 1584.3-2007	Technical Specification for 2GHz Digital Cellular Mobile Communications Network Management General Part 3 Interface Analysis
S1208	YD/T 1591-2009	Technical requirements and test method for power adapter and charging/data port of mobile telecommunication terminal Equipment
S1285	YD/T 1644.1-2007	Human exposure to radio frequency fields from hand-held and body-mounted wireless communication devices-Human models, instrumentation, and procedures Part 1: Procedure to determine the specific absorption rate (SAR) for hand-held devices used in close proximity
S1473	YD/T 1754-2008	Classified Security Protection Requirements for Telecom Network and Internet for Physics Environment
S1475	YD/T 1756-2008	Classified Management Security Protection Requirements for Telecom Network and Internet
S1485	YD/T 1762.1-2011	TD-SCDMA/WCDMA digital cellular mobile telecommunication network technical requirements for UICC-ME (Cu)interface-part 1: physical, electrical and logical characteristics
S1915	YD/T 206.10-1997	Ironworks for overhead communication line: Nail
S1917	YD/T 206.1-1997	Ironworks for overhead communication line: General technology
S1920	YD/T 206.14-1997	Ironworks for overhead communication line: Nut
S1921	YD/T 206.15-1997	Ironworks for overhead communication line: Gasket
S1924	YD/T 206.18-1997	Ironworks for overhead communication line: Stay anchor
S1925	YD/T 206.19-1997	Ironworks for overhead communication line: Steel anchor
S1932	YD/T 206.25-1997	Ironworks for overhead communication line: Dog
S3571	YD/T 514-1998	Technical requirements and test methods for interface between nonvoice subscriber terminal and public telephone network
S3824	YD/T 728-1994	Telephone lightning protection technology requirements and test methods
S3832	YD/T 735-1994	Telephone electro magnetic compatibility limits and test methods
S3855	YD/T 760-1995	Polyolefine insulation materials for communication cable
S3955	YD/T 837.1-1996	Communication cable test method Part 1: General rules
S3960	YD/T 838.1-1996	Multicore and symmetrical pair/quad cables for digital communications Part 1: Generic specification
S4134	YD/T 965-1998	The safety requirement and test method for telecommunication terminal equipment
S4530	YDN 020-1996	Specification of V5.1 interface between local digital switcher and access network
S4531	YDN 021-1996	Specification of V5.2 interface between local digital switcher and access network
S4580	YDN 065-1997	Telephone switcher general technical specification

Figure 9

B. Drafter Information (Figure 10)

d_j^t	Drafter name	Type
D1	China Telecom	Enterprise
D3	Institute of Telecommunication Transmission of MIIT	Government agency
D4	Academy of Telecommunication Research of MIIT	Government agency
D5	Communication Measurement Center of MIIT	Government agency
D10	Institute of P&T Industry Standardization of MIIT	Government agency
D13	Datang	Enterprise
D15	Chengdu Datang Communication Cable Company	Enterprise
D16	FiberHome Technologies	Enterprise
D23	Nanjing Ericsson Panda Communications	Enterprise
D24	China Information Technology Designing Consulting Institute	Enterprise
D25	Huawei	Enterprise
D27	ZTE	Enterprise
D29	AlcatelLucent Shanghai Bell	Enterprise
D30	Shanghai Bell Samsung Mobile Communication	Enterprise
D31	Nokia Siemens	Enterprise
D32	Beijing Zhanxun High-Tech Communication Technology	Enterprise
D33	State Radio Monitoring Center	Government agency
D34	Comba Telecom Systems (China)	Enterprise
D59	UTStarcom	Enterprise
D60	China United Network Communications	Enterprise
D62	China United Communications	Enterprise
D66	China Potevio Company	Enterprise
D84	China Mobile	Enterprise
D85	Beijing University of Posts and Telecommunications	University
D87	Beijing Tianyuan Network	Enterprise
D96	Beijing Communications Administration	Government agency
D115	Beijing P&T Equipment Factory	Enterprise
D135	Data Communications Science Technique Research Institute	Enterprise
D171	Nokia Solutions and Networks (Shanghai)	Enterprise
D294	Motorola	Enterprise
D297	TD Tech	Enterprise
D298	Samsung Mobile R&D Center of China-Tianjin	Enterprise
D299	ST-Ericsson	Enterprise
D301	Chongqing Chongyou Information Technology	Enterprise
D314	Shenzhen Winhap Communications	Enterprise
D318	Zhongyouke Communication Technology	Enterprise
D328	Delta Greentech (China)	Enterprise
D334	China Mobile Group Design Institute	Enterprise
D381	Guangzhou Research Institute of China Telecom	Enterprise
D398	Vertiv	Enterprise
D465	Xingtang Communication Technology	Enterprise
D501	China P&T Appliances	Enterprise
D502	Maanshan Telecommunications Equipment	Enterprise
D582	Beijing Starpoint Information Technology	Enterprise
D652	Guangdong Nortel Telecommunication Equipment	Enterprise
D742	Comba Telecom Systems China (Guangzhou)	Enterprise
D752	Mediatek (Beijing)	Enterprise
D927	Ericsson	Enterprise
D1021	CEPREI	Government agency
D1027	Telecom Technology Instrument Research Institute	Government agency
D1031	Fourth Research Institute of Telecommunication Technology	Government agency
D1035	Luoyang Telephone Equipment Factory	Enterprise

Figure 10

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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References

[1] J.-Y. Ho and E. O'Sullivan, "Strategic standardisation of smart systems: a roadmapping process in support of innovation," *Technological Forecasting and Social Change*, vol. 115, pp. 301–312, 2017.

[2] H. Jiang, S. Zhao, Y. Yuan, L. Zhang, L. Duan, and W. Zhang, "The coupling relationship between standard development and technology advancement: a game theoretical perspective," *Technological Forecasting and Social Change*, vol. 135, pp. 169–177, 2018.

[3] W. S. Lee and S. Y. Sohn, "Effects of standardization on the evolution of information and communications technology," *Technological Forecasting and Social Change*, vol. 132, pp. 308–317, 2018.

[4] H. Zoo, H. J. de Vries, and H. Lee, "Interplay of innovation and standardization: exploring the relevance in developing countries," *Technological Forecasting and Social Change*, vol. 118, pp. 334–348, 2017.

[5] L. Leydesdorff, C. S. Wagner, and L. Bornmann, "Betweenness and diversity in journal citation networks as measures of interdisciplinaritya tribute to Eugene garfield," *Scientometrics*, vol. 114, no. 2, pp. 567–592, 2018.

[6] Y. Li, H. Li, N. Liu, and X. Liu, "Important institutions of interinstitutional scientific collaboration networks in materials science," *Scientometrics*, vol. 117, no. 1, pp. 85–103, 2018.

[7] H. Choe, D. H. Lee, H. D. Kim, and I. W. Seo, "Structural properties and inter-organizational knowledge flows of patent citation network: the case of organic solar cells," *Renewable & Sustainable Energy Reviews*, vol. 55, pp. 361–370, 2016.

[8] K. Blind, J. Edler, R. Frietsch, and U. Schmoch, "Motives to patent: empirical evidence from Germany," *Research Policy*, vol. 35, no. 5, pp. 655–672, 2006.

[9] K. Blind, K. Cremers, and E. Mueller, "The influence of strategic patenting on companies' patent portfolios," *Research Policy*, vol. 38, no. 2, pp. 428–436, 2009.

[10] L. Bornmann and H.-D. Daniel, "What do citation counts measure? a review of studies on citing behavior," *Journal of Documentation*, vol. 64, no. 1, pp. 45–80, 2008.

[11] D. O. Cases and G. M. Higgins, "How can we investigate citation behavior? a study of reasons for citing literature in communication," *Journal of the Association for Information Science and Technology*, vol. 51, no. 7, pp. 635–645, 2000.

[12] J. Alcácer, M. Gittelman, and B. Sampat, "Applicant and examiner citations in U.S. patents: an overview and analysis," *Research Policy*, vol. 38, no. 2, pp. 415–427, 2009.

[13] M. E. Newman, "Scientific collaboration networks. i. network construction and fundamental results," *Physical Review E*, vol. 64, no. 1, Article ID 016131, 2001.

[14] S. N. Dorogovtsev and J. F. F. Mendes, "Evolution of networks," *Advances in Physics*, vol. 51, no. 4, pp. 1079–1187, 2002.

[15] A. Barabási, H. Jeong, Z. Néda, E. Ravasz, A. Schubert, and T. Vicsek, "Evolution of the social network of scientific collaborations," *Physica A: Statistical Mechanics and its Applications*, vol. 311, no. 3–4, pp. 590–614, 2002.

[16] E. Garfield, "Citation indexes for science: a new dimension in documentation through association of ideas," *Science*, vol. 122, no. 3159, pp. 108–111, 1955.

[17] P. Doreian, "A measure of standing of journals in stratified networks," *Scientometrics*, vol. 8, no. 5–6, pp. 341–363, 1985.

[18] J. P. A. Ioannidis, K. W. Boyack, H. Small, A. Sorensen, and R. Klavans, "Bibliometrics: is your most cited work your best?," *Nature*, vol. 514, no. 7524, pp. 561–562, 2014.

[19] R. Van Noorden, B. Maher, and R. Nuzzo, "The top 100 papers," *Nature*, vol. 514, no. 7524, pp. 550–553, 2014.

[20] P. Chen, H. Xie, S. Maslov, and S. Redner, "Finding scientific gems with google's pagerank algorithm," *Journal of Informetrics*, vol. 1, no. 1, pp. 8–15, 2007.

[21] K. S. Fursov and A. R. Kadyrova, "How the analysis of transitionary references in knowledge networks and their centrality characteristics helps in understanding the genesis of growing technology areas," *Scientometrics*, vol. 111, no. 3, pp. 1947–1963, 2017.

[22] J. Kim and J. Shin, "Mapping extended technological trajectories: integration of main path, derivative paths, and technology junctures," *Scientometrics*, vol. 116, no. 3, pp. 1439–1459, 2018.

[23] X. Sun and K. Ding, "Identifying and tracking scientific and technological knowledge memes from citation networks of publications and patents," *Scientometrics*, vol. 116, no. 3, pp. 1735–1748, 2018.

[24] J. Wang and L. Zhang, "Proximal advantage in knowledge diffusion: the time dimension," *Journal of Informetrics*, vol. 12, no. 3, pp. 858–867, 2018.

[25] F. Han and C. L. Magee, "Testing the science/technology relationship by analysis of patent citations of scientific papers after decomposition of both science and technology," *Scientometrics*, vol. 116, no. 2, pp. 767–796, 2018.

[26] F. Narin, "Patent bibliometrics," *Scientometrics*, vol. 30, no. 1, pp. 147–155, 1994.

[27] A. G. Hu and A. B. Jaffe, "Patent citations and international knowledge flow: the cases of Korea and Taiwan," *International Journal of Industrial Organization*, vol. 21, no. 6, pp. 849–880, 2003.

[28] B. H. Hall, A. B. Jaffe, and M. Trajtenberg, "Market value and patent citations," *The RAND Journal of Economics*, vol. 36, no. 1, pp. 16–38, 2005.

[29] M. J. Holgersson and O. Granstrand, "Patenting motives, technology strategies, and open innovation," *Management Decision*, vol. 55, no. 6, pp. 1265–1284, 2017.

[30] J. Moody, "The structure of a social science collaboration network: disciplinary cohesion from 1963 to 1999," *American Sociological Review*, vol. 69, no. 2, pp. 213–238, 2004.

[31] D. J. D. S. Price, "Is technology historically independent of science? A study in statistical historiography," *Technology and Culture*, vol. 6, no. 4, p. 553, 1965.

[32] T. W. Pike, "Collaboration networks and scientific impact among behavioral ecologists," *Behavioral Ecology*, vol. 21, no. 2, pp. 431–435, 2010.

[33] H. Kretschmer, "Author productivity and geodesic distance in bibliographic co-authorship networks, and visibility on the web," *Scientometrics*, vol. 60, no. 3, pp. 409–420, 2004.

[34] S. Choi, J. S. Yang, and H. W. Park, "The triple helix and international collaboration in science," *Journal of the Association for Information Science and Technology*, vol. 66, no. 1, pp. 201–212, 2015.

[35] H. Hou, H. Kretschmer, and Z. Liu, "The structure of scientific collaboration networks in scientometrics," *Scientometrics*, vol. 75, no. 2, pp. 189–202, 2008.

[36] F. Landini, F. Malerba, and R. Mavilia, "The structure and dynamics of networks of scientific collaborations in northern africa," *Scientometrics*, vol. 105, no. 3, pp. 1787–1807, 2015.

[37] J. Li and Y. Li, "Patterns and evolution of coauthorship in Chinas humanities and social sciences," *Scientometrics*, vol. 102, no. 3, pp. 1997–2010, 2015.

[38] H. D. White, B. Wellman, and N. Nazer, "Does citation reflect social structure? Longitudinal evidence from the globenet interdisciplinary research group," *Journal of the Association for Information Science and Technology*, vol. 55, no. 2, pp. 111–126, 2004.

[39] P. Liu and X. Haoxiang, "Structure and evolution of co-authorship network in an interdisciplinary research field," *Scientometrics*, vol. 103, no. 1, pp. 101–134, 2015.

[40] J. Fagan, K. S. Eddens, J. Dolly, N. L. Vanderford, H. L. Weiss, and J. S. Levens, "Assessing research collaboration through co-authorship network analysis," *The Journal of Research Administration*, vol. 49, no. 1, pp. 76–99, 2018.

[41] C. S. Wagner, J. D. Roessner, K. Bobb et al., "Approaches to understanding and measuring interdisciplinary scientific research (IDR): a review of the literature," *Journal of Informetrics*, vol. 5, no. 1, pp. 14–26, 2011.

[42] D. J. Teece, "Profiting from technological innovation: implications for integration, collaboration, licensing and public policy," *Research Policy*, vol. 15, no. 6, pp. 285–305, 1986.

[43] V. Barba-Sánchez, M. José Calderón-Miláan, and C. Atienza-Sahuquillo, "A study of the value of ICT in improving corporate performance: a corporate competitiveness view," *Technological and Economic Development of Economy*, vol. 24, no. 4, pp. 1388–1407, 2018.

[44] G. Dosi, M. Grazzi, and D. Moschella, "Technology and costs in international competitiveness: from countries and sectors to firms," *Research Policy*, vol. 44, no. 10, pp. 1795–1814, 2015.

[45] P. Lii and F.-I. Kuo, "Innovation-oriented supply chain integration for combined competitiveness and firm performance," *International Journal of Production Economics*, vol. 174, pp. 142–155, 2016.

[46] V. Kveton and P. Horak, "The effect of public R&D subsidies on firms' competitiveness: regional and sectoral specifics in emerging innovation systems," *Applied Geography*, vol. 94, pp. 119–129, 2018.

[47] R. Giuliano, S. Kampelmann, B. Mahy, and F. Rycx, "Short notice, big difference? The effect of temporary employment on firm competitiveness across sectors," *British Journal of Industrial Relations*, vol. 55, no. 2, pp. 421–449, 2017.

[48] C. Rammer, S. Gottschalk, M. Peneder, M. Worter, T. Stucki, and S. Arvanitis, "Does energy policy hurt international competitiveness of firms? A comparative study for Germany, Switzerland and Austria," *Energy Policy*, vol. 109, pp. 154–180, 2017.

[49] Y. Park, P. Hong, and S. Li, "Free trade agreements and maritime supply chain costs: competitiveness of Korean firms," *Maritime Economics & Logistics*, vol. 18, no. 1, pp. 3–18, 2016.

[50] A. Bodnaruk, W. O'Brien, and A. Simonov, "Captive finance and firm's competitiveness," *Journal of Corporate Finance*, vol. 37, pp. 210–228, 2016.

[51] S. Yang, Y. Li, and X. Wang, "Cohesiveness or competitiveness: venture capital syndication networks and firms' performance in China," *Journal of Business Research*, vol. 91, pp. 295–303, 2018.

[52] J. L. Solleiro and R. Castañón, "Competitiveness and innovation systems: the challenges for Mexico's insertion in the global context," *Technovation*, vol. 25, no. 9, pp. 1059–1070, 2005.

[53] S.-P. Chuang and S.-J. Huang, "The effect of environmental corporate social responsibility on environmental performance and business competitiveness: the mediation of green information technology capital," *Journal of Business Ethics*, vol. 150, no. 4, pp. 991–1009, 2018.

[54] V. Costantini and M. Mazzanti, "On the green and innovative side of trade competitiveness? The impact of environmental policies and innovation on EU exports," *Research Policy*, vol. 41, no. 1, pp. 132–153, 2012.

[55] L. M. Ferri and M. Pedrini, "Socially and environmentally responsible purchasing: comparing the impacts on buying firm's financial performance, competitiveness and risk," *Journal of Cleaner Production*, vol. 174, pp. 880–888, 2018.

[56] M. D. Lopez-Gamero and J. F. Molina-Azorin, "Environmental management and firm competitiveness: the joint analysis of external and internal elements," *Long Range Planning*, vol. 49, no. 6, pp. 746–763, 2016.

[57] J. L. C. Cheng and D. Yiu, "China business at a crossroads: institutions, international competitiveness, and innovation," *Long Range Planning*, vol. 49, no. 5, pp. 584–588, 2016.

[58] J. M. Goncalves, F. Ferreira, J. J. Ferreira, and L. Farinha, "A multiple criteria group decision-making approach for the assessment of small and medium-sized enterprise competitiveness," *Management Decision*, vol. 57, no. 2, pp. 480–500, 2019.

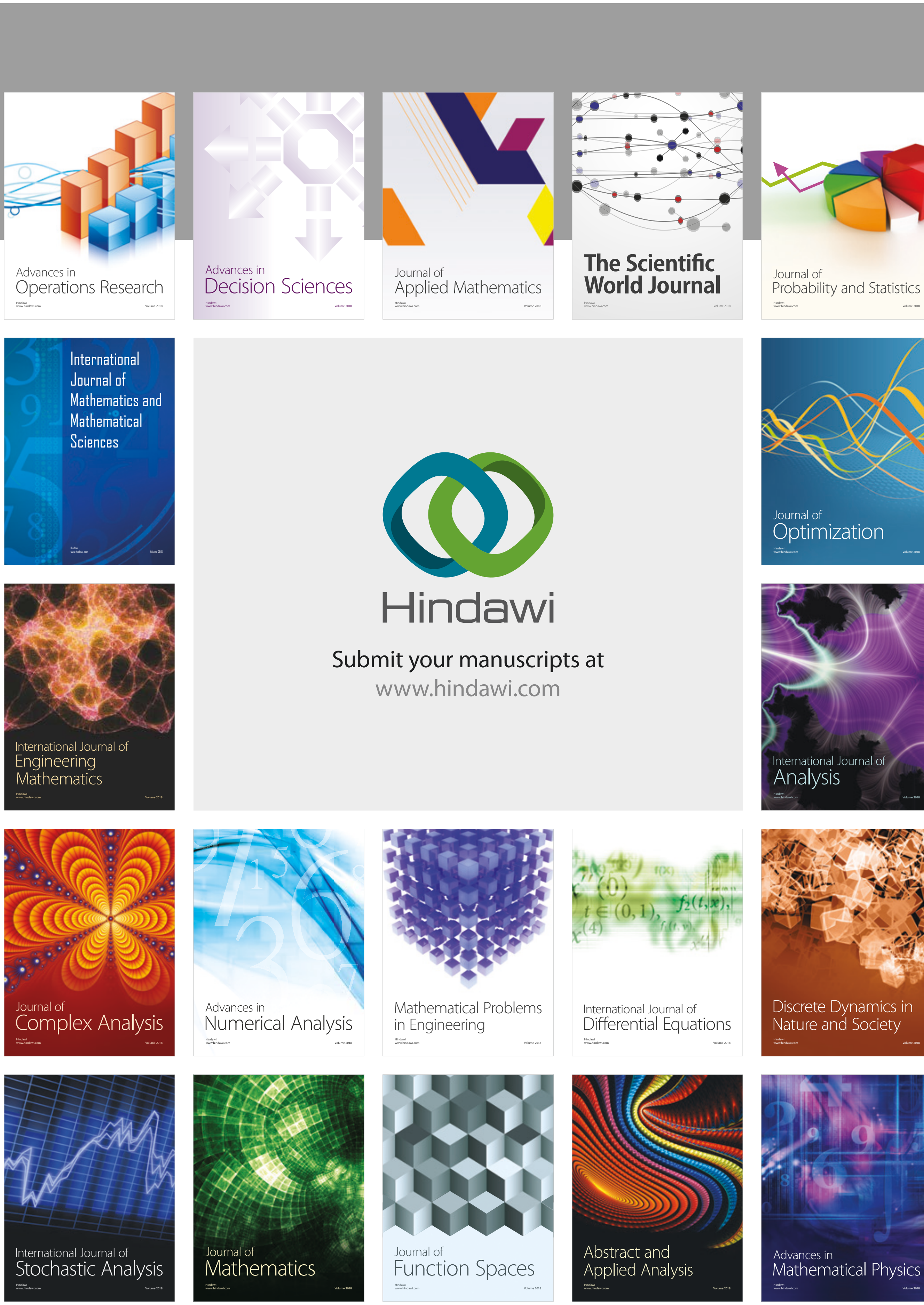
[59] D. J. Teece, "Reflections on 'profiting from innovation,'" *Research Policy*, vol. 35, no. 8, pp. 1131–1146, 2006.

[60] J. Dedrick, K. L. Kraemer, and G. Linden, "Who profits from innovation in global value chains?: a study of the iPod and notebook PCs," *Industrial and Corporate Change*, vol. 19, no. 1, pp. 81–116, 2010.

[61] G. P. Pisano and D. J. Teece, "How to capture value from innovation: shaping intellectual property and industry architecture," *California Management Review*, vol. 50, no. 1, pp. 278–296, 2007.

[62] G. Pisano, "Profiting from innovation and the intellectual property revolution," *Research Policy*, vol. 35, no. 8, pp. 1122–1130, 2006.

[63] E. Enkel, "Attributes required for profiting from open innovation in networks," *International Journal of Technology Management*, vol. 52, no. 3–4, pp. 344–371, 2010.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