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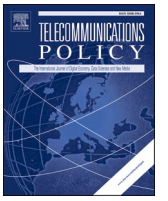

Understanding the evolution of China's standardization policy system

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ABSTRACT

This paper investigates the evolution of China's technology standardization policy system in the period from 1978 to 2021. The standardization policy system comprising the supply, demand, and environment policy tool types has evolved during standardization development process, which includes three sequential stages: 1) the following-up stage, 2) the catch-up stage, and 3) the upgrading stage. In responding to changes in institutional, economic and technological contexts, the policy orientation has transformed from supporting the government-controlled adoption and standardization of foreign technologies in the following-up stage of standardization development process to developing indigenous standards owning independent intellectual property rights (IPRs) through the government-led standardization system in the catch-up stage, and to international standardization adopting both government-led and market mechanisms in the upgrading stage. In this process, the Chinese Government continued to offer policy support to but tended to relax its control over standardization. Of the three policy tool types, the supply type have remained the dominant ones; the weight of the environment-type of tools tended to decrease, and that of the demand-type of tools tended to increase. Further, the government rationalized the mix of each type of policy tools as the standardization contexts changed. From the Chinese experience, theoretical prescriptions for how standardization policy systems evolve in latecomers are developed. Practical implications for latecomer countries to transform standardization policy system and design their standardization policies are discussed.

1. Introduction

Throughout history, a few industrialized countries have dominated the international standardization landscape. Other countries, such as China, have relied on foreign technologies in their economy and paid high patent licensing fees to foreign industrial alliances to use them (Ernst, 2011; Gao et al., 2014). In recent years, this situation has begun to change as China and some other countries have emerged as important players in technology standardization (Seaman, 2020). China in particular has experienced a long, painstaking transition from a foreign standard adopter and follower to an emerging co-leader in key information and communications technologies (ICTs) such as mobile communications systems and wireless communications technologies (Kim et al., 2020; Yu, 2011; Xia, 2022).

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According to the Director of the Standardization Administration of China (SAC), China has become one of the most active countries in international standardization; since the year 2000, the number of technology standard proposals that Chinese organizations have submitted to the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC) for their approval has grown by about 20 percent each year (Tian, 2019). Based on two standardization cases—a third-generation (3G) mobile communications system called Time Division Synchronous Code Division Multiple Access (TD-SCDMA) and a wireless device interconnection system called Intelligent Grouping and Resource Sharing (IGRS), Ernst (2011) concluded that China has strived to own technologies and adjusted its own standardization system to help achieve this ambition. China has quickly learned international standardization practices and focused on using its geopolitical power to change the international standardization system.

Standardization development in China has attracted much scholarly attention. Researchers have examined different aspects of China's transformation efforts from accepting foreign standards to developing indigenous standards and becoming a key player in setting international standards about, for example, geopolitics (Seaman, 2020) and law (Kim et al., 2014). Specifically, the roles that the Chinese Government plays in ICT standardization form a significant research topic in the standardization literature. In general, a weak capability and underdeveloped domestic market provide an upper hand to latecomer countries in standardization (Choung et al., 2012). In particular, latecomer governments need to support efforts to effectively standardize complex technology systems (Ho & O'Sullivan, 2019), which China and South Korea have demonstrated in that their governments have played a key role in enforcing an open policy that embraces collaboration between domestic firms and foreign firms (Gao, 2015; Gao et al., 2021; Kwak et al., 2011). Researchers have described Chinese policymakers as protecting national interests in technology in the face of global powers (Shim & Shin, 2016; Suttmeier & Yao, 2004). The wireless communications standard called Wireless LAN Authentication and Privacy Infrastructure (WAPI) represented techno-nationalism, which nurtured domestic innovation as the country pursued independence from foreign technologies, while the 3G mobile communications system called TD-SCDMA represented techno-globalism, which involved promoting domestic technological advancement along with globalization (Kim et al., 2020; Kwak & Lee, 2012; Lee et al., 2009). Kshetri et al. (2011) argued that China's regulatory system reflects how the country's political and national elites perceive and morally judge domestic and foreign standards, and the state-sponsored nationalism has shaped China's 3G landscape. Gao et al. (2014) attributed the success of China's national standardization campaign to develop TD-SCDMA to the government's ability to balance the interests of different stakeholders in the market. They argued that, in catch-up countries such as China, initiatives to develop and deploy complex technological systems require strong government support to succeed. In standardization, the government can play roles such as project creator, risk undertaker, interest moderator, cooperation facilitator, and process monitor. Through a case study that examined the role that the leading Chinese ICT firm Datang Group played in the TD-SCDMA standardization, Gao (2014) demonstrated that support from the government and public stakeholders such as academics allowed latecomers to overcome the disadvantage in standard competition and develop innovation capabilities. Jakobs (2014) compared China's standardization approaches to the European Union's, and found that Chinese standardization approaches involved government control over all aspects related to developing and using standards. Chinese standardization approaches conflicted with international norms such as free competition and economic liberalization. In recent years, the Chinese Government has faced increasing critiques from the international standardization society to continuously implement them. While the Chinese Government is still strongly involved in standardization, the market-driven mechanism has begun to play an increasingly important role (Kim et al., 2014).

The Chinese Government continues to exercise its influence over enterprise activity and actively designs industrial policy and development; in particular, it uses different policy measures to promote standardization development (van de Kaa et al., 2013; Krug & Hendrischke, 2008). However, researchers have not paid sufficient attention to the Government's role in standardization and its policy measures. Gao et al. (2021) systematically reviewed the literature on 3G mobile system standardization in China that the Chinese government strongly backed. They identified 18 relevant papers published from 2000 to 2017 in four leading journals including *Telecommunications Policy*. Only two papers explicitly focused on the government's role. Specifically, Gao et al. (2014) observed that the Chinese Government enrolled mobile technology stakeholders into the standardization process and balanced their interests in the market. Gao (2015) noticed that the government took regulative, financial, and administrative measures in combination to address emerging standardization challenges. The other 15 papers recognized the Chinese Government as an important actor and considered its role more or less but implicitly. No paper among the 18 focused on government policy. Further, among the limited studies on Chinese standardization policy, the majority used interviewed data to analyze specific cases and technologies. For example, van de Kaa et al. (2013) analyzed government efforts to standardize high-definition digital video disc technology compared to the WAPI system in China and argued that the inconsistency in government policies has threatened the Chinese Government's commitment to implement a catch-up strategy for the technology. Wang et al. (2014) analyzed competition between China and Western countries in Fieldbus standards, document format standards, and audio video coding standards. The three cases examined illustrate the challenges that the Chinese Government has faced in policy measures to encourage domestic firms to patent their standard-related technologies and promote innovation alliances between domestic companies to provide technologies. Ho and O'Sullivan (2019) described how the Chinese Government took appropriate policy instruments to promote smart grid development. However, we still lack work that has systematically analyzed China's standardization policy system, which evolved as the institutional, economic and technological contexts of standardization transformed against the background of economic and political system reform (Liu & Liu, 2015; Yu, 2011).

In this paper, we address this research gap and focus on the standardization policy system in China, a topic largely sidelined in the standardization literature. In particular, we address the following research question (RQ):

RQ How has China's standardization policy system evolved as its institutional, economic, and technological contexts have changed?

To answer this question, we conducted a content analysis on ICT standardization policies that state agencies in China published in

the period from 1978 to 2021. This paper contributes to the literature on standardization (and, in particular, on governmental roles and policies) in latecomer countries through a new research perspective on China's standardization development (i.e., standardization policy system). We delineate the Chinese standardization policy system in transition and how this links to changing institutional, economic and technological contexts. Based on the Chinese experience, we develop theoretical prescriptions for how standardization policy systems evolve in latecomers. Practical implications for latecomer countries to transform their standardization policy systems and design their standardization policies are discussed.

2. Background, theoretical base and analytical framework

From 1978, China started to reform its economic and political system. During this process, its standardization policy system underwent transformation, and the government used different policy measures to promote standardization development (Liu & Liu, 2015; Yu, 2011). Table 1 summarizes key events in China's standardization development process, which includes three sequential stages: 1) the following-up stage, 2) the catch-up stage, and 3) the upgrading stage[1]. In the following-up stage (1978–2000), China mainly adopted foreign standards. In the catch-up stage (2001–2014), China started to catch up developed countries in standardization and could develop standards for both national and international markets. In the upgrading stage (the present stage, 2015–2021), Chinese organizations became important players and competitors to developed countries. Even though we indicate a period for each stage, one cannot clearly separate them. Instead, we divide the standardization development process into the three stages based on milestone events. Specifically, in 2001, China joined the World Trade Organization (WTO). As a WTO member, China needed to form a national standardization system following WTO rules to open the market to foreign technologies and join in international standardization (Liu & Liu, 2015). The Chinese Ministry of Science and Technology implemented (T) implemented a "Talents, Patents, and Technical Standards" strategy to support Chinese organizations to catch up in technology and counter international competition. In 2015, based on the progress in standardization development following the 12th Five-Year Development Plan for Standardization, China published the Scheme for Deepening Reform of the Work of Standardization and the Plan for the National Standardization System Construction (2016–2020), which encouraged a broader range of Chinese organizations to cooperate with foreign standard developers and become key players in both national and international standardization. In this paper, we analyze China's standardization policy system in the following-up, catch-up, and upgrading stages of standardization development.

A standardization policy constitutes a kind of public policy, which refers to a theoretical or technical instrument that one formulates to solve specific problems that affect societies. A public policy refers to a deliberate system of guidelines for decisions to achieve rational outcomes that a government adopts (https://www.sciencedirect.com/science/article/pii/S0161893811000196?casa_token=YJZ7QEIqtasAAAAA:vkxjdS6TxRJB6ya4e0ma56HaGkquKmWIqHdbprzwGygKVsXGrd-qrqBFGsnX0LR8Z5bejz_2uARuizEstrada, 2011). Policy often has a rather broad definition and includes laws, regulations, judicial decrees, and even agency guidelines and budget priorities (Brownson, Chriqui and Stamatakis, 2009).

Governmental actors develop and pursue policies through policy tools (instruments) (Capano & Howlett, 2020); that is, the methods and means that they adopt to solve policy problems, implement policy programs, and achieve policy goals under a corresponding policy environment (Howlett & Rayner, 2007). Researchers have classified policy tools in different ways (Schneider & Ingram, 1990). For example, one can classify policy tools as coercive, non-coercive, or hybrid based on their nature (Howlett, Ramesh and Perl, 2009); as regulatory (i.e., tools that regulate laws and binding regulations to enforce compliance), economic (i.e., tools that provide specific pecuniary incentives), or soft (i.e., tools that offer recommendations and make normative appeals for supporting specific innovation activities) tools (Borrás & Edquist, 2013); or as "generic" (that do not pick up particular technologies or standards) or "targeted" (that select and earmark investments for specific technologies and standards) policies (Choung et al., 2012). Some scholars have considered policy for specific innovation aspects in particular industries or technologies. For example, Georghiou et al. (2014) focused on policy that supports innovation public procurement and divided policy instruments into categories of "framework conditions", "organization and capabilities", "identification, specification, and signalling of needs", and "incentivising innovative solutions".

In this paper, we illustrate China's standardization policy system development. We need a generic and comprehensive policy framework to describe a standardization policy system. From an institutional perspective, Nemet (2009) proposed that one can generally categorize innovation policies as either technology-push or demand-pull ones. However, their framework does not go deeper to consider specific policy tools and, thus, lacks sufficient complexity to serve our research objective here. In the same vein, King et al. (1994) conceptualized a framework for institutional intervention in the innovation process. Institutional actions from both the supply and demand sides include knowledge building, knowledge deployment, mobilization, standards, subsidy, standards, and innovation directive. This framework deals with ICT innovation in general rather than standardization in particular and defines standards as a type of tool. Researchers have widely used the framework to analyze the effect that government actions (but not necessarily their policy measures) have on the extent to which various information technologies diffuse throughout various contexts, such as the 3G mobile system in China (Gao, 2015), cellular telephone service in three continents (West, 2000), and messaging services in Norway and Japan (Knutsen & Lyytinen, 2008). Adding the environment dimension to the institutional perspective, Rothwell and Zegveld (1985) classified policy tools as either supply, demand, or environmental tools that provide support or exert influence on industrial development and technological innovation from the supply side, the demand side, and the environment side, respectively. Su (2014) further

[1] We refer to this stage as the upgrading stage based on the SAC Director (i.e., the top standardization official in China). See Tian (2019).

Table 1
Key events in China's standardization development.

Stage	Time	Events
Following-up stage	May 1978	Established Standardization Administration of China (SAC) under the State Council
	September 1978	Set up China Association for Standardization (CAS) (changed to National Standards Bureau in May 1982; changed back to CAS after being re-structured in 2001)
	July 1979	The State Council promulgated the Regulations on Standardization Administration
	August 1979	Started to set up technical standardization committees for specific sectors
	April 1984	National Standards Bureau issued the Administrative Measures for the Adoption of International Standards and Advanced Foreign Standards
	December 1984	AQSIQ issued the Administrative Measures for Review of Standardization in Technology Introduction and Equipment Import
	July 1988	National Standards Bureau, National Metrology Bureau and State Economic Commission Quality Bureau were merged to form the State Technical Supervision Bureau
	December 1988	National People's Congress promulgated the Standardization Law
	December 1989	Formed the National Standardization Technical Committee for Quality Management and Quality Assurance
	April 1990	The State Council issued the Regulations for the Implementation of the Standardization Law
	October 1992	AQSIQ issued Guidance for Quality Management and Quality Assurance in Standards
	May 1996	National People's Congress promulgated Law for Promoting the Transformation of Scientific and Technological Achievement
Catch-up stage	2001	MOST implemented "Talents, patents and technical standards" strategy
	December 2001	China joined the WTO
	December 2005	State Council published the National Medium- and Long-Term Plan for the Development of Science and Technology (2006–2020)
	December 2006	SAC issued the 11th Five-Year Development Plan for Standardization
	January 2007	AQSIQ, MOST etc jointly issued the Rules for Supporting the Research and Application of Key Technical Standards
	October 2008	China became a permanent member of the 1SO
	December 2009	MOST issued Measures for Promoting the Formation of Industrial Technology Innovation Strategic Alliances
	October 2011	China became a permanent IEC member
	December 2011	Issued the 12th Five-Year Development Plan for Standardization
Upgrading stage	March 2015	Issued the Scheme for Deepening Reform of the Work of Standardization
	December 2015	The State Council issued the Plan for the National Standardization System Construction (2016–2020)
	September 2016	Hosted the 39th ISO Conference
	April 2017	SAC and ISO signed agreements to jointly build an international standardization training base (in Qingdao) and an international standardization conference base (in Hangzhou)
	June 2017	MOST and SAC issued the 13th Five-Year Plan for Technical Standards and Science and Technology Innovation
	November 2017	Amended the Standardization Law
	November 2018	Published Action Plan for Harmonization of Standards for Jointly Building the Belt and Road
	October 2019	Hosted the 83rd IEC Congress
	November 2019	Issued the Notice on Synchronizing Project Approval, Simultaneous Formulation and Simultaneous Release of National Standards and their Foreign language versions
	April 2020	State Administration for Market Regulation revised the Administrative Measures for Rewarding Innovative Standard Development
	October 2021	The State Council issued the Outline of National Standardization Development
	December 2021	SAC etc released the 14th Five-Year Plan for the Construction of a National Standard System

specified the policy tools in each type. Supply-type tools represent policies that focus on emerging technologies and industries and include "education and training", "information support", "government subsidy", "public service", and "technology and organization". Demand-type tools reduce market uncertainty and include "government procurement", "standard internationalization", "pilot and demonstration", "propaganda", and "setting up overseas institutions". Environment-type tools include "goal planning", "financial support", "tax incentive", "intellectual property", and "regulation control".

A standardization policy system revolves around these three aspects of technological and industrial development (i.e., supply, demand, and environment) (Zhang & Qin, 2018). Accordingly, we refer to how Rothwell and Zegveld (1985) and Su (2014) define a standardization policy system as comprising the supply-, demand- and environment-type policy tools (see Table 2 for a summary). We use this generic classification and specification to analyze China's standardization policy system in depth.

How governments design policy tools and select the specific tool combinations depend on a brand range of factors such as institutional context, governmental capacity, financial resources, political support or opposition, information availability, and past policy choices. As these factors can change, governments will have different standardization objectives and face differing and fluctuating

Table 2
Definitions of standardization policy tools (Based on Rothwell & Zegveld, 1985; Su, 2014).

Policy tool type	Policy tool	Functions
Supply type	Education and training	Provide talent training and training platforms and channels
	Information support	Disclose standard texts to the society, and provide a platform for sharing standard information
	Government subsidy	Offer financial support for standardization activities
	Public service	Provide consulting, promotion and guidance services for standardization and other related information e.g. WTO/ITU-T calls for standardization initiatives
	Technology and organization	Support R&D, establish science and technology projects to develop standards, and set-up of new standards-setting organizations
Environment type	Goal planning	Have a strategy and describe and outline the standardization goals and vision in general
	Financial support	Promote standard development through means such as financing, subsidies, venture capital, franchises, financial allocation, equipment loans, export credits, etc.
	Tax incentive	Support relevant entities engaged in standardization activities through fiscal means, tax incentives, subsidies, etc.
	Intellectual property	Protect IPRs, and adopt RAND (reasonable and non-discriminating) principle in licensing
	Regulation control	Supervise and regulate the standardization activities
Demand type	Government procurement	Implement public procurement regulations and improves the procurement information release mechanism
	Standard internationalization	Adopt international standards and foreign advanced standards Strengthen mutual recognition with foreign standards, participate in the formulation of international standards, and participate in international standardization activities
	Pilot and demonstration	Establish standard pilot project bases, and promote standards through pilot demonstrations
	Propaganda	Disseminate standardization knowledge, and improve standardization awareness
	Setting up overseas institutions	Directly or indirectly support setting up standardization bodies and standard demonstration bases overseas

challenges; accordingly, they need to employ a different mix of policy tools (McDonnell & Elmore, 1987). In this paper, we analyze how the standardization policy system in China has evolved against dynamic standardization contexts. Based on the literature that we discuss above, we form our analytical framework as we show in Fig. 1. Specifically, we can divide the standardization development in China into the following-up, the catch-up, and the upgrading stages. Each stage involves a specific standardization context that includes institutional, economic, and technological dimensions that determine the role that the government plays in standardization (Choung et al., 2012; Narayanan & Chen, 2012). Thus, in a standardization policy system, governments have different policy orientations and employ supply-, demand- and environment-type policy tools in different combinations to address specific standardization problems and challenges.

3. Research methods

We organized the data collection and analysis according to the framework in Fig. 1. We focused on collecting data that we could use to delineate how the Chinese Government has used different standardization policy tools across the following-up, catch-up and upgrading stages of standardization development. In particular, we sourced data from "pkulaw.com", a website affiliated with the Law School of Peking University that offers online Chinese legal services and supplies various databases that contain Chinese laws and regulations with supplementary judicial cases, legal news, and other legal materials. From 15 January to 10 February 2021, and from 5 to 31 December 2021, we first used "standardization policy" and "technology standard" as keywords to search the databases and initially found 396 documents. In accordance with the research question, we then further screened these gathered policy documents to

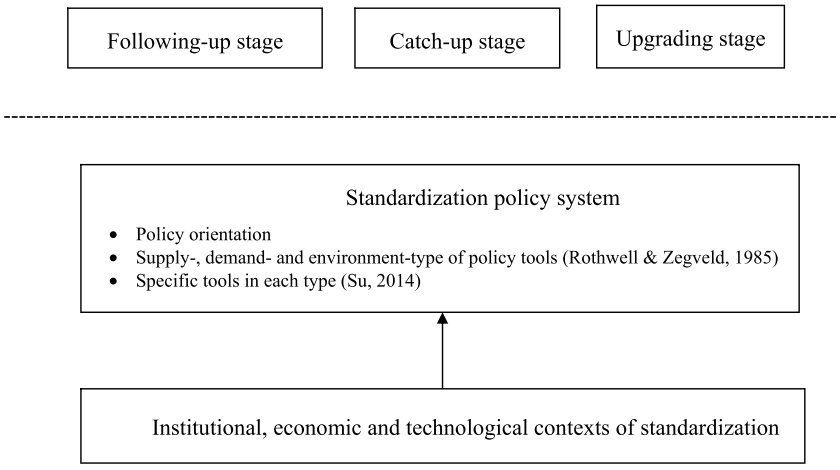

Fig. 1. Analytical framework of standardization policy system evolution in China.

identify national policies concerning ICT standardization. We found and retained 191 such documents for content analysis, which the state lawmaker (the National People's Congress) and national authorities responsible for ICT standardization work (e.g., State Council; the SAC; the General Administration of Quality Supervision, Inspection and Quarantine (AQSIQ); the MOST; the Ministry of Industry and Information Technology; and others) issued individually or jointly. Furthermore, we read through the 191 documents and identified 647 policy tools in them. Based on the definitions in Table 2, we labeled each of these identified tools, and categorized it to the supply-type, or the demand-type, or the environment-type. To ensure we validly categorized the policy tools found in the documents, the first and the third authors read and coded the documents independently. In cases where the authors disagreed or felt unsure about how to categorize a policy tool, we consulted colleagues who conduct standardization policy research to achieve consistency. Finally, we profiled standardization policy tools in each standardization development stage in China and understood trends in policy tool combinations by analyzing the institutional, economic, and technological contexts.

4. Results

4.1. Overview of the published standardization policies and their use of policy tools

In the standardization development process in China, we found the average number of standardization policies released per year has tended to increase over time (see Fig. 2). Of the 191 standardization policy documents that we analyzed, 33 policies appeared in the following-up stage (i.e., 1.4 policies per year on average), 60 policies appeared in the catch-up stage (i.e., 4.3 policies per year on average), and 98 policies in the upgrading stage (i.e., 14 policies per year on average).

According to how we define and classify policy tools (see Table 2), we categorized how frequently the Chinese Government used the 191 different standardization policy tools (see Table 3). One can see that it used the policy tools 647 times in total. In particular, it used supply-type policy tools the most often (311 times/48.07%), the environment-type policy tools the second most frequently (173 times/26.74%), and the demand-type policy tools the least frequently (163 times/25.19%). Thus, the supply-type policy tools dominated throughout all three stages (i.e., they accounted for 46.05, 47.40, and 48.74% of all policy types in the following-up, the catch-up, and the upgrading stages, respectively). The environment-type policy tools tended to decrease in proportion over time from 46.05 percent in the following-up stage to 29.48 percent in the catch-up stage and 21.86% in the upgrading stage. The demand-type policy tools tended to increase in proportion over time from 7.89 in the following-up stage to 23.12 in the catch-up stage and 29.40 percent in the upgrading stage.

As for specific tools, the government used the "technology and organization" tool (supply-type) the most frequently (119 times) followed by the "regulation control" tool (environment type) (109 times), which implies that the government provided strong support and guidance in regards to standardization.

4.2. The evolution of the standardization policy system

Draw on the framework in Fig. 1 and definitions on standardization policy tools in Table 2, we now analyze how the standardization policy system in China evolved during the three standardization development stages alongside transformations in the institutional, economic, and technological standardization contexts.

In the following-up stage, two legal documents played a fundamental role in the government's activities to govern standardization activities. Specifically, the "Regulations on Standardization Administration" promulgated in 1979 provided the legal basis for China's standardization work for the next decade (1979–1988). It stipulated that relevant government-formed technical committees should draft standards that the government would then publish. In December 1988, policymakers promulgated the "Standardization Law" to replace the "Regulations on Standardization Administration". This law sustained the government's position in standardization, the only provider of national standards with the responsibility to not only invest in standardization but also establish standard-setting organizations (e.g., technical committees), train standardization personnel, and publicize and promote standards. The government allowed companies to formulate their own standards only for their own products, which they needed to report to the relevant standardization authorities for record purposes. Two policies played a fundamental role in the government's efforts to implement these

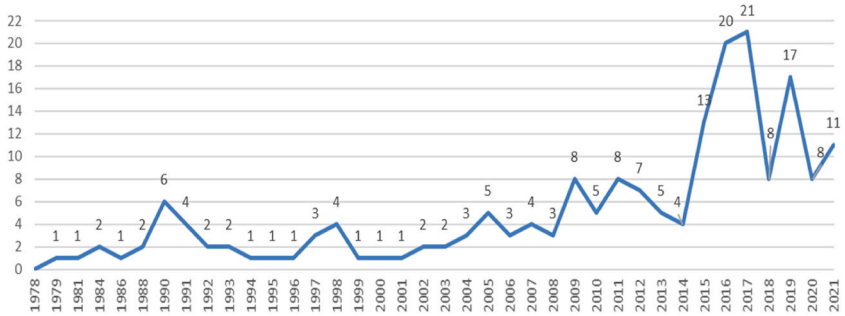

Fig. 2. Number of policies released by year.

Table 3
Statistics on the How Frequently the Chinese Government used Standardization Policy Tools.

Policy tool Type	Policy tools	Overall frequency	Whole process overall (%)	Following-up stage (%)	Catch-up stage (%)	Upgrading stage (%)
Supply type	Education and training	57	48.07%	46.05%	47.40%	48.74%
	Information support	43				
	Government subsidy	62				
	Public service	30				
	Technology and organization	119				
		311				
Environment Type	Goal planning	30	26.74%	46.05%	29.48%	21.86%
	Financial support	14				
	Tax incentives	2				
	Intellectual property	18				
	Regulation control	109				
		173				
Demand Type	Government procurement	5	25.19%	7.89%	23.12%	29.84%
	Standard internationalization	72				
	Pilot demonstration	29				
	Propaganda	51				
	Setting up overseas institutions	6				
		163				
Overall		647	100%	100%	100%	100%

laws. The first, the Administrative Measures for the Adoption of International Standards issued in April 1984, helped organizations adopt international standards and advanced foreign standards as an important component of introducing technology in China. The second, the Administrative Measures for Standardization Review of Technology Import and Equipment Import, required Chinese companies to consider absorbing international standards to benefit indigenous standardization when introducing foreign technologies and equipment.

In the following-up stage, in the standardization policy system, the supply-type and the environment-type tools each accounted for 46.05 percent of all tool types followed by demand-type tools, which accounted for only 7.89 percent (see Fig. 3 for illustration). Among the supply-type policy tools, the "government subsidy" tool, which included providing funding and offering incentives for localizing foreign standards, accounted for 28.57 percent of all such tools. The "technology and organization" tool, which involved establishing science and technology projects and supporting government-controlled standardization bodies to undertake these projects to develop standards, accounted for 22.86 percent. The "information support" tool, which involved providing information on domestic and foreign standards, accounted for 22.86 percent. The "education and training" tool, whose content covered supporting standardization training, and offering guidance on standard assessment for standard developers and publishers, and standardization supervisors and inspectors, accounted for 20.00 percent. Among the environment-type policy tools, the "regulation control" tool accounted for 94.29 percent of all such tools, which reflects the government's tight control over standards development activities. The "intellectual property" tool accounted for only 2.86 percent, which reflects that the government did not pay significant concern to

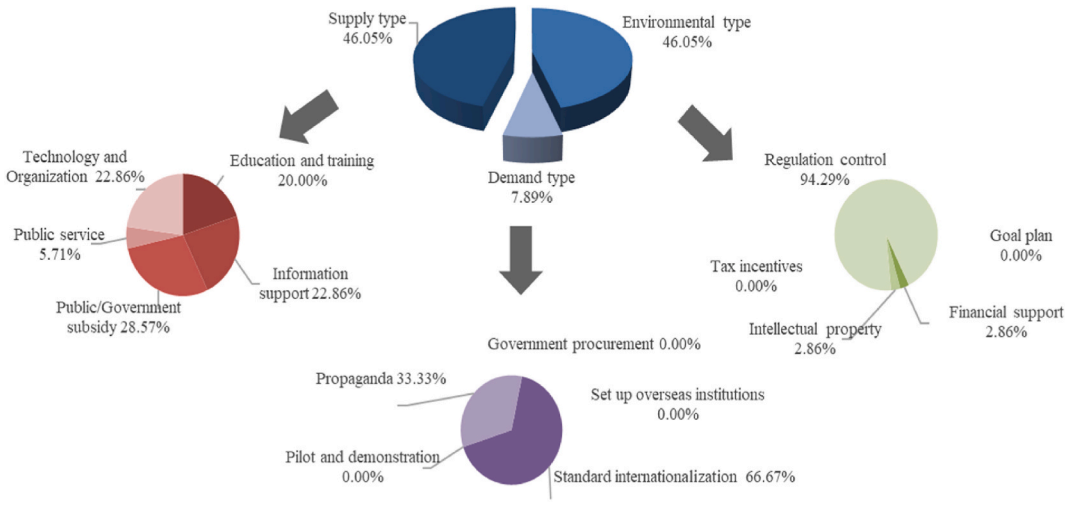

Fig. 3. Frequency with which the Chinese Government Used Policy Tools in the Following-up Stage.

developing standards with their own independent intellectual property rights (IPRs). Among the demand-type policy tools, the government used only the "standard internationalization" and the "propaganda" tools, which accounted for 66.67 and 33.33 percent, respectively. The government used both tools to support different industries following foreign technologies and standardization and adopting international standards and advanced foreign standards.

In the catch-up stage (2001–2014), the government took policy measures to support developing indigenous technologies and ensured they won in competitions with foreign technologies. In 2001 China became a formal member country of the WTO. The impetus of this policy orientation was to cope with the WTO requirement for competition in technologies and market mechanism in standardization (Liu & Liu, 2015). The State Council published the National Medium- and Long-Term Plan for the Development of Science and Technology, which proposed an indigenous innovation strategy of supporting standardization based on improving technological capability. Like in the previous standardization development stage (i.e., the following-up stage), in the catch-up stage, the government led standard formulation and implementation efforts. Different from before, the government encouraged industrial organizations and research and development (R&D) institutions and their alliances to develop indigenous standards while controlling the IPRs (Ernst, 2011; Kennedy, 2006). For example, during the period from 2002 to 2005, China established the TD-SCDMA industrial alliance to develop a 3G mobile communications standard, and IGRS alliance worked on a standard for the wireless interconnections between computer, communications, and consumer electronics devices. The 11th Five-Year Development Plan for Standardization promulgated in December 2006, set the target for standardization technical committees to increase in number from 700 in 2006 to 2000 in 2008 and 2600 in 2010.

In the catch-up stage, the supply-, environment- and demand-type policy tools accounted for 47.40, 29.48, and 23.12 of the whole, respectively (see Fig. 4). Among the supply-type policy tools, the "technology and organization" tool, which accounted for 36.59 percent of all such tools, saw the most use. The government used this policy tool to support forming more standardization technical committees and industrial alliances to work on various science and technology projects to develop indigenous technological standards. The "government subsidy" tool accounted for 23.17 percent. It focused on providing financial funds to R&D and standard development efforts and encouraging companies, research institutes, and universities to jointly form standardization alliances to engage in indigenous innovation and develop standards while controlling IPRs. The "regulation control", the primary environment-type policy tool, accounted for 60.78 percent. The "intellectual property" tool accounted for 13.73 percent, much higher than in the previous stage, which reflects the attention that the government paid to developing standards with its own independent IPRs. Among the demand-type policy tools, we identified the "propaganda" (35.00%) and the "standard internationalization" (32.50%) as the main tools that the government adopted. It used both these tools to support Chinese companies and industrial alliances to adopt international standards and advanced foreign standards and to participate in or lead efforts to formulate international standards. Compared to the following-up stage, the "pilot and demonstration" and the "government procurement" tools accounted for 25.00 and 7.50 percent, respectively. The "pilot and demonstration" tool included setting up national standardization pilot projects, conducting experiments, and promoting standards with social and economic benefits to the whole country.

The standardization development entered the upgrading stage in 2015. In this stage, the government supported efforts that Chinese organizations made to play a leading role in international standardization. China tried to integrate its standardization system with major standard-setting bodies' standardization systems such as the ISO and various international industrial forums and to jointly set standards with foreign companies (Seaman, 2020). The State Council promulgated the Scheme for Deepening Reform of the Work of Standardization in March 2015. Furthermore, the government amended the Standardization Law in 2017. Both policy documents outlined a new standardization system and granted industrial alliances and associations legal status as standardization organizations. It allowed not only government coordination to develop standards as before but also industrial organizations and, hence, the market to do so themselves. It also encouraged Chinese organizations to cooperate with foreign standard developers and to participate in

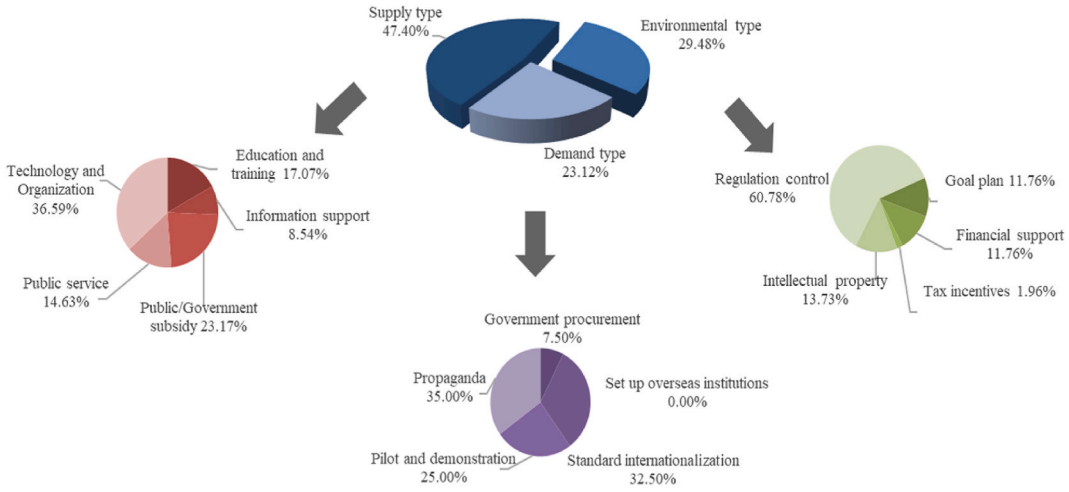

Fig. 4. Frequency with which the Chinese Government Used Policy Tools in the Catch-up Stage.

international standardization. According to the Annual Report on Standardization Development of China (2019) that the SAC published, by 2019, China signed 97 agreements on bilateral and multilateral standardization cooperation projects. In 2017 the MOST and SAC jointly issued The 13th Five-Year Plan for Technical Standards and Science and Technology Innovation, which set the National Science and Technology Program that, by 2020, would sponsor to develop more than 1000 technological standards. The government would strengthen support for efforts to standardize digital ICTs, complex manufacturing systems, and so on that had critical importance for Chinese firms to become key players in the global value chain. In October 2021, the State Council promulgated the Outline of National Standardization Development, which defined goals and identified key tasks for developing standards by 2025 and 2035, respectively. It also proposed various supportive measures.

In the upgrading stage, the supply-, demand- and environment-type policy tools accounted for 48.74, 29.40, and 21.86 percent, respectively (see Fig. 5). Among the supply-type policy tools, the "technology and organization" tool accounted for 41.75 percent. The government used this policy tool to increase the number of standard-setting organizations (which included companies and their alliances and associations), grant these market entities the legal status as standardization bodies, and support them to develop indigenous standards and compete in international standardization. The "education and training" tool accounted for 18.56 percent. It enhanced the standardization knowledge base and capability, which involved setting up training programs and degree certification courses on standardization in several universities and publishing various education and training textbooks (Jakobs, 2014). The major environment-type policy tools "regulation control" and "goal planning" accounted for 51.72 and 27.59 percent, respectively, which reflects the government's involvement in standardization. The "intellectual property" tool accounted for 11.49 percent, a similar level to the previous stage. Thus, the government continued to support developing indigenous standards with independent IPRs. Among the demand-type policy tools, "standard internationalization" (47.01%) emerged as the most used tool. The "propaganda" and "pilot and demonstration" tools accounted for 29.91 percent and 16.24 percent, respectively. The policy tool "setting up overseas institutions" emerged in this stage and accounted for 5.13 percent. The "government procurement" tool accounted for only 1.71 percent, which shows the government exerted very weak pull force to standardization development.

4.3. *Trends in how frequently the government used different types of standardization policy tools*

First, as Table 3 shows, we identified the supply-type policy tools as the most frequently used tools across all three standardization development stages in China. We illustrate the changes in how frequently the government used these different supply-type policy tools in Fig. 6. The supply-type policy tools provide thrust to standardization activities from the supply side (Rothwell & Zegveld, 1985). The government used these tools more than any other (i.e., they accounted for 46.05%, 47.4%, and 48.74% in the following-up, catch-up, and the upgrading stages, respectively). This finding concurs with an OECD survey on Chinese Government innovation policies, which found that the Chinese Government has traditionally relied on supply-side policies to promote innovation (OECD, 2008). Among the supply-type policy tools, the government used the "technology and organization" tool the most frequently and it increased over time through the three stages (from 22.86% in the following-up stage to 36.59% in the catch-up stage and 41.75% in the upgrading stage). In contrast, it tended to use the "government subsidy" less frequently over time. This trend for both tools reflects an orientation towards gradually relaxing government control on standardization activities and supporting domestic companies to participate in standardization.

We have identified the different standardization bodies in different stages. Specifically, in the following-up stage, technical committees under governmental jurisdiction were the main standardization bodies to adopt foreign standards and formulate national standards. In the catch-up stage, in addition to different technical committees, industrial organizations and R&D institutes as well as

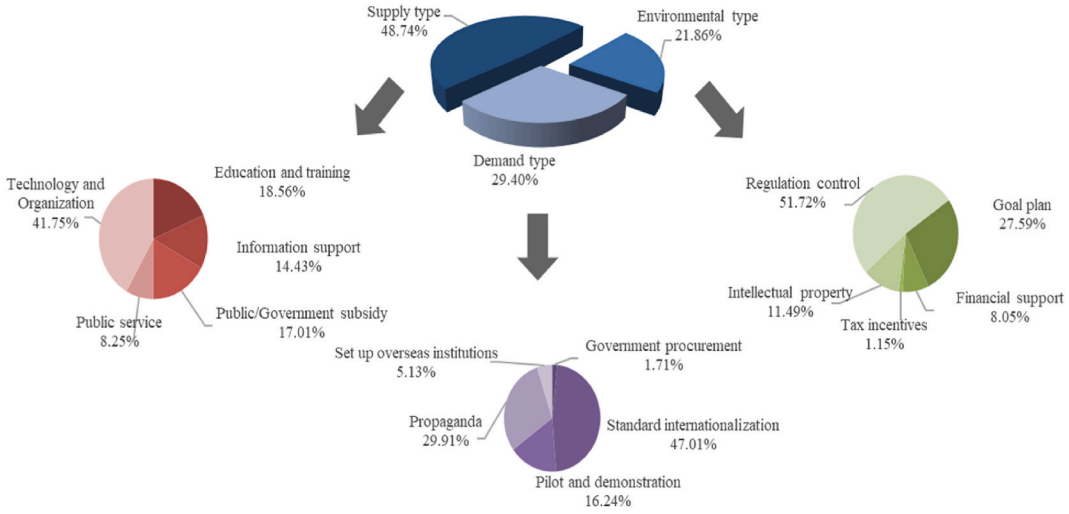

Fig. 5. Frequency with which the Chinese Government Used Policy Tools in the Upgrading Stage.

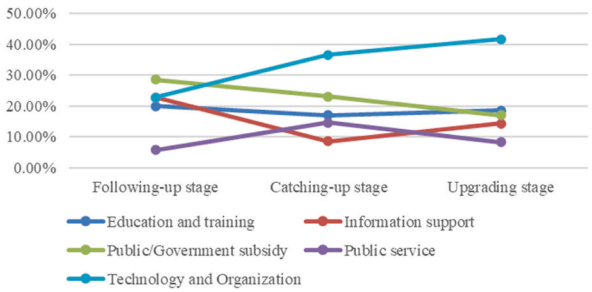

Fig. 6. How the Frequency with which the Chinese Government Used Supply-type Policy Tools Evolved Over Time.

their alliances were encouraged to develop standards for both national and international markets while controlling the IPRs. In the upgrading stage, industrial alliances and associations received legal status as standardization organizations and actively participated in international standardization.

Second, the frequency with which the government used demand-type policy tools tended to increase over time (see Table 3). Fig. 7 illustrates this trend for different supply-type policy tools. Demand-type policy tools pull standardization activities from the market side (Rothwell & Zegveld, 1985). While demand-type policy tools attracted low use in the following-up stage and accounted for only 7.89 percent, their use increased to 23.12 percent in the catch-up stage and 28.53 percent in the upgrading stage. These results suggest that the government tended to increase the extent to which it supported standardization from the demand-pull side.

As Borrás and Edquist (2013) suggest, demand-side policies can help governments identify demand for new products and form new product markets. In this way, the policies can help them apply new standards. We identified the "standard internationalization" tool as the main demand-type policy tool in each stage of standardization development in China. In the following-up stage, the government used it to support efforts to adopt international standards and advanced foreign standards; in the catch-up stage, the government used it to support Chinese organizations to develop standards for international market; finally, in the upgrading stage, the government used it to promote Chinese organizations to actively participate in international standardization, guide international collaboration, and promote collaborative efforts between China and other countries to mutually inspect, certify, and adopt standards. For example, the Action Plan for Harmonization of Standards for Jointly Building the Belt and Road issued in 2018 applied this tool to promote standard internationalization between China and the "belt and road" countries. The "setting up overseas institutions" tool emerged as a new tool in the upgrading stage. The government used it to help diffuse Chinese standards in other countries and foster Chinese organizations to participate in international standardization.

Third, overall, the government used environment-type policy tools less frequently over time. Fig. 8 illustrates this trend for different environment-type policy tools. The environment-type policy tools provide support to or influence on standardization activities (Rothwell & Zegveld, 1985). During the standardization system evolution process, among environment-type policy tools, the "regulation control" emerged as the main tool that the government used though it did so significantly less frequently over time (from 94.29% in the following-up stage to 60.78% in the catch-up stage and 51.72% in the upgrading stage). On the contrary, the government used the "goal planning" tool more frequently over time (from 0% in the following-up stage to 11.76% in the catch-up stage and 27.59% in the upgrading stage). The frequency with which the government used the "intellectual property" tool significantly increased from 2.86 percent in the following-up stage to 13.73 percent in the catch-up stage before remaining at a similar level in the upgrading stage being 11.49 percent. The "financial support" tool and the "tax incentive" tool to support companies to participate in standardization activities remained at a low use frequency. These changes in how frequently the government used specific environment-type policy tools reflects that the government tended to play a less important role in standardization and changed from direct intervention to guidance. In other words, the Chinese standardization system transformed from the government exerting control to letting the market play a more important role with companies and R&D institutes and their alliances as the key players in standardization (Kim et al., 2014; Seaman, 2020).

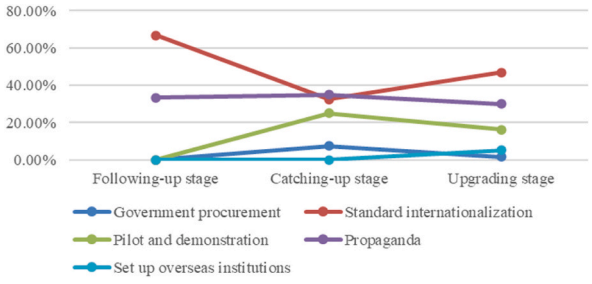

Fig. 7. How the Frequency with which the Chinese Government Used Demand-type Policy Tools Evolved Over Time.

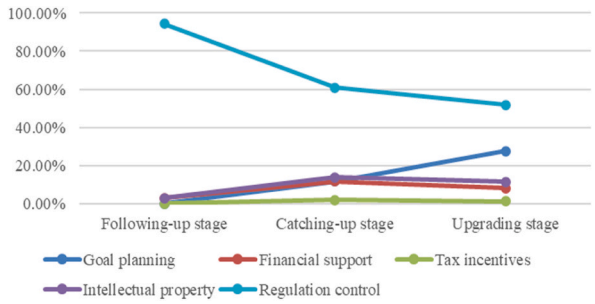

Fig. 8. How the Frequency with which the Chinese Government Used Environment-type Policy Tools Evolved Over Time.

5. Discussions

5.1. Linking the standardization policy system with the context

Kim et al. (2014) found that China's focus in standardization has evolved in a trajectory of using foreign technologies in domestic market, developing indigenous technologies, and participating in international standardization of technologies targeting on foreign markets. Kim et al. (2020) demonstrated that, as China's position in international economy has rapidly strengthened, its standardization strategy has shifted from catching up to first mover. Kim et al. (2014) found that has changed into weighing more on the

Table 4
China's standardization policy system and contexts by stage.

	Following-up stage (1978–2000)	Catch-up stage (2001–2014)	Upgrading stage (2015–2021)
Institutional, economic and technological, contexts	• Planned economic system • Underdeveloped economy • Low technological capability	• Joining WTO; government-controlled market mechanism • Fast economic development • Catch up with foreigners in technological capability	• Market mechanism • Leading economy in the world • Caught up in technological capability
Standardization policy orientation	• Government controlled standard development and diffusion • Adopt and localize international standards and foreign advanced standards • Standard development by committees of government-controlled organizations	• Government-led standard development and diffusion. The government relaxed control on standardization • Encouraged industrial organizations and R&D institutes as well as their alliances to develop standards for both national and international markets while controlling the IPRs	• Both the government-led and market mechanisms existed in standardization • Promote the internationalization of national standards and the participation of Chinese organizations in international standardization.
Policy tools	• Supply- and environment-types of tools accounted for 46.05% of all policy tools each; demand-type of tools only 7.89%. • Major tools by type: *Supply-type*: Government subsidy (28.57%), Technology and organization (22.86%); Information support (22.86%); Education and training (20%) *Environment-type*: Regulation control (94.29%) *Demand-type*: Standard internationalization (66.67%); Propaganda (33.33%)	• Supply-type tools were dominant, accounting for 47.4%; demand- and environment-types of tools 23.12%, 29.48%, respectively. • Major tools by type: *Supply-type*: Technology and organization (36.59%); Government subsidy (23.17%) *Environment-type*: Regulation control (60.78%) *Demand-type*: Propaganda (35%); Standard internationalization (32.5%); Pilot and demonstration (25%) • Emerging tools: *Demand type*: Pilot and demonstration (25%); Government procurement (7.5%) *Environment-type*: Goal planning (11.76% Tax incentives (1.96%)	• Supply-type tools were dominant, accounting for 48.74%; demand- and environment-types of tools 29.4%, 21.86%, respectively. • Major tools by type: *Supply-type*: Technology and organization (41.75%) *Environment type*: Regulation control (51.72%); Goal planning (27.59%) *Demand-type*: Standard internationalization (47.01); Propaganda (29.91%) • Emerging tools: *Demand type*: setting up overseas institutions (5.13%)

development of international standards rather than on national standards. We describe the standardization development in China as a process that has gone through three stages: the following-up stage (1978–2000), the catch-up stage (2001–2014), and the upgrading stage (2015–2021). In each stage, the specific institutional, technological, and economical context confined the policy orientation and, furthermore, the policy system's design (see Table 4).

Narayanan and Chen (2012) suggested institutional environment as a condition for a standardization organizer to design a standardization strategy. Choung et al. (2012) concluded that indigenous innovation evolves as national industries accumulate capabilities; a government should base its indigenous innovation policy on its catch-up status and its country's indigenous capabilities. Governments should tailor policy tools according to their specific standardization challenges and targets (Borrás & Edquist, 2013; bib_citation_to_be_resolvedCapano et al., 2020), which contextual factors determine (McDonnell & Elmore, 1987). Our analytical results add to the literature and show that, in China, in the standardization development process consisting of following-up, catch-up and upgrading stages, the government had a specific policy orientation in each stage, and accordingly used a mix of the supply-, demand-, and environment-type policy tools to address relevant challenges raised from specific institutional, economic, and technological contexts (see Table 4).

In the following-up stage, China had a weak technological capability and limited R&D funds. The national economy remained undeveloped. As Choung et al. (2012) and Zoo et al. (2017) have suggested, in such a technological and economic context, China adopted international standards and advanced foreign standards for domestic use rather than develop indigenous standards with independent IPRs. The government oriented its standardization policy to ensure economic growth based on foreign technologies and localized foreign standards. China developed technological capability and improved its standardization level by learning from foreign countries and imitating cutting-edge Western technologies (Gao et al., 2021). With regard to the institutional context, in this stage the government controlled the national economy and planned the national R&D activities, though there was a sign of gradually opening the market for competition. Against this background, the government relied on tools such as "regulation control" and "government subsidy" to control standardization. It formed various different committees of government-controlled organizations as the national standardization bodies and granted firms opportunities to participate in standardization though mainly on their own standards.

Through the following-up stage, the national economy grew quickly, which set the economic foundation for China to further build up indigenous technological capabilities to develop standards with independent IPRs to reduce its dependence on foreign technologies in economic development (Kennedy, 2006). As a result, the country significantly improved its national technological capability. The national science and technology strategy changed from imitating foreign technologies in the previous stage to catching up to Western countries in standardizing cutting-edge technologies (Gao et al., 2021). Moreover, in 2001, China joined the WTO. As a result, China would further open the market for competition and became an important member in the global production and technology network (Liu & Liu, 2015; Yu, 2011). China started to follow WTO rules to manage its economic system. Public-private business partnerships emerged and grew. Alliances between economic and government actors has pursued and developed their economic interests (van de Kaa et al., 2013; Krug & Hendrischke, 2008). In this context, in 2001, China entered the catch-up stage in standardization. To maneuver broader resources into standardization and technological development, China reformed its incumbent national standardization system and transformed its standardization policy orientation. The government relaxed its control on standardization and encouraged industrial organizations and R&D institutes and their alliances to develop standards for both national and international markets while controlling IPRs. The government tended to use the "regulation control" tool less frequently to control the standardization and rely more on the "technology and organization" policy tool to promote efforts to set up science and technology projects and form new standard-setting organizations.

Through the catch-up stage, China gained substantial technological capability for developing standards of important technological systems and emerged as a key player in important ICTs such as 5G mobile communications systems (Kim et al., 2020; Xia, 2022). China reached the top level of the "standardization ladder" that the International Telecommunications Union's Telecommunication Standardization Sector (ITU-T) set (Jakobs, 2014). Against this background and also based on the national economy's growth, in 2015, technology standardization moved into the upgrading stage when China made efforts to develop indigenous standards and became increasingly active in setting international standards. China needed to reform its existing government-led standardization system and let the market mechanism coordinate standardization activities, which meant firms become main standardization bodies that engaged in standardization. The government started to use the "setting up overseas institutions" tool to promote Chinese participation in international standardization. It used the "technology and organization" tool to create standard-setting organizations that could have competitive R&D capability and engage in developing both indigenous and international standards.

As Table 3 shows, across the following-up, catch-up, and upgrading stages in the standardization development process, the supply-side tools dominated the standardization policies that the government issued (especially the "technology and organization" tool). It also tended to use environment-type tools less frequently over time and the demand-type tools more frequently over time. The government continued supporting standardization development, but its policy orientation and the types of policy tools it used changed as one can see in its continued emphasis on the "technology and organization" and "goal planning" tools and less emphasis on the "government subsidy" and "regulation control" tools (see Figs. 6–8). This trend reflected a change in the government's roles. Gao et al. (2014) note that a latecomer government can play several roles in standardization: a founder, risk undertaker, interest moderator, collaboration facilitator, and process monitor. In this paper, we further found that the Chinese Government played different roles at different stages and contexts. In the following-up stage, the government played all of these roles. In the catch-up stage, both the Chinese Government and companies acted as standardization founders, risk undertakers, and process monitors. In both the catch-up and the upgrading stages, the government's role changed from a standardization implementer to a facilitator and a guider. It continued to have an interest in moderating and facilitating collaborations for standardization alliances or associations as its other roles weakened. In each stage, the policy system i.e. a mix of different policy tools is designed to support the government fulfilling specific

roles.

5.2. Theoretical prescriptions

From the Chinese experience, we can conclude with theoretical prescriptions for how policy systems evolve in latecomers. First, the standardization development in a latecomer country should proceed by following-up stage, catch-up stage and upgrading stage. The onset and completion of each stage depends on the technological, economic, and institutional contexts. Second, within each stage of standardization development, a latecomer government should set its policy orientation and design its policy system with a mix of policy tools by referring to the technological capability, economic development level, and institutional environment within that stage. Third, across the three stages of standardization development, a latecomer government may continue applying demand-type policy tools moderately, gradually reduce the use of environment-type tools, but focus on using supply-type policy tools to create momentum for relevant organizations to engage in standardization.

5.3. Practical implications

We can draw several implications from China's experience for technology latecomers to transform standardization policy systems. The key point is that in each stage of standardization development governments should adopt a mix of policy tools that may work efficiently in the specific standardization context mainly comprising the institutional, economic, and technological dimensions. First, a country's policy orientation should match its technological context. Considering the technological context, in principle, when a latecomer has a weak technological capability and lacks R&D resources, it should adopt the following-up strategy. The standardization policy orientation should focus on adopting foreign standards and following advanced foreign technologies while engaging in building capabilities in innovation and standardization. When the technological capability has reached a certain level, standardization can move to the catch-up stage, and policy focus can shift to supporting companies, R&D institutes, and their alliances to develop standards while owning IPRs. Once a country has established sufficient technological capability and some leading national companies already have their own IPRs on key technologies, the country can enter the upgrading stage and government policy can shift to encouraging domestic organizations to play a key role in international standardization. Second, as the institutional, economic, and technological contexts change, a country needs to reform its policy system's structure and re-balance the extent to which it uses supply-, demand- and environment-type policy tools to improve their comprehensive effectiveness. The impetus of the supply-type policy tools is to contribute to the development of emerging technologies and industries. Thus the government should continuously rely on supply-type policy tools in the whole standardization development process crossing the following-up, catch-up and upgrading stages (Su, 2014).

6. Conclusions

In this research, first we advance the literature on latecomer governments in standardization by delineating how standardization policy system evolved in China in the period from 1978 to 2021. Specifically, the Chinese Government continued to offer policy support to standardization development. Among the three policy tool types, the supply-side tools remained the dominant ones, while the environment-type tools tended to decrease in frequency and the demand-type tools tended to increase in frequency. Further, the government rationalized mixing different policy tool types. It tended to relax control but focus on offering guidance on standardization. It first relied on the "government subsidy" tool but later the "technology and organization" tool to increase the supply and improve standardization organizations' working efficiency. Moreover, it increasingly used "goal planning" tool to guide standardization and less frequently used "regulation control" tool to control standardization.

The Chinese experience suggests that the standardization development in a latecomer country should follow a process that begins with the following-up stage before transitioning to the catch-up and upgrading stages. In each stage, due to restrictions from specific technological, economic, and institutional contexts, the government should accordingly set its policy orientation and design its policy system with supply-, environment- and demand-type policy tools. In principle, the government should focus on using supply-type tools and maintain demand-type tools. As time goes on, it can then use less environment-type tools and, thus, decrease its control over the market and let it play a more important role in standardization.

This paper has limitations but open opportunities for future research. Our research presents a historical picture of standardization system change under dynamic institutional, technological, and economic contexts in China. Our three-stage division of the standardization development process reflects the historical reality. The future development in standardization in China, which is not within the scope of this paper, may present new characteristics due to new institutional, technological, and economic contexts (e.g., due to tensions between China and the US in technology). A new stage may emerge or has already begun to emerge, which represents a valuable topic for exploration in the future. Moreover, standard development and diffusion in different sectors may present different characteristics, which can be the topic of future research. Last, in this paper, we study China's national standardization policy system and consider policy tools' general characteristics based on how Rothwell and Zegveld (1985) and Su (2014) define such tools. Future research may focus on standardization system and policies at national level and/or sector level and more deeply consider specific policy tools' characteristics and functions (e.g., to address problems and issues that require urgent action or to build a long-term standardization plan of the nation or an industry).

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Data availability

The authors do not have permission to share data.

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