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Article

The dynamics of policy coordination: The case of China's science and technology policy-making

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Abstract

The literature on policy coordination between government agencies reveals little about how coordination is managed in centralized political systems. This paper, therefore, presents a dynamic and quantitative analysis of policy coordination in China based on the science and technology (S&T) policy documents issued by China's central government agencies in the period 1978–2019. From a series of snapshots depicting inter-agency policy development in five historical stages over this timeframe, we find that (1) policy coordination has developed steadily and has mainly occurred to interpret macro strategies and put in place more detailed implementation measures. (2) Ministries under the purview of the State Council have played a leading role in policy coordination, while other types of agencies have cooperated in more supporting roles. (3) Coordination efforts have mainly focused on inclusive and national demand-oriented themes, such as high-tech industrialization, rural S&T, and social development. This research offers a panoramic view of policy coordination trajectories and mechanisms in centralized political systems. As such, it adds to the analysis methods available for quantitatively studying policy documents.

Key words: S&T policy; policy coordination; China; policy informatics; quantitative analysis.

1. Introduction

Coordinating the different relationships between government agencies is one of the oldest and most fundamental problems in public policy. Yet, it continues to vex academics and practitioners in their attempts to enhance both administration efficiency and the quality of public services (Peters 2018; Peters and Tarpey 2019). As early as the 20th century, under the New Public Management Movement, governments began to rethink the relationships between agencies, as the fragmentation of political authority in traditional bureaucracies gradually revealed its drawback (Trein et al. 2019). Specialization without coordination was believed to be centrifugal in government agencies (Bouckaert et al. 2010). Afterward, with the increasing complexity of social events, inter-agency coordination has received considerable attention for its ability to improve public service delivery and solve wicked problems in a range of social fields (Tosun and Lang 2017). Many countries, such as New Zealand, the United Kingdom, The Netherlands, and Sweden, have actively introduced a series of reforms for better coordination (Braun 2008). However, it is noteworthy that, although coordination is increasingly being emphasized in many countries, there is little research concerning how coordination trajectories evolve over time (Bouckaert et al. 2010). Nor is there research comprehensively exploring how coordination is managed in different political systems. Most studies pay attention to how coordination develops in Europe and North America, where the political systems are decentralized (Griessen and Braun 2008; Tamtik 2017). This has left a great gap in the literature when it comes to exploring inter-agency coordination under centralized politico-administrative cultures.

Specifically, according to the policy process, coordination relations within government agencies include policy coordination and administrative coordination. Policy coordination pertains to the formulation level of policy issues, requiring agencies to develop policies and strategies consistent with each other, and in line with a set of determined policy priorities to minimize conflict (Boston 1992). Administrative coordination pertains to the implementation level of policy issues. It emphasizes the process of agencies putting policies into practice in a widely agreed way (Painter 1981). Of the two topics, policy coordination has attached more discussion, with the assumption that if the formulated policies are fundamentally consistent, their implementation will then undoubtedly be compatible (Flanagan et al. 2011). For policy issues involving the interests of multiple stakeholders, policies must be formulated through interactions and bargaining between agencies. Only this way can policies be oriented toward the respective interests of each stakeholder group (Sun and Cao 2018). Therefore, finding an appropriate method to identify how such inter-agency relationships are established and how they evolve is crucial if we are to understand the internal mechanisms of policy coordination.

Most existing research has been conducted either from a theoretical point of view or via more qualitative methods of research like interviews, questionnaires, or experiments. This more subjective form of research needs to be complemented with objective material, like co-signed policy documents, as a systematic record of coordination output. Co-signed policies offer a wealth of information for tracking inter-agency relations (Huang et al. 2018). We extracted the information of issuing agencies and keywords from a large number of policy

texts to reveal, in quantitative terms, the details of policy coordination. Further, most previous research observes policy coordination from a static perspective, which limits contexts to one given period. However, it is well known that policy coordination is not built in a day. Rather, it is an incremental process. Countries like New Zealand, Netherlands, Sweden, and the United Kingdom have spent decades honing their policy coordination efforts (Bouckaert et al. 2010). To this end, the evolution of inter-agency relationships must be traced over a long time to gain a complete and accurate picture of policy coordination. A diachronic analysis can be conducive to determining the historical reasons why inter-agency relations at present are shaped as they are. Also, long-term observation provides more information through which to summarize the common characteristics and find the distinctions, which can be beneficial for thoroughly understanding the growth pathways of policy coordination.

Social network analysis (SNA), a research method of investigating social structures through the use of networks and graph theory, has been used to explore complicated and interactive relationships in policy research (Zhang et al. 2021). Nevertheless, so far, the commonly adopted SNA for inter-agency relations still has its drawback. First, as stated by many studies, the first co-signer plays a leading role in making the policy (Huang et al. 2015; Sun and Cao 2018). However, most research for analyzing the policy network has not yet considered the rank of agencies in co-signed policy documents. This ignores the heterogeneous responsibilities and power of each agency in the policy coordination process, which can mean key actors are not properly identified. Second, the policy networks in the existing research do not consider the number of agencies co-signing a policy document. In academia, we know that ignoring the number of co-authors of a paper will overrate the contribution of some papers and some authors in the given research field (Newman 2001c). Similar to a research network, ignoring the number of agencies may skew the core subnetworks toward minor parties since their contributions to policies may be overrated. To avoid these problems, we adopted a modified social network method that meticulously constructs a series of S&T policy coordination networks based on rank and the number of co-signees.

Our case setting is S&T policy coordination in China. As a representative country with a centralized authoritative system (Xiang and Ma 2021), China's coordination strategies and trajectory may differ from countries with decentralized political systems. Since the reform and opening up, China has vastly increased the number of policies designed to guide S&T development. The centralized power and government support have been recognized as competitive advantages for China's S&T development (Appelbaum et al. 2016). However, it has also been repeatedly mentioned that China needs to ensure better coordination among agencies to promote innovation (Cao et al. 2013). In recent years, the Chinese government has taken a great many measures to respond to these S&T policy coordination challenges, such as organizing large-scale S&T institutional reforms, convening an Inter-Ministerial Joint Committee (IMJC), and others. Nevertheless, the effects of such measures still need to be examined, which is one of the research goals of our study.

Unlike previous research that only uses the issuing entities as units of analysis, we also extracted the time of issue, the policy authority level, and the keywords in policy texts as analysis units to comprehensively investigate policy coordination conditions. The study is beneficial for addressing the current literature gap by exploring the characteristics of coordination strategies in centralized political systems such as China and deepening the understanding of how and why policy coordination occurs and evolves in a specific political context. It may also contribute to the use of informetric methods in political science in general. Additionally, our methods should be applicable to analyzing policy documents and policy coordination outside of the domain of S&T policy. However, the specific research questions guiding this particular study are as follows:

1. From tracking the policy documents formulated through inter-agency negotiation, what is the general trend and characteristics of China's S&T policy coordination?
2. What kind of roles do different agencies play in the policy coordination networks? What factors may shape such inter-agency relations in China?
3. What policy themes in the S&T field are often the focus of policy coordination? Why do such policy coordination priorities form?

2. Data and methods

2.1 Data sources

In this paper, we use S&T policy documents as a key channel for tracing policy coordination behaviors and, more specifically, those behaviors that manifest as agencies collaboratively making S&T policy. The policy texts were collected via the PKUlaw database,[1] which contains comprehensive policy documents issued in mainland China since 1949. The main steps for data acquisition and processing were as follows.

First, based on the literature review of both domestic and international S&T papers, we selected the keywords 'technology', 'science and technology', 'scientific research', 'innovation', 'patent', 'intellectual property', 'basic research', 'applied research', 'scientific fund', 'talent', 'laboratory', 'science popularization', 'scientific instrument', 'high-tech industry', and 'university' (in Chinese) to search all of the related S&T policy texts issued by the central government.[2]

Second, to ensure data integrity to the extent possible, we also retrieved policy documents issued by the major S&T administrative bodies, including The Ministry of Science and Technology (MOST), the Chinese Academy of Sciences (CAS), the Chinese Academy of Engineering (CAE), the Chinese Academy of Social Sciences, and the National Natural Science Foundation of China (NSFC). After deleting duplicate policy documents and manually removing documents irrelevant to S&T activities, we were left with 8,341 policy documents.

Third, we considered the level of authority of these policy documents, as listed in the Appendix (see Table A1). As some of the categories are actually removed from concrete S&T affairs, such as decisions on legal issues, appointments and removals, treaty ratifications, etc., these were discarded from the data sample. Additionally, since military policies are only partly open to the public and only a few samples were collected (which were not enough to sufficiently reflect the characteristics of S&T-related military policies), S&T-related military policies were also discarded.

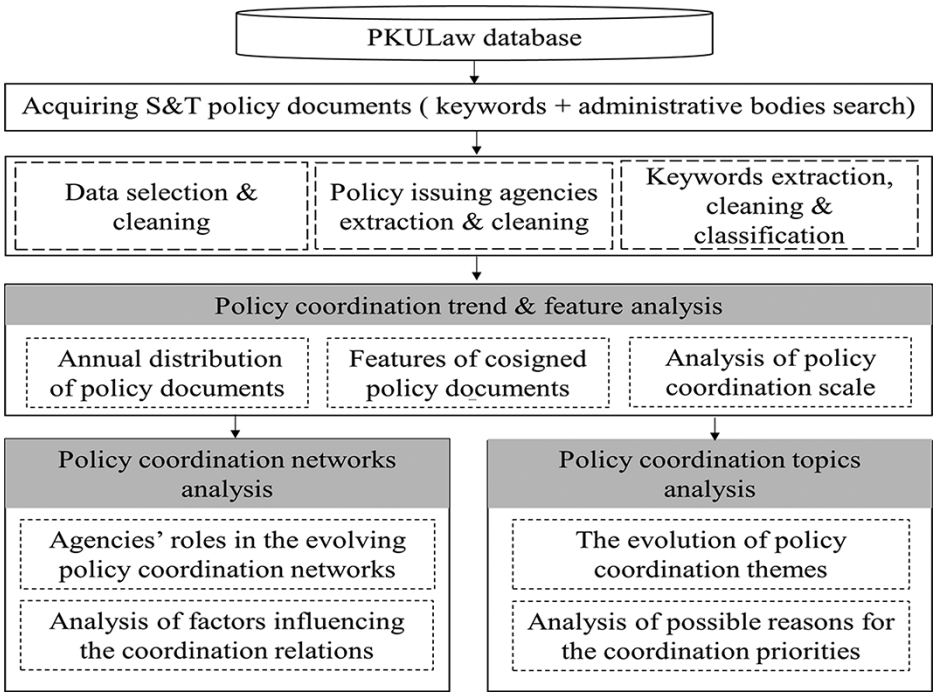

Figure 1. Research framework.

Ultimately, 8,318 policy documents containing policy topics, policy issuers, authority level, release/birth dates, implementation dates, and policy contents were validated to serve as the analysis data, with 1,799 of these being co-signed policy documents.

Because Chinese agencies have experienced several large-scale institutional reforms since 1978, the names and functions of some agencies have frequently changed. To intuitively present the evolution of inter-agency policy coordination, we changed the historical names of agencies to match their current names.

The research framework illustrating our research route is shown in Fig. 1.

2.2 Methods

Similar to academic publications, the number of issuing agencies and the hierarchy of the byline in co-signed policy documents are meaningful data points that indicate the authority and responsibility of each agency. Thus, accurately representing these is important for accurately reflecting the coordination between agencies. We, therefore, conducted a modified SNA to trace the evolution of the policy coordination networks and analyze the role of each agency in the network. Further, we used text analysis tools from policy informatics to explore the coordination priorities of these agencies at different points in time.

2.2.1 Social network analysis

SNA is widely used in bibliometric analysis to visualize network structures and analyze the connections between actors (Newman 2001a). Generally, SNA can be divided into unweighted networks and weighted networks (Newman 2004). Unweighted networks only reflect whether two actors have connections or not, while weighted networks capture the different strengths of connections between actors in a network. In the past, most policy networks have been built based on cumulative co-occurrence frequencies, with the strength of each edge tied to the number of times the two actors co-occur in policy documents. However, such weighted networks may overrate the influence of policy documents issued by multiple agencies, making it difficult to identify the true core subnetworks. For example, a policy document with multiple co-signers may be given too great an edge weight within the overall network.

Tackling this issue, we employed Newman's approach (Newman 2001b), which considers the number of agencies used to calculate the coordination strength between agencies i and j as follows.

$$w_{ij} = \sum_k \frac{\delta_i^k \delta_j^k}{n_k - 1} \quad (1)$$

In this formula, if i is one of the co-signers in a policy document k, then $\delta_i^k = 1$(otherwise $\delta_i^k = 0$), and n_k is the number of co-signers in policy document k. Another vital issue is the credit given to each agency in a co-signed policy document (represented as a node's weight in a social network). The most widespread counting methods for co-authored publications are full counting and fractionalized counting (Sivertsen et al. 2019). Historically, most researchers have used the full counting method to calculate the credit of agencies in policy networks, but this ignores the varied responsibility and authority of agencies in co-signed policy documents. In this study, we used harmonic allocation to assign credit to each agency. Harmonic allocation was originally proposed by Hodge and Greenberg (1981) and further developed by Hagen (2010). It is a counting system that uses the hierarchy of co-signers in the byline to quantify each agency's contribution. The i^{th} agency's credit of a policy document with N co-signers

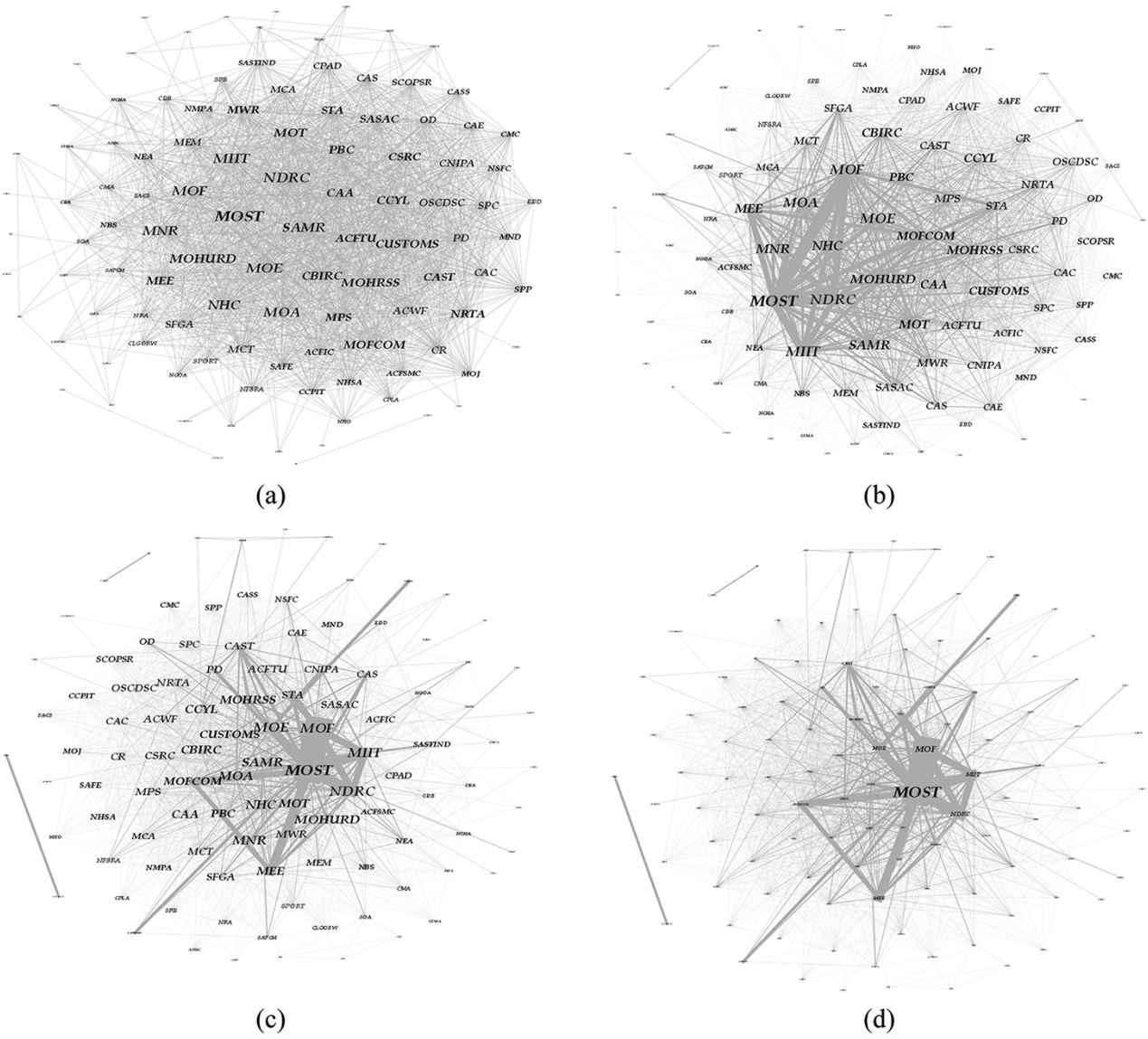

Figure 2. Policy coordination networks under different weighting methods.

is therefore calculated as follows:

$$Harmonici^{th}agency\ credit = \frac{\frac{1}{i}}{\left[1+\frac{1}{2}+\ldots+\frac{1}{N}\right]} \qquad (2)$$

To examine the effectiveness of the modified social network mentioned above, we compared the policy coordination networks under different weighting methods. We took the policy documents issued by multiple agencies during 2013–19 as a sample and used Gephi software to construct policy coordination networks using four different weighting methods. Fig. 2 presents the four resulting networks. Here, the node labels indicate the issuing agencies, and the size of the labels represents the credit given to the agency. The edges indicate the connection among agencies, and the strength of edges represents their closeness. Among these four networks, Networks (a) and (b) show the policy networks using the methods commonly adopted by former studies—unweighted networks and weighted networks based on cumulative co-occurrence frequencies, respectively. Networks (c) and (d) show the results using our modified method. It can be seen that Network (a) only portrays a few critical nodes, and it is hard to distinguish the closeness of relations between different nodes. Network (b) includes many vital nodes and strong edges, but the contribution of some nodes has been overestimated, and the average weighted degree is far above the other networks. We partly adjusted the method by using Newman's modified edge weight algorithm in the Network (c). It decreases the negative weight caused by multi-departmental cooperation and shows a prominent core subnetwork. Network (d) applies Newman's modified edge weight algorithm to calculate the weight of edges and adds the harmonic counting to calculate the node weights. The policy coordination network not only shows the closeness among different agencies but also reflects the real contribution and position of each agency in the network, which proves the advantages of the modified policy coordination network in identifying coordination intensity and heterogenous roles of agencies in S&T policy-making.

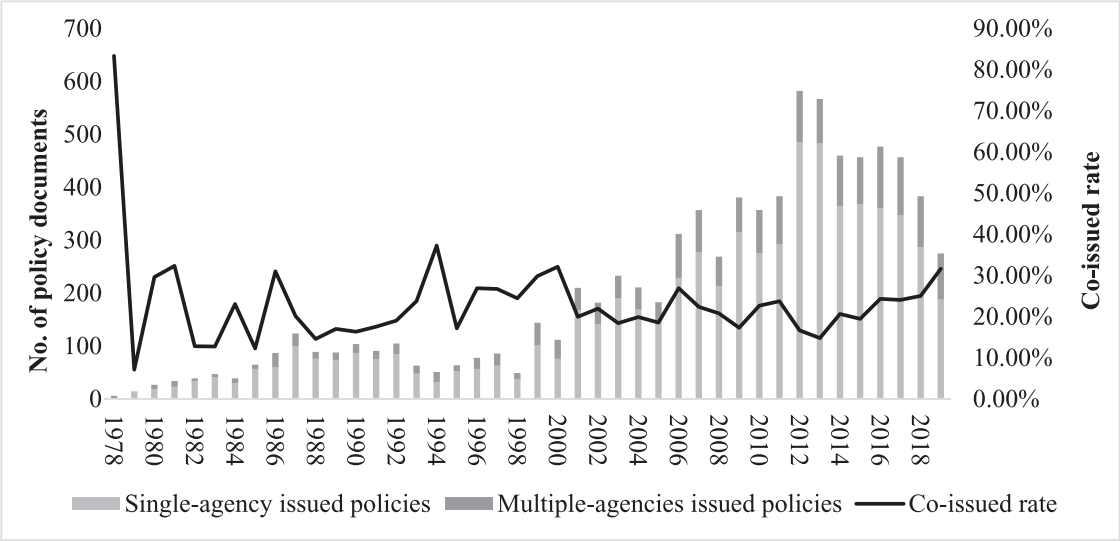

Figure 3. The annual number of S&T policy documents during 1978–2019.

2.2.2 Policy informatics

Policy informatics incorporates information technology into the study of public policy (Johnston and Kim 2011). Within this field, there are two main research streams. In one stream, scholars work to extract useful insights from digitized government information. In the other, scholars use computational methods and tools to analyze policy issues, thus converting data into valuable and insightful information that can be used to help governments make decisions (Desai and Kim 2015). The rapid development of information technology has brought great opportunities to this emerging field. Hence, its pioneers are leveraging network models (Hatmaker et al. 2011), text analysis tools (Hagen et al. 2015), and visualization tools (Goyal 2017) to study policy processes, policy-making agencies, and government projects. Among these, extracting keywords from policy texts is one of the most fundamental ways to discover latent policy themes (Hagen et al. 2015, 2019). Keyword co-occurrence analysis, also known as co-word analysis (Callon et al. 1983), uses keywords or the basic words of documents to study the conceptual structure of a field (Cobo et al. 2011). This is the only method that uses the actual content of documents to construct a similarity measure or to build up semantic maps of a field (Aria and Cuccurullo 2017). Other studies introduce informetrics to trace the interactions between policy documents and scientific research (Li et al. 2022; Vilkins and Grant 2017). In this paper, we explored the dynamic changes in policy coordination themes through policy text analysis.

Policy texts are generally relatively long, which may influence the validity and veracity of properly identifying core words. Therefore, we modified how keywords were extracted from policy documents, as well as how dynamic changes to policy themes were identified in the keyword co-occurrence networks. The specific steps were as follows. To systematically present the evolution of S&T policy themes, we initially adopted the classification criteria issued by MOST,[3] dividing S&T policy documents into fifteen categories according to the social issues they were designed to solve.[4] An introduction to different types of policy themes is found in the Appendix (see Table A2). We then summarized the characteristics of the S&T policies in different categories by referring to MOST's official website. We also drew on insights from two books that introduce and classify various kinds of S&T policy documents and list many keywords in different policy themes. The two books were *Selected Science and Technology Laws, Regulations and Policies* (中国科技法律法规与政策选编) and *Catalog Guide to the Science and Technology Policy of China* (中国科技政策要目概览) (in Chinese). Based on the accumulated S&T policy information, we constructed a keyword thesaurus for the fifteen categories of S&T policy documents. We then used the ITGInsight (http://en.itginsight.com/) text mining software to segment the 1,799 co-signed policy texts and extracted the keywords corresponding to the designed keyword thesaurus for subsequent analysis. All the keywords matched with our thesaurus were extracted to construct a co-word matrix and then entered into Gephi (https://gephi.org/) to visualize the evolution of coordination themes over time.

3. Findings

3.1 The general trend and characteristics of S&T policy coordination

Among the overall 8,318 policy documents, 1,799 documents were jointly formulated by multiple agencies. Fig. 3 shows the number of S&T policy documents by year between 1978 and 2019. Generally, the number of policy documents issued by multiple agencies has increased. But the policy documents issued by one sector still predominate, and the co-signing rate remains between 10 to 40 per cent.[5] This reflects the prominent characteristic of bureaucracy that emphasizes the division of labor. Moreover, observing the features of the co-signed policy documents, we find that these documents often appear in the form of rules, regulations, and measures; they interpret the laws and macro strategies issued by the National People's Congress, the State Council (SC), and the Central Committee of the CPC (CCCPC) and formulate more detailed implementation measures. This is correlated with China's top-down policy-making system, where the decision-making power is concentrated in some senior agencies with S&T strategies, while the underlying implementation design

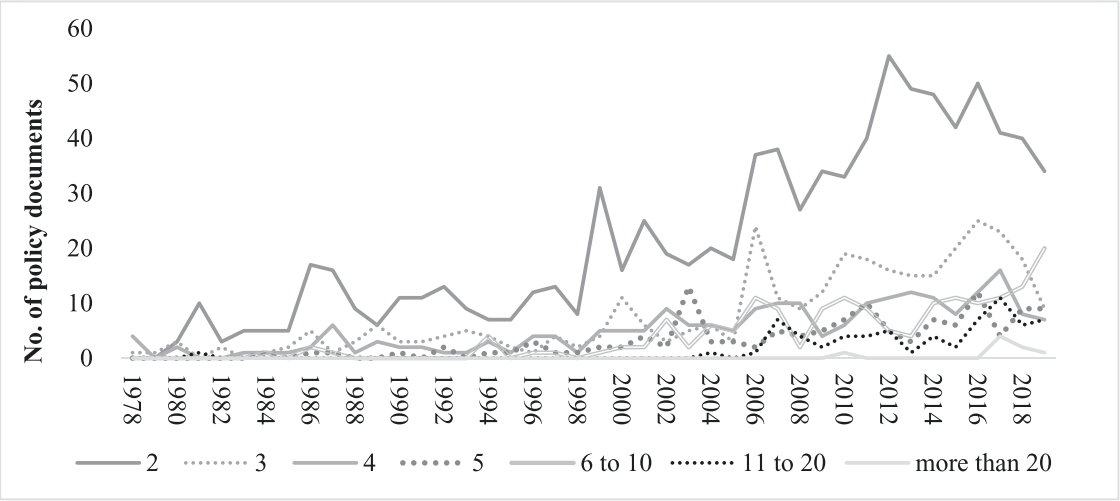

Figure 4. Policy coordination scale: the number of agencies in co-signed S&T policy documents.

is dispersed to multiple involved agencies with specific rules and measures.

We further targeted the co-signed policy documents and explored the coordination scale changes by counting the number of issuing agencies. As shown in Fig. 4, small-scale policy coordination is popular in S&T policy-making, and the policy documents issued by only two agencies account for a large part of all co-signed policy documents. Nevertheless, it is clear that more coordination has occurred in the last two decades. This may be explained by the complexity of the coordination process, which requires trust and rich information exchange among agencies to help mitigate collaboration hazards in solving a policy issue (Gulati and Gargiulo 1999). In the early stages, coordinating relations among a small number of agencies can be more accessible. But gradually, with S&T policy documents involving the interests of more stakeholders, it may be inevitable to bring in more agencies to balance the interests of various groups. Further, accumulated collaboration experience and trust in the early stages also make the climate more conducive to realizing larger-scale coordination.

3.2 S&T policy coordination networks by historical stages

To further investigate the evolving relations among agencies, we analyzed policy coordination networks at different historical stages according to the policy issuing behavior of agencies. The full names of some key agencies in the networks can be found in the Appendix (see Table A3). Reviewing the progress of China's S&T policies, we find that some remarkable conferences or laws are of considerable significance to the overall direction of China's S&T landscape. These representative events have separated the development of China's S&T policy into several historical periods, each with its specific goals and tasks. Following the view of Xue (2018), we divided S&T development in China after 1978 into five phases: the rejuvenation period (1978–84); the reform for science, technology, and innovation (STI) system period (1985–97); the construction for the national STI system period (1998–2005); the improvement for national STI system period (2006–12); and the implementation of the innovation-driven development strategy period (2013–19).

Over the time periods investigated, as many as 146 agencies joined the S&T policy-making network. We classified all agencies into nine types according to their administrative attributes, each represented by different colors in the network (shown in Fig. 5). The color-coding reveals that institutions under the SC are the main actors in the S&T policy coordination networks, but other types of agencies join to help implement S&T activities. Networks (a)–(e) are the policy coordination networks across these historical stages. The size of the node indicates that the total weight of the agency has contributed to co-signed policy documents using the harmonic counting method, with the thickness of an edge indicating the coordination strength between agencies calculated by Newman's modified edge weighting method. The colors of nodes and edges correspond to the type of agency. Table 1 shows some related indicators corresponding to the coordination network at each phase.

3.2.1 The position of agencies in the policy coordination networks

Visualizing the policy coordination networks across periods, we find that agencies' positions appear to reflect the interest relationships within the network. For example, it is known that departmental interest is a critical factor in an agency deciding whether to cooperate with others and who those partners should be. Constructing inter-agency relations appears to be initially based on an agency's interests and area of authority, followed by its financial needs and relationships with public administration offices of various concerns (Xie 2000).

The policy coordination networks show that more and more agencies of various types have engaged in the S&T policy-making process, and connections among agencies have increased. Further, this has happened against a background where China has been actively and rapidly constructing its S&T system. According to the Main Science and Technology Indicators provided by the Organization for Economic Co-operation and Development (OECD) (2021), China's Gross National Product (GNP) doubled every 10 years, and in the meantime, the percentage of GNP spent on R&D has doubled at the same time. This strong national support in S&T

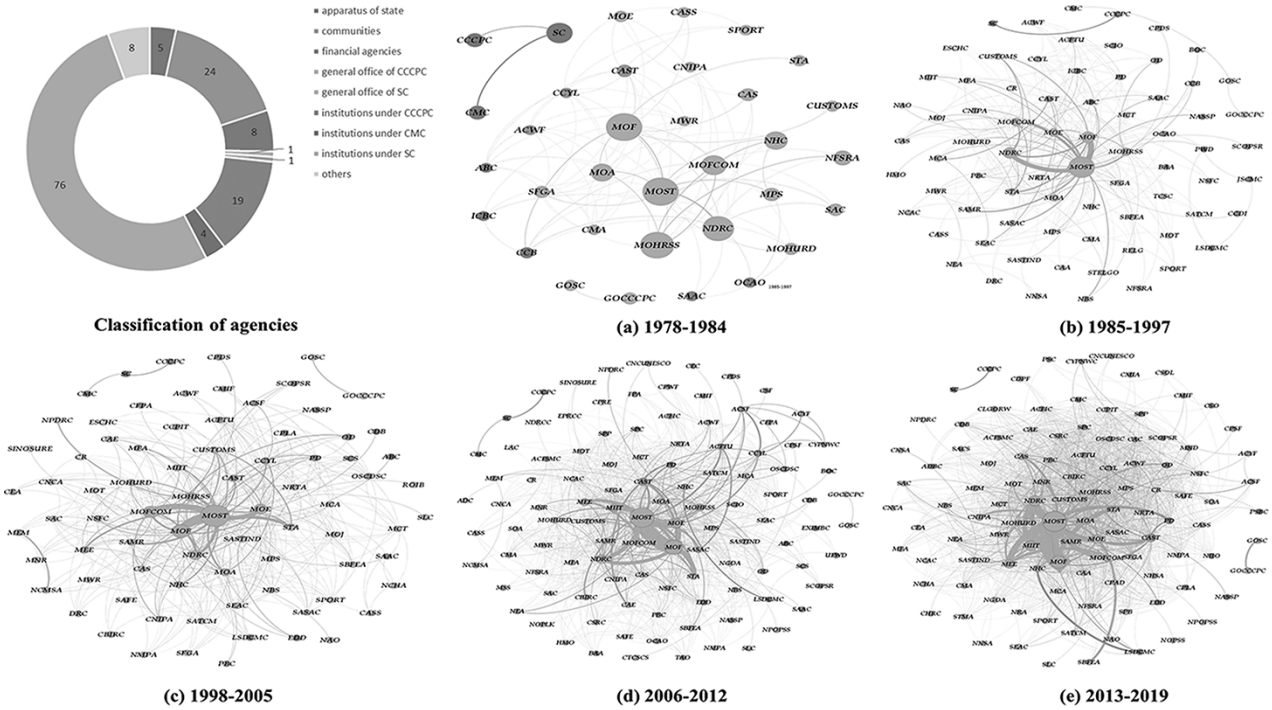

Figure 5. China's S&T policy coordination networks in historical phases (1978–2019).

Table 1. Indicators of policy coordination networks in different stages.

Period	No. of co-signed policies	Nodes	Edges	Graph density	Clustering coefficient
1978–84	45	34	108	0.184	0.746
1985–97	230	74	262	0.097	0.753
1998–2005	292	80	852	0.270	0.757
2006–12	555	108	1059	0.183	0.789
2013–19	677	108	1967	0.340	0.846

development has mobilized more agencies to push harder in the country's efforts to construct an S&T system, and of course, it has brought great challenges to policy coordination for better S&T management. Beyond external environment influences, the increasing complexity of the S&T policy mission itself can also be an important factor. This extended policy mission requires policymakers to invite more actors to join the policy-making process as they must include those who represent the interests of a wide range of stakeholders. Only this way can they promote the rational allocation of resources and benefits. Second, although different types of agencies join these networks, the core subnetwork still consists of ministries under the SC, especially the leading ministries such as MOST, the Ministry of Finance (MOF), and the National Development and Reform Commission (NDRC). These agencies steadily gain weight within the network, likely due to their abundant administrative resources and financial support. By contrast, other types of institutions are located at the periphery of the network; these agencies merely assist the core agencies to accomplish shared goals. Interestingly, the networks all present a prominent characteristic in that they are radially distributed. Further, compared to MOF and the NDRC, the connection between the Ministry of Education (MOE) and MOST is not as strong. This is notable since it is a commonly held belief that education and science should maintain close connections and that education is a very important part of the innovation process. This is particularly true of universities, which sit at the forefront of generating knowledge and technology (Kolomytseva and Pavlovska 2020). In China, the strategy of 'Revitalizing the Nation through Science and Education' put forward in 1995 has already placed education and science on the same strategic level. But it can be seen that, actually, the work of MOE and MOST have not coordinated well. This is hardly conducive to generating and implementing new ideas. Compared with the MOF and NDRC, the MOE has relatively fewer physical resources, which may be one reason their collaborations have not been stronger. All of these findings are consistent with the power-dependency thesis (Dowding 1995), where the agencies in the policy networks are bargaining for more benefits for themselves, and the legitimate authority, reputation, information, and capital of an agency affect its position and popularity in the network.

Another point worth mentioning is that, recently, the Chinese government has been making efforts to reform the education system, with various combinations of MOE, MOST, and the NDRC issuing policies such as 'Opinions on standardizing the use of relevant indicators of SCI papers in colleges and universities and establishing correct evaluation guidance' and 'Opinions on expanding the autonomy of universities and research institutes related to scientific research'. These policies signal increased coordination between MOST and MOE, but the effects are yet to be borne out.

3.2.2 The impact of the centrally planned system on policy coordination networks

A centrally planned system is one of the most prominent features that fundamentally differentiate China from other

political contexts (Zheng et al. 2010). In the past few decades, the Chinese government has actively adjusted its national S&T development strategy to meet the national economic and social development demand, as well as follow international technological frontiers. From a comparison of these policy coordination networks at different phases, it is clear that the evolution of a national strategy has been influential in shaping new relations and strengthening the existing interactions between agencies.

During the recovery period 1978–84, S&T was recognized as a primary productive force and received the support of national institutions. The SC, the CCCPC, and the Central Military Commission became 'active managers' in the S&T policy coordination network, collaboratively working to provide national guidance for S&T activities. In 1985, the CCCPC issued a pivotal policy titled 'Decision on the Reforms of the S&T System', which emphasizes the necessity of transforming research findings into practical applications. It also advocates for a reform of the S&T system. Following the guidance of the CCCPC, research institutions, universities, and enterprises started to collaboratively explore pathways for expanding the technology market and improving S&T productivity. Under such circumstances, the closest partners of MOST in this period were the MOF (for the reform of funding system), the NDRC (for the reform of institutions), and the Ministry of Commerce (MOFCOM) (for the commercialization of research findings). From 1998 to 2005, the strategy 'Revitalizing the Nation through Science and Education' emphasized the necessity of cultivating high-quality talent in the 21st century. Therefore, the MOE became one of the main actors in the network and built frequent interactions with other agencies. In 2006, The SC issued 'the Medium and Long-Term Plan (MLP) for the Development of Science and Technology (2006–20)', offering a blueprint for China's S&T development. This plan introduced a series of supporting policies connected to the responsibilities and resources of multiple agencies, which led to a significant increase in the network's scale. From 2013 to 2019, China continued to implement an innovation-driven development strategy for promoting S&T development. Although the number of agencies in the coordination network did not increase, the connections between existing agencies were significantly reinforced.

In some ways, these science planning theories date back to the thoughts of J. D. Bernal. He advocated constructing middle- and long-term schemes for guiding S&T development and adjusting those plans in a timely fashion to suit new contexts (Bernal 1939). China has fully accepted and emphasized Bernal's theories of science planning (Zhao et al. 2020). Governments frequently make long-term S&T plans for orienting the nation's S&T development pathways. Its centrally planned system has proven to be effective and influential, contributing to the explosive growth of China's S&T strengths in a relatively short period of time (Gao and Tisdell 2004). What we see in these networks is that the S&T plans made by the central government are the macro goals of S&T development in a given period. Therefore, it is understandable that subordinate agencies adjust their behaviors according to the requirements of those plans to achieve stated goals.

3.2.3 The evolution of coordination patterns

Generally, the cooperative relationships between agencies can be characterized into two extremes according to the levels of voluntarism or coerciveness in the relationship. Voluntarism refers to relationships entered freely, such as those based on common tasks, shared values and cooperation agreements. Coerciveness describes relationships stimulated by authority and power (Alexander 1993). This view is related to Hayek's idea of 'cosmos and taxis'. Hayek thought there were two sources of order in society (Hayek 1978). The 'grown' order spontaneously emerges within a system, mainly as the result of elements following certain rules in response to their immediate environment. The 'made' order is formed by the forces outside the system, which rests on the decisions of some single supreme authority in a hierarchical structure. Suppose we regard S&T mission-oriented agencies as a small community. In that case, the 'grown' order would be constructed gradually by the efforts of internal agencies that voluntarily interact with others. By contrast, the 'made' order would be formally constructed by administrative orders, plans, budgets, and rules issued by a supreme authority. It is noteworthy that constructing a 'made' order strongly depends on the authority of the leading agencies and how much they push their affiliated agencies to accept and obey the rules and orders of coordination. If the authority of the leaders is not strong enough to guide the affiliates—in other words, if the affiliates refuse to comply with the regulations—coordination efficiency may be undermined. From this standpoint, constructing a self-organized order may be more stable and effective. However, cultivating and shaping such self-organized coordination requires a relatively long process of building mutual interdependencies and trust. During this process, external power may help to accelerate mutual understanding between agencies; that is, the positive guidance of authority may give the agencies a chance to learn each other's culture, rules, and habits and thus help them to proactively seek out their own most suitable partners.

In the context of China, there are four forms of inter-agency coordination with respect to S&T management:

1. The establishment of a specific coordinating entity. In the case of S&T management, this role is served by the Leading Group on Science and Technology (LGST). This is an organization operating under the guidance of SC that is responsible for reviewing major S&T policies, studying national S&T tasks and projects, and coordinating inter-agency relations to achieve significant S&T tasks. It is a formal model that borrows the authority of the SC to integrate departmental resources and enhance inter-agency coordination in S&T activity.
2. Coordinating inter-agency relations through the super ministries system. This is a widely used coordination model aimed at improving administrative efficiency and enhancing inter-agency communication. In this approach, the responsibilities of each agency are reshuffled, and departmental functions are integrated by merging, renaming, separating, or even abolishing various bodies. For instance, the overarching agency for S&T management changed its name from the State Scientific and Technological Commission to the MOST in 1998, and the Leading Group on Science, Technology and Education became the LGST as a result of functional transformations.
3. Convening an IMJC with the participation of MOST (the primary organizer), MOF, NDRC, and other S&T

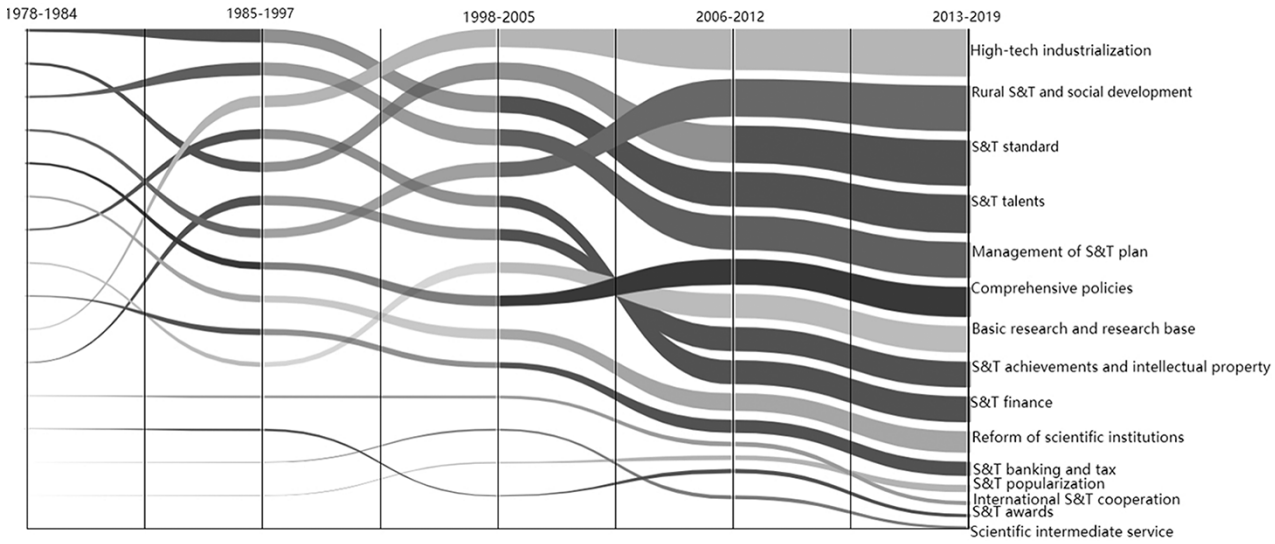

Figure 6. The dynamic changes of general coordination categories.

mission-oriented agencies. As these participants are at equal administrative levels, they mainly enter into partnerships to solve common problems and achieve consistent goals through interactive negotiations.

4. Following a task-oriented coordination model. This is an informal coordination model where agencies may spontaneously seek collaboration with others because of the complexity of tasks.

In terms of the specific process of shaping coordination relationships, the first two forms of coordination are more likely to be an authority-imposed coordination pattern, while the second two forms reflect features of self-organized pattern. These two patterns coexist in China's S&T policy-making and function in a mixed mechanism to push inter-agency relations. Moreover, the dynamics of the policy coordination network shed new light on understanding the historical trajectory of the two coordination patterns in China, which may also give some hints for further insights into the two patterns. Observing the policy coordination networks across periods, we see that each agency's position has gradually stabilized, and the links between some agencies have also strengthened in the networks. This may be an indication that the general framework of S&T policy coordination has been gradually shaped under the stimulation of supreme authority. Some representative agencies such as MOST, MOF, NDRC, MOFCOM, and MOE have formed long-term and increasingly interlocked collaborative relations. Further, we suppose that, even without the intervention of the superiors, these agencies would likely voluntarily continue their collaborations based on their mutual trust and common tasks at this point. In other words, self-organized coordination patterns may continue to grow with the cumulative trust and shared goals formed during their long-term collaboration processes.

3.3 The evolution of S&T policy coordination topics

The themes at play in coordinated policies do not stay static; there are very different emphases at each stage to keep pace with the times. We tracked the dynamic changes in these topics and further explored the factors influencing change using keyword co-occurrence maps. Fig. 6 shows the changes in theme as a count of the frequency of occurrence at different stages. The display order from top to bottom indicates the frequency of each category from high to low. The network maps (a)–(e) in Fig. 7 present the topic shifts across the periods. The nodes refer to keywords, and the edges represent occurrences. The size of the node indicates the document frequency in all co-signed policy documents, and the color represents the type of S&T policy as labeled near the corresponding cluster.

3.3.1 The general distribution of policy coordination topics

From Fig. 6, it can be seen that the themes of high-tech industrialization, rural S&T, and social development have become the most prominent coordination topics over time. By contrast, the specific topics directly subordinate to an agency's mission, such as international S&T cooperation, S&T awards, and intermediate scientific service, have been given less attention. Also, the themes are unevenly distributed, which could be for two reasons. First, hot topics are often consistent with national strategic demands that naturally get more attention and support from multiple agencies. Second, coordination and specialization have an antagonistic relationship. Both coordination and its antithesis, specialization, are essential values in public governance, and most public sector reforms move back and forth between them to find the best governance balance (Peters 2018). The broader themes often involve heavy tasks from various social fields that are relevant to the interests of multiple stakeholders. As a result, it can be hard to assign all the tasks to one agency. For instance, high-tech industrialization includes the tasks of mastering key technologies, researching market demands, developing market-oriented products, and realizing batch production, which may need policy support across multiple agencies. Rural S&T and social development is also a topic spanning multiple policy areas. It not only concerns the modernization of agriculture but also involves missions of improving the quality of human life through medical advancements, environmental protection, and so on. By contrast, the more specific topics, such as international S&T cooperation, S&T awards, and intermediate scientific services, are often assigned

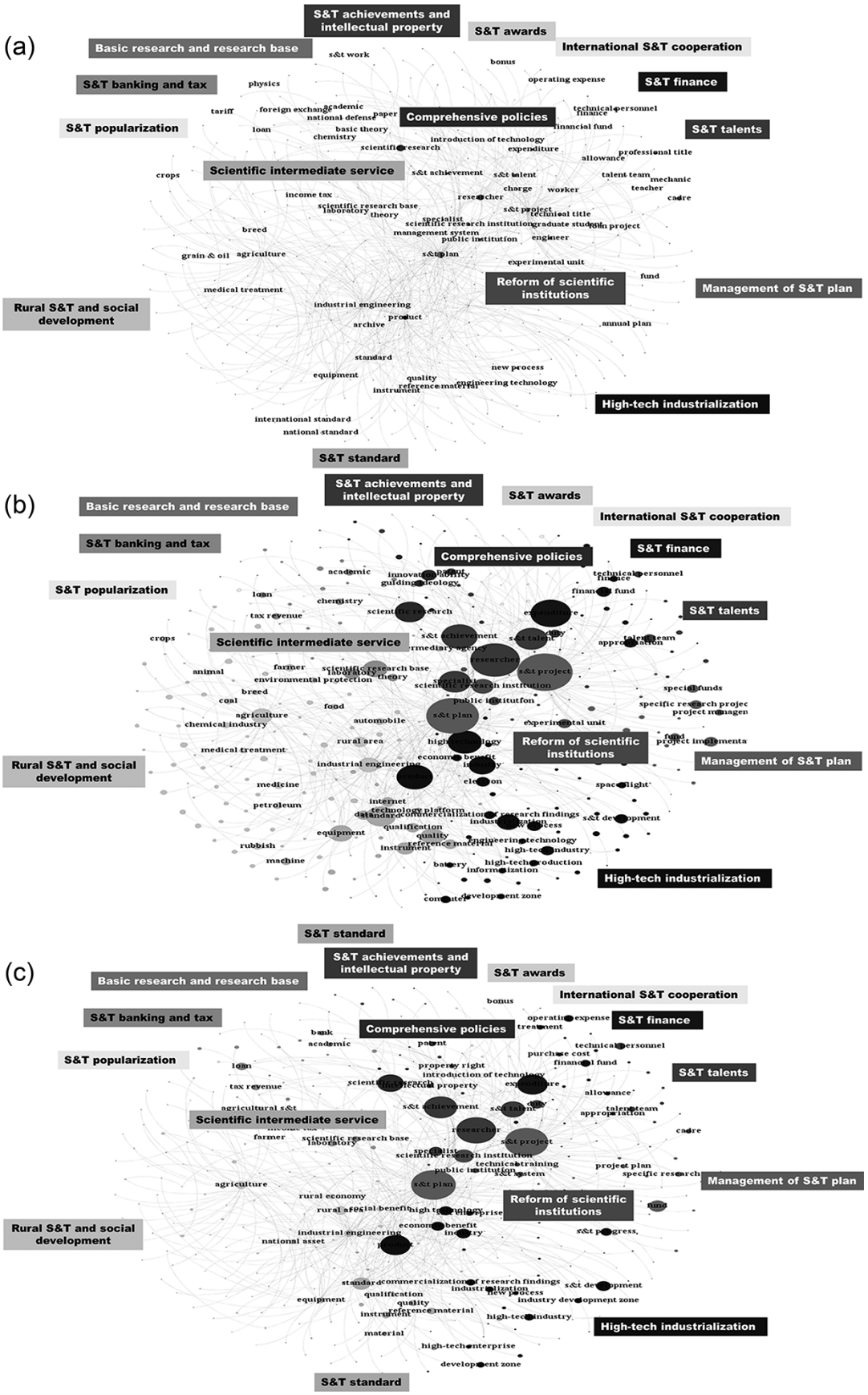

Figure 7. (a) The coordination topics in 1978–84. (b) The coordination topics in 1985–97. (c) The coordination topics in 1998–2005. (d) The coordination topics in 2006–12. (e) The coordination topics in 2013–19.

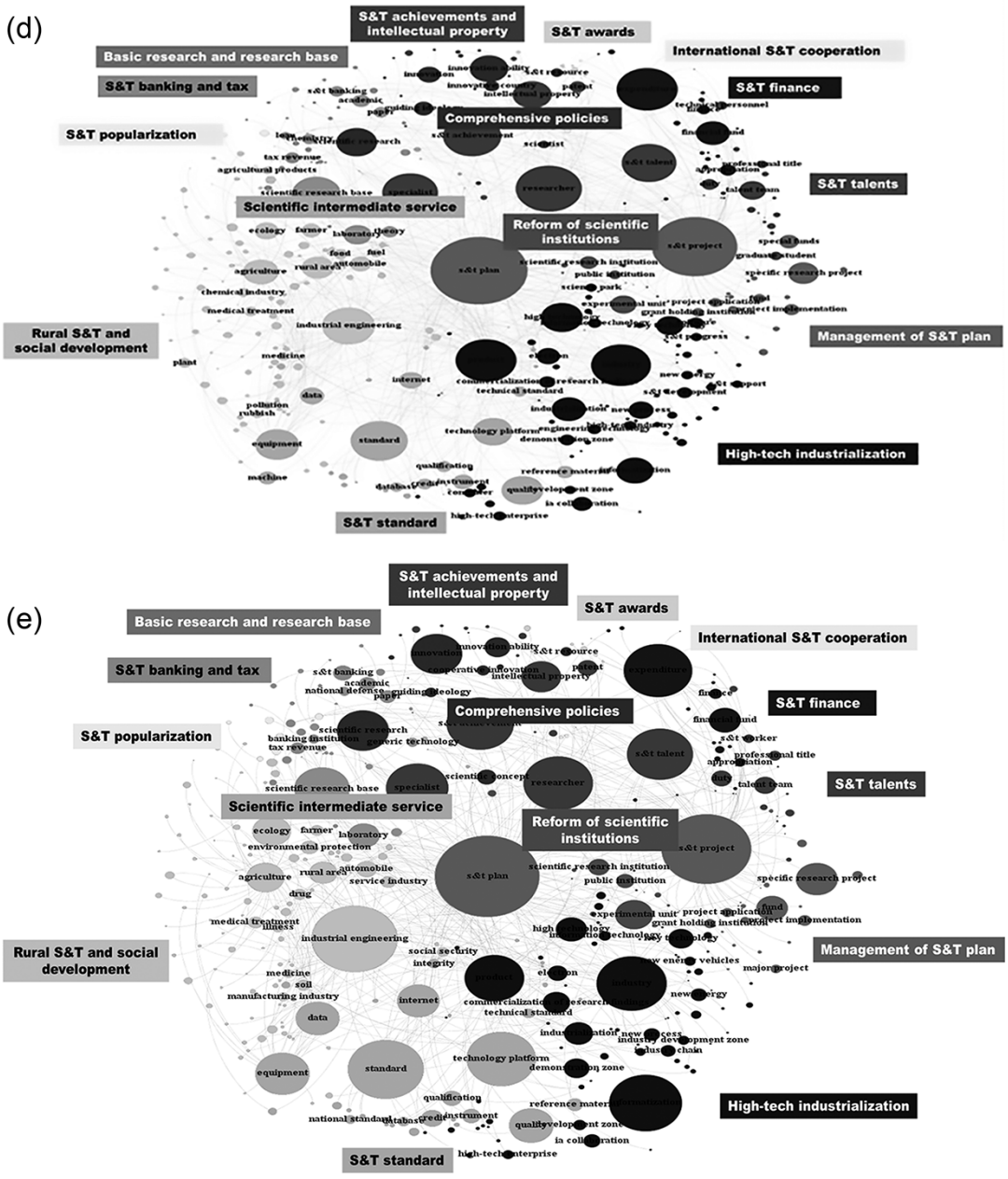

Figure 7. (Continued).

to one particular agency. In short, the themes containing issues from multiple social fields often need inter-agency coordination to improve the quality of public service and products, whereas themes involving relatively specialized tasks are more likely to be assigned independently to promote administrative efficiency.

3.3.2 The impact of the national strategy on policy coordination themes

Figs 7a–e presents the topic shifts in coordination by historical stage from 1978 to 2019. From the network maps, we find that the emergence of essential policy documents always accompanies the emergence of new hotspots in the network. Under the highly bureaucratized system in China, the national strategies declared by the CCCPC or the SC have far-reaching effects on downstream policy documentation. Moreover, the evolution of policy coordination priorities is one indication that agencies are reacting to the guidance of the supreme authority.

In 1978, the convening of the national science conference was a significant turning point for China's S&T development. S&T activity in this period was more concentrated on steering future-oriented S&T pathways and creating a better environment for S&T development. This is because there was a need to both correct people's perceptions about scientific knowledge and talents and construct a new order after the Cultural Revolution. Consequently, S&T talents, S&T standards, and the management of S&T plans were popular topics from 1978 to 1984. Unsurprisingly, as the primary industry of the time,[6] agricultural development received support from multiple agencies to improve productivity. In the rural S&T

and social development category, many keywords reflect the driving force of innovation in agricultural technology.

Over time, however, China's highly centralized S&T management system, which depends solely on the administrative force, showed its weakness in motivating the creativity of S&T personnel and transforming S&T achievement into productivity. In response, the CCCPC in 1985 issued the 'Decision on the Reform of S&T system', declaring the necessity to reform the S&T system to improve economic progress. This policy document introduced a series of plans for enhancing the development of several critical high-tech industries, such as the National High-Tech R&D Program in 1986 (also known as the '863 Program'), the Spark Program in 1986, the China Torch Program in 1988, the Stata Key S&T Achievement Promotion Program in 1990, and the Climbing Program in 1992. Consequently, high-tech industrialization and S&T plans became coordination hotspots during this period. Reforms to the funding system were also introduced, so another emerging topic was S&T finance. The aim of this reform was to ensure that resources were appropriately allocated to support crucial technological breakthroughs in basic research. Additionally, there was a hope that reform would lessen the dependency of some scientific institutions on government agencies and strengthen the communication between institutions and enterprises. Yet, the effect of these changes (reflected in the network map) was that basic research received less policy attention during this period, as the government focused on developing applied research and the commercialization of research findings to boost economic growth.

In 1996, the OECD issued a report titled the 'Knowledge-Based Economy', which argued that knowledge and technological innovation would become the backbone of global economic development in the 21st century. Following this trend, CAS, at the end of 1997, published a report on 'Embracing the Era of the Knowledge Economy and Constructing the National Innovation System'. This marked the coming of a new era, where knowledge innovation was recognized as a fundamental driving force for economic growth. Between 1998 and 2005, innovation became a central keyword in China's S&T development. As the ultimate goal of implementing the knowledge innovation system was still reforming the S&T system and bridging the indivisible relationship between S&T innovation and economic take-off, topics pertaining to high-tech industrialization significantly increased in frequency.

The period 2006–12 witnessed the launch and implementation of China's innovation strategy. In 2006, the SC issued the 'MLP' to transform the mode of national economic growth. This also marked a transition in S&T activity from introducing and imitating advanced international techniques to strengthening domestic innovation abilities. The long-term orientation of the new S&T policy reflected the government's inclination to make full use of the centralized system to promote S&T development (Zhao et al. 2020). Following the guidance of the SC, agencies worked collaboratively on such topics as S&T investments, tax incentives, finance support, and government procurement to stimulate the development of domestic innovation. The frequency of keywords surrounding innovation significantly increased, while other coordination themes remained relatively stable. These changes demonstrate how a macro S&T development framework has gradually been shaped.

To further develop and enhance international S&T competitiveness, an innovation-driven development strategy was first put forward at the 18th CPC national congress held at the end of 2012. This strategy recognized the importance of cultivating a domestic capacity for innovation. Subsequently, in 2015, the CCCPC and the SC cooperatively issued 'Opinions on Deepening the Reform of Systems and Mechanisms to Accelerate the Implementation of Innovation-driven Development Strategies', which focused on three steps to promote China as an S&T innovation superpower. Responding to this report, the agencies frequently collaborated on S&T innovation. Moreover, S&T popularization policies also involve more coordination. This likely correlates with implementing the 'Notice on the 13th Five-Year Plan for S&T Innovation', issued by the SC in 2016. This Notice arranges S&T activity according to six primary perspectives and further strengthens the idea that scientific knowledge should be popularized. In fact, the Notice adds a new indicator to the national agenda of increasing the percentage of citizens with a scientific qualification from 6.2 to 10 per cent. The value of information technology in boosting economic growth was also stressed during this period, and accordingly, the term 'informatization' becomes a hotspot in high-tech industrialization. Agencies were directed to support the growth of the information industry from the perspectives of talent cultivation, tax incentives, and financial investment.

4. Conclusion and discussion

This paper tracks the trajectory of China's S&T policy coordination development through a quantitative study of policy documents. A dynamic perspective helps to capture more details about China's policy coordination at different historical stages, which is beneficial for learning how policy coordination grows in a typical centralized country. Further, comparing policy networks and coordination topics at different periods reveals some of the factors that influence how cooperative relationships are established.

Generally, we find that policy coordination in centralized countries steadily develops under the intervention of authority. When agencies decide whether to collaborate with others and whom to collaborate with, their own interests are one of the most important factors affecting their decision. The agencies with rich resources occupy the center of the policy network, while other agencies at the periphery are inclined to collaborate with the core agencies rather than agencies at the same level. Hence, the networks show a prominent characteristic of spreading outwards from a center. A centralized planning system is particularly influential for fostering interagency coordination in centralized countries. The changing position of agencies in the policy coordination network, as well as the policy coordination priorities, can be linked with the requirements of national strategies.

China's experiences prove that the vagaries of its political systems have led to quite heterogenous coordination mechanisms. Self-organized coordination and authority-stimulated coordination patterns coexist in centralized countries. However, compared to decentralized countries that transfer responsibilities and resources over subnational units of government (Dillinger and Fay 2000), where self-organized coordination develops gradually, centralized countries use the tools of macro planning, intervention, and control

more frequently (Martinez-Vazquez and Vaillancourt 2011). Authority-stimulated coordination patterns still play the dominant role in policy coordination. As the saying goes, 'all coordination mechanisms have some virtues, but none is a panacea' (Peters 2018). There is no doubt that authority-stimulated coordination patterns have their own advantages. They are fast and ruthless in forcing inter-agency coordination. But this tactic has limited powers to engender a positive outlook on joint policy coordination in the long run. Therefore, cultivating self-organized coordination as the primary coordination pattern while occasionally using some of the necessary authority-stimulated tools may be a more optimal solution.

To encourage agencies to collaborate spontaneously, countries should start by creating opportunities for agencies to communicate with each other. As discussed, self-organized coordination must be built based on mutual trust, which can only be accumulated slowly and incrementally from common experiences. Hence, constructing a super coordination agency to organize inter-agency activities, such as convening inter-agency meetings, and realizing information flows between agencies can be a necessary and important step. Countries should make an effort to decentralize their resources. As this research shows, agencies with rich resources, especially with efficient financial support, often take the initiative in a coordination network. Centralizing resources to only a few agencies would decrease their willingness to collaborate with others since they no longer need to cooperate in exchange for the resources they want. Meanwhile, for the other agencies, a lack of resources not only affects their ability to act but also limits their options to assist other agencies to achieve common policy tasks passively. There are already researchers claiming that fiscal decentralization has positive effects on technological innovation, as it gives more flexibility to transfer resources and adopt innovative technologies (Chi et al. 2021). The rational allocation of resources can be beneficial for improving both the technological innovation rate and rate of coordination.

This paper enriches the literature on studying policy coordination in centralized countries. Additionally, it expands the analysis dimensions and methods for quantitatively analyzing policy documents, providing further ideas for studying policy coordination. Nevertheless, this research still has some limitations. First, we focus on policy documents at the central level, but variations in policy coordination mechanisms may exist across different provinces in China. Further research comparing the coordination mechanisms at the central and local levels would systematically unveil more information about China's coordination structures. Second, our analysis is concentrated on content analysis of co-signed policy documents. As coordination is a dynamic process, this only reflects limited aspects of coordination among agencies. Integrating the analysis of other policy coordination processes, such as exploring how agencies reach collaborative agreements and set shared goals, would be necessary to paint a complete portrait of inter-agency coordination. Third, this study mainly explores the characteristics of policy coordination under centralized political systems. Further horizontal comparison between the coordination under centralized and decentralized politico-administrative cultures would be beneficial to revealing their fundamental differences.

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Notes

1. See http://www.pkulaw.cn/.
2. The Chinese version of search queries: TI= '技术' OR '科技' OR '科研' OR '科学研究' OR '科学技术' OR '创新' OR '专利' OR '知识产权' OR '基础研究' OR '应用研究' OR '科学基金' OR '人才' OR '实验室' OR '科普' OR '科学技术普及' OR '科学仪器' OR '高新产业' OR '高等学校' OR '高校'.
3. See http://www.most.gov.cn/kjzc/.
4. MOST has divided S&T policy documents into fifteen categories: basic research and research base; S&T standard; S&T talents; S&T finance; high-tech industrialization; S&T achievements and intellectual property; rural S&T and social development; S&T awards; rural S&T and social development; S&T popularization; management of S&T plan; S&T achievements and intellectual property; S&T banking and tax; international S&T cooperation; and reform of scientific institutions.
5. Except for the year 1978, when MOST was just rebuilding from the Great Cultural Revolution and only published few policy documents under the assistance of other agencies.
6. Agriculture accounted for 28.2% of the industrial infrastructure in 1978; see http://www.gov.cn/jrzg/2013-11/06/content_2522445.htm.

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Table A1. The data selection of S&T policy.

Issuing authority	Level of authority	Count	Sample selection	Example
NPC/SCNPC (National People's Congress/Standing Committee of the National People's Congress)	Laws (法律)	17	Y	Patent Law of the People's Republic of China—SCNPC [2005]
	Decisions on legal issues and significant issues (有关法律问题和重大问题的决定)	1	N	Decision on Several Issues concerning Judicial Procedures for Patent and Other Intellectual Property Cases—SCNPC [2019]
	Working documents (工作文件)	1	N	Decision on the Establishment of the Commission of Science, Technology and Industry for National Defense—SCNPC [1982]
	Appointment and removal (任免)	1	N	Decision on the Appointment and Removal of Chairmen of the Commission of Science, Technology and Industry for National Defense—SCNPC [1996]
	Treaty ratification (条约批准)	3	N	Decision on Acceding to the WIPO Copyright Treaty—SCNPC [2006]
SC	Administrative regulation (行政法规)	58	Y	Regulation on the National Natural Science Funds—SC [2007]
	Regulatory documents of the SC (国务院规范性文件)	203	Y	Notice of Several Measures for Optimizing the Management of Scientific Research and Improving Scientific Research Performance—SC [2018]
Ministries/Commissions/Administrations	Departmental rules (部门规章)	576	Y	Measures for Punishments against Misconducts in Scientific Research in Implementation of National Scientific and Technological Plans (for Trial Implementation)—MOST [2006]
	Departmental regulatory documents (部门规范性文件)	2,549	Y	Measures for the Administration of the Accreditation of National Independent Innovation Products (for Trial Implementation)—MOST, NDRC, and MOF [2006]
	Departmental working documents (部门工作文件)	3,597	Y	Notice on the Establishment of Expert Advisory Group for the Fifth National Key Basic Research Development Program—MOST [2011]
Departments of the CMC (Central Military Commission)	Military regulation (军事法规)	4	N	Regulations on National Defense Science and Technology Intelligence Work—SC and CMC [1984]
	Military rules (军事规章)	5	N	Notice on the Issuance of the National High-tech Research and Development Program (863 Program) Management Measures—MOST, EDD, and MOF [2006]
	Military regulatory documents (军事规范性文件)	8	N	Notice on issues of the retired military senior experts—Political Work Department of People's Republic of China Central Military Commission and MOST [1987]
Departments and institutions of the CPC (Communist Party of China)	System of party regulation (党内法规制度)	135	Y	Notice on Establishing the LGST under the SC—CCCPC and SC [1982]
Associations	Group provisions (团体规定)	1,183	Y	Notice on the Survey of the Science Popularization Status in Urban communities—CAST [2012]

Table A2. The sample of different S&T policy themes.

Policy theme	Characteristic	Example
High-tech industrialization	Policies to guide the research, development, application, and diffusion of new technologies	'Plan for Promoting the Development of the Automotive Power Battery Industry'—MIIT, NDRC, MOST, and MOF [2017]
Rural S&T and social development	Policies to enhance the use of S&T in agriculture as well as rural and urban living	'Plan for Innovation-driven Rural Revitalization (2018–22)'—MOST [2019]
S&T standard	Policies to establish unified standards for regulating technical works	'Measures for the Management of Scientific Data'—GOSC [2018]
S&T talents	Policies to cultivate and motivate talents to increase their research creativity and productivity	'Notice on Enhancing the Implementation of Giving More Autonomy to Research Institutes and Researchers'—GOSC [2019]
Management of S&T plan	Policies to manage S&T programs, such as project application, fund appropriation, and project acceptance	'Interim Measures for the Management of the National Key R&D Program'—MOST and MOF [2017]

(continued)

Table A2. (Continued)

Policy theme	Characteristic	Example
Comprehensive policies	Policies with a general goal and many measures from different S&T fields	'Outline of the Innovation-Driven Development Strategy of China'—CCCPC and SC [2016]
Basic research and research base	Policies to support basic research development and establish/manage large-scale S&T innovation base for conducting basic research, technological transformation research, and industry generic technology research	'Notice on the issuance of the "Thirteenth Five-Year Plan" National Basic Research Plan'—MOST, MOE, CAS, and NSFC [2017]
S&T achievements and intellectual property	Policies to manage S&T achievements and protect their creativity, such as patents and copyrights	'Interim Provisions on Intellectual Property Management for Key National Science and Technology Projects'—MOST, NDRC, MOF, and CNIPA [2010]
S&T finance	Policies to manage S&T expenditure	'Measures for the management of funds for the National High Technology Research and Development Program (863 Program)'—MOF, MOST, and EDD [2006]
Reform of scientific institutions	Policies to reform the system of S&T institutions to optimize the allocation of S&T resources and improve S&T productivity	'Guiding Opinions on Supporting and Encouraging Professional Technical Personnel of Public Institutions in Innovation and Entrepreneurship'—MOHRSS [2017]
S&T banking and tax	Policies to manage tax and financial service for innovation enterprises	'Notice on Tax Policies Regarding Science and Technology Enterprise Incubators, University Science Parks and Makerspaces'—MOF, STA, MOST, and MOE [2018]
S&T popularization	Policies to promote the diffusion and application of S&T knowledge in society	'Several Opinions on Strengthening National Science Popularization Capacity'—MOST, PD-CCCPC, NDRC, MOE, SASTIND, MOF, CAST, and CAS [2007]
International S&T cooperation	Policies to use global S&T resources and enhance international communication and cooperation	'Notice on Actively Leading and Organizing International Big science and Engineering Programs'—SC [2018]
S&T awards	Policies to reward individuals and organizations making outstanding contributions to China's S&T progress	'Regulation on National Science and Technology Awards (2020 Revision)'—SC [2020]
Scientific intermediate service	Policies to promote the development of the S&T intermediate service industry that helps to accelerate the transformation of S&T achievements	'The Administrative Measures for Technology Incubators'—MOST [2018]

Table A3. Information on the agencies.

Agencies' full name	Abbreviation
National People's Congress	NPC
State Council	SC
General Office of the State Council	GOSC
Central Military Commission	CMC
Central Committee of the Communist Party of China	CCCPC
Ministry of Science and Technology	MOST
Ministry of Finance	MOF
National Development and Reform Commission	NDRC
Ministry of Education	MOE
Ministry of Commerce	MOFCOM
Chinese Academy of Sciences	CAS
Chinese Academy of Engineering	CAE
National Natural Science Foundation of China	NSFC
Chinese Academy of Social Sciences	CASS
China Association for Science and Technology	CAST
Leading Group on Science and Technology	LGST
Inter-Ministerial Joint Committee	IMJC
Ministry of Industry and Information Technology	MIIT
China National Intellectual Property Administration	CNIPA
Equipment Development Department of the Central Military Commission	EDD
Ministry of Human Resources and Social Security	MOHRSS
State Administration of Science, Technology, and Industry for National Defense	SASTIND
State Taxation Administration	STA