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Technology Transfer Systems and Modes of National Research Institutes: Evidence from the Chinese Academy of Sciences

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Abstract: Technology transfer systems (TTSs) and modes of national research institutes (NRIs) have become increasingly significant in shaping national innovation systems. However, few studies have addressed this issue in the context of emerging economies. To fill this research gap, this paper explores the TTSs and modes of Chinese NRIs based on a case study of the Chinese Academy of Sciences (CAS). We clarify the institutional factors that influence the adoption of an academy-branch-institute-level TTS, reveal the policy-driven evolvement of this multi-level TTS, and elucidate the operational mechanisms of the TTS. We find that the effective collaboration between the actors within or across the three levels of the TTS could enhance the functions of integration management, science and technology (S&T) resource allocation, and public research and development. Through a thematic synthesis approach, we identify three technology transfer modes of the CAS. These three modes exhibit an evolutionary sequence from the CAS-region cooperation mode to the incubation ecosystem mode and then to the platform-driven mode, following the progress of the Chinese S&T system reform and the repositioning of the CAS mission. These modes have diverse demands for technological cognition and resource allocation capability that can be satisfied by the co-specialised interaction among the three levels of the TTS. Apart from the theoretical

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implications for technology transfer studies, our findings provide managerial implications for guiding technology transfer from NRIs.

Keywords: National Research Institutes, Technology Transfer System, Technology Transfer Modes, Chinese Academy of Sciences

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1. Introduction

National research institutes (NRIs) are an important component of national innovation systems (NISs). They often receive significant public research funds and are expected to transfer technologies to enhance national innovative capacity (OECD, 2011; Rogers et al., 1998; Intarakumnerd and Goto, 2018). As a result, different countries have developed various forms of technology transfer systems (TTSs) and modes of NRIs to promote the technology transfer. With increasing global competition in science and technology (S&T), governments around the world attempt to further enhance the effectiveness of technology transfer from NRIs by improving the TTSs and modes (NIST, 2019; OECD, 2011). For example, the United States introduced new administrative models to remove barriers that hinder the way in which national laboratories transfer their technologies (PCAST, 2021). Similarly, the United Kingdom, German, and Japan launched a series of incentive schemes to promote technology transfer from NRIs. As an emerging economy, China has reoriented the technology transfer purpose of NRIs from supporting economic catch-up to sustaining S&T-led high-quality socio-economic development. Considering the crucial role of NRIs in the Chinese innovation system, it is interesting to explore the TTS and modes of NRIs and to further elucidate their evolution and dynamics, which can help yield new theoretical and empirical insights into technology transfer from NRIs.

Technology transfer from NRIs is not always a simple task (George et al., 2002; Markham and Lee, 2013; Siegel et al, 2007). It involves a range of professional activities beyond the R&D function of NRIs, such as the confirmation of intellectual property (IP) rights (Siegel et al., 2007; Wright et al., 2007), financing through external investors (Wilhelm et al., 2020), identification of industry partners (Festel, 2013), evaluation of technology transfer (Baglieri et al., 2018) and technology pricing (Bidault, 2004). Consequently, various TTSs and modes have been developed to effectively transfer the technology from NRIs, which attracts scholars' increasing attention to explore the performance of those TTSs or modes (e.g., Buenstorf, 2009; Link, 2019; Link et al., 2011; Upstill and Symington, 2002). However, there is still a lack of exploration of the formation, operation, and dynamic mechanisms of TTSs and modes. This is unfortunate because revealing these mechanisms can help understand how technology transfer from NRIs has contributed to the changes in the nature of NISs. Moreover, relatively little research has been conducted on this topic in the context of emerging economies which are usually characterized by market-oriented reforms, institutional transformations, and government' active interventions.

China as the largest emerging economy offers an ideal context to explore technology transfer from NRIs. China has transformed from a planning economy to a market-oriented economy, and has seen rapid economic development over the past four decades. During this period, the Chinese government has attached ever-increasing importance to technology transfer from NRIs and has used it as an important means to achieving a leading global position in S&T (Liu et al., 2011). However, the Chinese innovation system has been subject to a longstanding issue, namely, the separation of S&T activities at public academic sectors from production activities at industry (Chen et al., 2020; Motohashi and Yun, 2007; Xue, 1997; Zhang et al., 2016). These public academic sectors own a majority of S&T resources and have conducted the most advanced researches and developed the most potentially transformational technologies (Richard, 2015; Sun and Cao, 2014). Conversely, enterprises usually have low levels of S&T resources and lack innovative capacity, and they are unable to effectively absorb knowledge or technologies from public research bodies (Zhang et al., 2016). Within such a NIS, transferring technology from NRIs to industry is particularly crucial in China. The Chinese government has played a vital role in probing into institutional design and policy development for promoting and advancing technology transfer from NRIs. For example, the government has implemented various polices to reform China's S&T system, which pushes forward the improvement of TTSs and modes of NRIs and therefore increases the efficiency of technology transfer from NRIs. Given the fact that few studies have investigated the formation and development of the TTSs and modes of NRIs in the context of emerging economies, a case study of Chinese NRIs can fill in a significant research gap in extant literature.

The Chinese Academy of Sciences (CAS), as the largest and most prominent NRI in China, has played a key role in pioneering the reforms to boost technology transfer and to stimulate national economic growth (Liu and Zhi, 2010). As of mid-2021, the CAS is composed of 115 research units, 95 national laboratories, and 20 large research infrastructures, covering nearly all research fields. In addition, the CAS has 798 domestic and 104 foreign academicians. The CAS has made significant contributions to the construction of China's national innovation system over the years (Bai, 2016: 2115). In 1949, the year of the establishment of the People's Republic of China, the CAS came into existence and acted as a national administrative department under the State Council (Liu and Zhi, 2010). Over the last seven decades, the CAS as a public service organisation has also played a key role in promoting national S&T development to serve the national strategy of transitioning toward an innovation-oriented economy. The CAS is not only responsible for creating public knowledge and solving large-scale social challenges in accordance with the guidelines imposed by the Chinese government, but also for promoting technology transfer in response to the market-oriented reforms that have taken place in China over several decades. Moreover, the CAS has created and constantly improves its own TTS and modes to meet the demands for transferring all types of technology and to support the construction of Chinese NIS. In such context, it is interesting to study this topic using the CAS as a case to advance the theoretical understanding of technology transfer from NRIs.

Based on a case study of the CAS, this paper explores the TTSs and modes of NRIs and further clarifies their evolution and dynamics in the context of emerging economies. We make three main contributions. First, we elucidate the formation and dynamic mechanisms of the multi-level TTS in the CAS by clarifying the institutional factors that influence the adoption of the multi-level TTS and the policy-driven evolvement of the TTS. Our research contributes to the development theory of NIS by revealing the dynamic response of TTSs to the construction of NIS in emerging countries. Second, we investigate the operational mechanisms of the multi-level TTS, which clarifies the inherent dynamics of the TTS's responses to technology transfer from NRIs. Third, we identify three technology transfer modes of the CAS, reveal the evolutionary dynamics of these three modes, and explore the role of the multi-level TTS in the modes. Lastly, this paper provides managerial implications for guiding technology transfer from NRIs.

The remainder of this paper is organised as follows. Section 2 provides the theoretical and empirical background of this study. Section 3 describes the formulation, policy-driven evolvement, and operational mechanisms of the multi-level TTS of the CAS. Section 4 identifies three types of technology transfer modes, reveals the evolutionary dynamics of the three modes, and clarifies the role of a multi-level TTS in these modes. Section 5 concludes the paper and provides theoretical and managerial implications.

2. Research background

2.1 Theoretical background

Technology transfer is regarded as “an active process during which the technology (and knowledge related to it) is transferred between two distinct entities” (Battistella et al., 2016: 1196). Numerous studies have shown that technology transfer from the public sector is often tortuous and even inefficient (Agrawal, 2006; Decter et al., 2007; Goldhor and Lund, 1983). There is often a gap between the quality of technologies provided by the public sectors and that desired by the private sectors (Hellmann, 2007; Min et al., 2019). An effective way of bridging this gap and promoting technology transfer is the confirmation of IP rights (Siegel et al., 2007; Wright et al., 2007). The validity of this view is fully reflected, for example, in the success of the Bayh-Dole Act that contributes to the creation of the Standard Patent Rights Clauses. As a result, it promotes the transfer of publicly developed technology to private sectors and makes significant changes in the ways technologies are commercialised and diffused from universities (Grimaldi et al., 2011). Some European countries, such as Germany, Austria, and Norway, introduced similar policies after the Act was passed (Bengtsson, 2017; Geuna and Rossi, 2011). In China, the Law of the People’s Republic of China on Scientific and Technological Progress (2007 Revision) endowed universities and NRIs with the right to retain the IP rights of the inventions generated from government-funded research.

Numerous studies have been undertaken to clarify issues with respect to technology transfer from universities (Anderson et al., 2007; Comacchio et al., 2012; Debackere and Veugelers, 2005; Etzkovitz and Goktepe, 2005; Min et al., 2019; Mowery et al., 2015; Rasmussen, 2008). Apart from universities, NRIs are also an important component of the public academic sectors that contribute to the public research landscape (Barge-Gil and Modrego, 2011; Metcalfe, 2010). Accordingly, scholars have emphasised the importance of technology transfer from NRIs and have conducted studies to examine this topic in recent years (e.g., Aldridge and Audretsch, 2010; Goel and Göktepe-Hultén, 2018; Link, 2019; Link et al., 2011; Saavedra and Bozeman, 2004; Strong et al., 2018). For example, Giannopoulou et al. (2019) and Readman et al. (2018) contend that NRIs should actively support the transfer of technology. However, NRIs are different from universities in terms of the role, function, governing body and autonomy in national innovation systems as well as funding sources, knowledge focus or other characteristics (Giannopoulou et al., 2019; Intarakumnerd and Goto, 2018; Zhang et al., 2016). These suggest that the TTSs and modes of universities may not be suitable for technology transfer from NRIs. For example, as shown by Link et al. (2011) in their study, the Bayh-Dole Act has significant impacts on patenting and licensing by U.S. universities, whereas it is insufficient to promote technology transfer from U.S. national laboratories.

In the literature of technology transfer from NRIs, a relatively small but increasing body of research has focused on the TTSs and modes of NRIs (Ambos et al., 2008; Lockett et al., 2005; Siegel et al., 2003; Weckowska, 2015; Yusuf, 2008). The research on TTSs have already explored organisational structures (Bercovitz and Feldman, 2006), organisational support systems (Ambos et al., 2008; Siegel et al., 2003), and norms toward S&T commercialisation (Owen-Smith and Powell, 2001). Meanwhile, the research on technology transfer modes have investigated several channels for transferring technologies. These channels could be formal ones such as licensing, research joint ventures, and the formation of spin-off companies

(Lockett et al., 2005), or be informal ones like the individual communications between researchers in academia and industry (Yusuf, 2008). Prior studies have also explored the performance of these TTSs or modes on technology transfer (Perkmann and Walsh, 2007; Weckowska, 2015). For example, Buenstorf (2009) analysed technology transfer from the Max Planck Society and found that licensing would have a positive impact on the transfer of basic research.

It should be noted that the NRIs in different countries with different institutional backgrounds have distinctive ways of technology transfer, and therefore develop various TTSs and modes. When it comes to the emerging countries, the NRIs assume the mission of technology transfer to improve enterprises' technology ability, to realize economic caching-up, and to support the construction of NIS. This suggests that the TTSs and modes of NRIs in emerging countries, especially in China, are characterized by the changing nature of the NIS where they are operating. However, this topic has tended to be overlooked in the academic literature. In this paper, we attempt to explore the TTS and modes in China through the case of the CAS.

2.2 Empirical background

As Giannopoulou et al. (2019) have argued, NRIs have diverse inherent characteristics and their missions, goals, and R&D activities vary across countries (OECD, 2011). To clarify the empirical background, we follow Bai (2013) and OECD (2011) and select 11 typical NRIs from eight developed economies. We then collect the text materials of these NRIs from the official websites, available annual reports, and related articles. Three kinds of NRI are identified in terms of the types of R&D activity. The first one refers to those primarily focusing on basic research, such as the National Institutes of Health (NIH) in the United States, the Max Planck Society (MPG) in Germany, the French National Centre for Scientific Research (CNRS) in France, and the European Organization for Nuclear Research (CERN) in Europe. The second one comprises NRIs that focus on applied research, such as the National Institute of

Advanced Industrial Science and Technology (AIST) in Japan, the Fraunhofer-Gesellschaft (FHG) in Germany, and the Commonwealth Scientific and Industrial Research Organization (CSIRO) in Australia. The third one covers NRIs devoted to both basic research and applied research, such as the national laboratories in the United States, the Rikagaku Kenkyusho (RIKEN) in Japan, the Russian Academy of Sciences (RAS) in Russia, and the NRIs in UK Research Councils. Appendix A1 provides an overview of all the selected NRIs and their missions, goals, and R&D activities.

2.2.1 Typical TTSs in NRIs

Since each NIS has its unique characteristics and evolutionary process, NRIs embedded in each system have their own roles and unique ways of fulfilling their functions to transfer the technology to industries (Buenstorf, 2009; Hemmert, 2004; Intarakumnerd and Goto, 2018; Wilhelm et al., 2020). In addition, different NRIs from the same country might assume different roles or functions in NISs, so they are likely to employ distinctive ways of technology transfer. Consequently, various TTSs and modes are developed by different NRIs under their particular circumstances. As for the 11 typical NRIs we collected in our study, four types of common TTS are identified by their functions. They are as follows: the centre-dominated TTS, the academia-oriented TTS, the fund-oriented TTS, and the company-dominated TTS. Appendix A2 provides an overview of these typical TTSs in NRIs worldwide.

In the centre-dominated TTS, intermediary and bridging organisations, such as technology transfer centres (TTCs), technology transfer offices (TTOs), or S&T Hubs, play an important role in fostering technology transfer from public academic sectors. NRIs such as the NIH, the AIST, the CSIRO, and the national laboratories in the United States have already established their own TTCs, TTOs, or departments to promote technology transfer (Link, 2019; Link et al., 2019). In this kind of TTS, NRIs such as the CSIRO also emphasise the critical role of collaboration with enterprises in transferring technologies. They provide incentives for researchers and entrepreneurs to engage in cooperative research efforts through open innovation strategies and joint alliances.

In the academia-oriented TTS, NRIs encourage the emergence of entrepreneurial ideas from the research institutes and nurture academic entrepreneurs by providing training programmes, resources, services, and other supports. For example, the MPG, which acts as a partner to scientists and businesses, encourages researchers in faculty to apply for IP rights or register patents, and to establish start-ups based on their S&T achievements in the research institute (Annual Report Max Planck Society, 2019).

In the fund-oriented TTS, the technology transfer fund from non-profit and profit organisations plays a critical role in commercialising the IP generated at the NRIs. For example, the FHG, a non-profit organisation in Germany, operates under a unique funding model in which 70 percent of the organisation's budget comes from industry. The Fraunhofer Tech Transfer Fund aims to commercialise the IP generated at the FHG from its institutes across Germany. As a result, researchers in the research institutes collaborate more with the industry, thereby cultivating more high-tech start-ups in Germany (Fraunhofer Annual Report, 2019).

In the company-dominated TTS, NRIs such as the CNRS, the RIKEN, and the research institutes in the UK Research Councils emphasise the important role of technology transfer companies in turning the technology into business. For example, the RIKEN Innovation Co., Ltd, a private sector company fully owned by the RIKEN, uses its venture system to strengthen industry–academia collaboration and accelerates technology transfer by providing support and services in technology licencing, collaboration projects, cooperation with industry, and start-up companies.

2.2.2 Typical technology transfer channels in NRIs

In this paper, we review the text materials about the 11 NRIs and identify five channels for embracing technology transfer modes by their missions and functions. The five types of technology transfer channels are as follows: IP management, technology transfer alliance, spin-offs of public research, contract research, and non-commercial transfer.

First, IP management as one of the most common channels are widely adopted the NRIs. The NIH, the MPG, the CNRS, the RIKEN, the FHG, and the CERN adopt this channel by means of patent licencing, licence agreement, or joint IP strategy. Second, NRIs adopting the technology transfer alliance channel tend to promote technology transfer by developing and implementing collaboration projects, programmes, initiatives, or cooperation with companies (Link, 2019; Link et al., 2011; Rogers et al., 1998). For example, the CNRS Innovation Office (DGDI) in France and its industrial partners work cooperatively to increase the maturity level of emerging technologies and help them access the market. The technology transfer companies of the CNRS play a vital role in transferring innovative technologies in the maturation stage from CNRS-linked laboratories to industry. Third, spin-offs of public research have become a popular channel for technology transfer (Rogers et al., 2001; Upstill and Symington, 2002). The MPG, the FHG, the CSIRO, and the national laboratories of the U.S. adopt this channel. Fourth, contractual research for bringing innovation into application is mainly adopted by the CNRS, the FHG, the RIKEN, and the CSIRO. Taking the CNRS as an example, the collaboration between the CNRS and companies is influenced by numerous contracts, such as the joint completion of science programmes that produce deliverables, thereby improving institutes' close relations with industry. Fifth, non-commercial transfer is an invisible but influential channel for technology transfer. A typical case, as the CSIRO case shows, is employment mobility, such as staff exchanges and training (Upstill and Symington, 2002). Appendix A2 provides an overview of some typical technology transfer channels in NRIs worldwide.

3. The multi-level TTS of the CAS

The literature review of typical TTSs in last section suggests that NRIs from different countries have developed distinct TTSs and modes under their particular circumstances (Giannopoulou et al., 2019; Intarakumnerd and Goto, 2018). The CAS from China is a typical one and has a multi-layered organisational structure (as shown in Figure 1). It has continually adjusted its mission to meet S&T challenges related to the nation's economic and social development. These institutional factors significantly influence the adoption of an academy-branch-institute-level TTS. In recent years, China has issued a set of innovation policies to stress the acceleration of technology transfer from laboratories to production, and to provide support for nurturing institutional arrangements that facilitate S&T progress and innovation (Sun and Cao, 2018). In this context, the CAS attached increasing importance to technology transfer and continuously optimised its technology transfer policies. Consequently, the multi-level TTS has gradually been improved by this dynamic policy-making process. The institutional setting and historical context above thus determine the formation and development of multi-level TTS, in which actors within and across different levels work cooperatively to manage technology transfer activities.

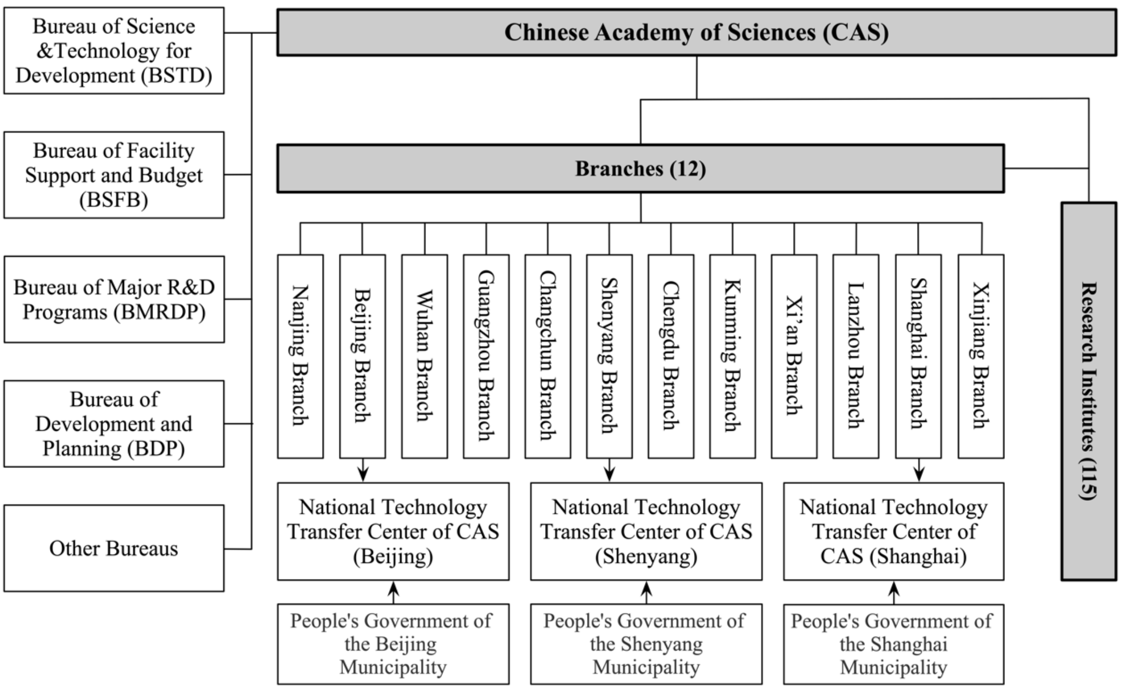

Figure 1. The multilayered organizational structure of the CAS

3.1 The adoption of the multi-level TTS at the CAS

In terms of the longstanding issue about the separation of academic and industry sectors in China's innovation system (Motohashi and Yun, 2007; Xue, 1997), the public academic sectors in China is expected to be able to improve their academic contribution to industry development. These public academic sectors, especially NRIs possessing main S&T resources in China, assume the mission of transferring their technologies to enhance enterprises' innovation performance and competitiveness (Hong, 2008; Zhang et al., 2016). The CAS has been one of the foremost NRIs that drive China's innovation development. Over the last seven decades, it has committed to creating public knowledge, conducting cutting-edge research, and serving major national S&T needs (Bai, 2016; Liu and Zhi, 2010; Yoon, 2015), and has been devoted to the transfer of technologies in response to S&T system reforms and market-oriented reforms in China (Xue, 2018).

With the deepening of the reforms above, the CAS has faced many new challenges in promoting technology transfer, such as establishing partnerships between research institutes and industry or facilitating the transfer of technologies that firms are incapable of absorbing. As global competition in S&T and industry intensifies, the CAS undertook a new mission to meet the needs of national development in response to the national strategy of building an innovation-oriented economy (Zhan, 2015). Accordingly, the CAS is required to transfer its S&T achievements more effectively in order to improve the competitiveness of China's indigenous industries. In this context, the CAS has gradually developed a multi-level TTS to meet the challenges regarding technology transfer. There are four institutional factors that determines the adoption of the multi-level TTS at the CAS. They are listed below.

First, the multi-layered organisational structure of the CAS requires a multi-level governing system for managing activities more effectively, resulting in a multi-level TTS for the technology transfer activities. The research institutes of the CAS located throughout China are independent and autonomous organisations. Therefore, the academy headquarters are unable to effectively administer or supervise these institutes. Consequently, branch-level administration was set up for more effective management. The branches have always been responsible for strengthening cooperation between research institutes and industry in their own jurisdictions (Yearbook of Chinese Academy of Sciences, 1997). The branches are knowledgeable about the advantages and disadvantages of each research institute in a particular scientific and technological domain, and also have close connections with local industries and local governments. Therefore, they can facilitate the technologies provided by the institutes to find a market and help the technologies desired by the market find suitable R&D teams, thereby contributing to the promotion of regional technology transfer and economic development. In addition, the branches also take charge of implementing the technology transfer policies released by the CAS, participate in institute-local cooperation policy drafts, and provide professional services for the transfer of technologies (see Yearbook of Chinese Academy of Sciences, 2019). For these reasons, the CAS chooses a multi-level TTS to improve management efficiency of technology transfer.

Second, the CAS is engaged in all types of R&D activity and makes itself an all-round player in the entire innovation chain in order to deal with different demands for technology transfer. Consequently, the CAS chooses a multi-level TTS to handle such complex technology transfer activities. China was inferior in S&T during the initial period of its founding. The CAS was established to assemble the S&T talents and pool S&T resources for conducting all types of R&D activity, which made the CAS an all-round player. Transferring different kinds of technologies into products has always been a difficult task for the CAS. Besides, much of these promising product always fall into the “Valley of Death” due to the lack of S&T resources or other institutional barriers. As a result, the CAS adopts a multi-level TTS in which actors within each level have different capabilities of resources allocation or institutional design, thereby providing various resources and supports for transferring different types of technology.

Third, the multi-faced roles of the CAS played in Chinese NIS determine its obligation to settle a variety of technology transfer tasks, which can be handled effectively by a multi-level TTS. As an important research actor in Chinese NIS, the CAS has committed to producing ground-breaking research that aligns innovation with national priorities in economic and social development. In addition, as a pioneer in supporting nationwide S&T activities, CAS research institutes are requested to cooperate with local governments and enterprises, thereby supporting regional economic development (Yearbook of Chinese Academy of Sciences, 2019). Moreover, assuming the mission of driving national technological innovation, the CAS is also in charge of turning basic research into marketable technologies. In this case, the multi-faced roles determine the CAS to engage in various technology transfer tasks across the whole country. To fulfill these tasks, the CAS chooses to develop a multi-level TTS to effectively manage and support technology transfer activities.

Fourth, the CAS is one of the institutions directly under the State Council of China. This unique position in the Chinese political system allows the CAS to participate in or to affect the policymaking process by multiple ways, which guarantees the operating efficacy of the multi-level TTS. In contrast to the usual technology transfer organisations in universities, those in the CAS are subordinate bodies of administrative departments rather than service organisations. They are thus endowed with more privileges to allocate resources, thereby influencing the formation and development of multi-level TTSs.

3.2 The policy-driven evolvement of the multi-level TTS

The Chinese government plays a critical role in guiding the construction and improvement of the NIS through dynamic interventions (Zhang, et al., 2019). To fulfill its function of supporting the construction of NIS, the CAS further refines its TTS for transferring the technology more effectively. The Chinese government has adopted a series of political measures to strengthen integration and coordination within and across academic and economic participants. Accordingly, the CAS pushes ahead with its programmes in relation to the repositioning of its mission toward high-impact and high-value research (Bai, 2016). These policies and practice have changed the design of the multi-level TTS and strengthened the roles of the CAS in advancing technology transfer. To reveal the historical background of the evolution of the multi-level TTS, this paper collects the relevant policies from various sources such as the official websites or the literature in the CAS library and conducts a systematic review. As a result, we divided the collected policies into three stages: the consolidation stage (before 2006), the further perfection stage (2007–2013), and the new era (after 2014).

In the consolidation stage, the CAS initially formed the multi-level TTS. Nine policy documents are selected from the Rotary Code of Policies in the CAS, as shown in Table 1. Many policies have been developed to promote technology transfer in the initial period. The three typical policies enacted in 1996 and 1999 regulated precisely how to promote technology transfer. After that, the policy released in 2005 strengthened the functions of branches in revitalising northeast China. In 2006, the Programme of the Development of CAS-Region Cooperation (2006–2010) was enacted, which clarified the duties of the academy, branches, and research institutes to transfer publicly developed technology to the industry, thereby promoting the development of regional economy. In this stage, the multi-level TTS of the CAS came into being.

Table 1 Technology transfer policies in the stage of consolidation

Year	Policy	Influence
1985	Decision of the Central Committee of the Communist Party of China on the Reform of the Science and Technology System	Following this policy, the CAS adjusted its mission thus: 'The main S&T forces of the CAS are devoted to the main battlefield of national economic construction, while maintaining a competent force engaged in basic research and high-tech tracking.'
1993	Provisions of the CAS on the Protection of Intellectual Property Rights	The conditions of details related to IP protection are standardised.
1996	Law on Promoting the Transformation of S&T Achievements	Promoting the transfer of S&T achievements to productive forces and the development of the economy and society.
1998	Knowledge Innovation Project	Puts forward higher requirements for IP management.
1999	Decision on Strengthening Technological Innovation, Developing High Technologies and Realising Industrialisation	Making clear and specific provisions on the reform of research institutions, pricing investment in IP rights, rewards and remuneration for S&T, financial investment in S&T, taxation in S&T, finance in S&T, intermediaries in S&T, and so on, which promote the technology transfer from NRIs.
1999	Notice on Certain Provisions on Promoting the Transformation of S&T Achievements	
2005	Trial Measures for Project Management on the CAS S&T Action Plan of Revitalising the Northeast China	The Shenyang and Changchun Branch are responsible for promoting the development and application of technologies, as well as the transformation of the technologies above in Northeast China.
2006	Interim Measures for the Related Work on the Co-construction of Research Institutes by the CAS and Local Governments	It strengthens the role of the academy headquarters and branches in managing and servicing the construction of research institutes.
2006	The Programme of the Development of CAS-Region Cooperation (2006–2010)	Under this policy, the academy-branch-institute-level TTS was initially formed. It clarifies that the duty of academy headquarters is to guide the missions and goals of branches and research institutes, the duty of branches is to bridge the relationships among all stakeholders, and the duty of institutes is major collaboration with local governments.

In the further perfection stage, the multi-level TTS was further improved with the advancement of the IP management work. Six policy documents are identified from the Rotary Code of Policies in the CAS and the official websites of the CAS, as shown in Table 2. The

Law of the People's Republic of China on Scientific and Technological Progress (2007 Revision) is the first law in China that legally endows R&D institutes with the IP rights to their technologies. The other five polices were enacted by the CAS, which gradually perfect the IP management of its research institutes. These policies lay the foundation for the operation of the multi-level TTS.

Table 2 Technology transfer policies in the stage of further perfection

Year	Policy	Influence
2007	The Law of the People's Republic of China on Scientific and Technological Progress	The first law to legally confirm that R&D institutes owe the IP rights to their technologies.
2007	Guiding Opinions on Further Strengthening the Intellectual Property Work of the CAS	Clarifies one of the principles of IP work in the CAS is strengthening the transformation of IP. It also established an IP management supporting service system.
2008	Interim Measures for the Administration of Intellectual Property Rights of CAS Institutes	The creation, application, protection, and management of IP rights are stipulated in detail.
2012	The Promotion Plan of CAS Intellectual Property Work during the 12th Five-Year Plan Period	The first systematic IP strategy plan of the CAS. It clarifies the specific IP work of the CAS during the 12th Five-Year Plan period, involving the establishment of an IP transfer and transformation system.
2013	Twelfth Five-Year Plan of the CAS for Promoting Intellectual Property Rights Work	Building an IP transfer system.
2013	Interim Measures for the Intellectual Property Management of Research Institutes of the CAS.	Requests that research institutes adopt methods such as implementation, licencing, transfer, and equity purchase to vigorously promote the transfer of IP rights.

In the new era, the multi-level TTS is gradually being improved. Ten policy documents are identified from the Reports of the CAS on Science and Technology for Development (2015–2019) and the official websites of the CAS, as shown in Table 3. In 2014, the Science and Technology Service Network Initiative (thereafter the STS initiative) was released. The STS initiative designed different types of programmes run by the academy, branches, and research institutes. The multi-level TTS therefore plays a bigger role in transferring technologies. After the STS initiative, the CAS issued a policy (as shown in the fourth row of Table 3) requiring an annual report on the transfer and transformation of its S&T achievements to better match the multi-level TTS. This policy has gradually become an important reference for evaluating the performance of institutes. In recent years, many related policies have been enacted, leading to the gradual improvement of multi-level TTSs. For example, the guiding opinions enacted in 2016 announced the establishment of the Intellectual Property Operation and Management Center, thereby enriching the academy-level TTS.

Table 3 Technology transfer policies in the stage of the new era

Year	Policy	Influence
2014	Science and Technology Service Network Initiative (STS)	The STS initiative designed three kinds of programmes for academy, branches, or institutes. It gives the multi-level TTS a bigger role to play in transferring technologies that have significant influence on national economic and regional development. It also provides support for institutes transferring their technologies by way of entrepreneurship.
2015	The revised edition of the Law on Promoting the Transformation of S&T Achievements	Effectively improves the poor operability of the 1993 version of the law. In the revised edition, as well as strengthening the power of research institutes and researchers to transform S&T achievements and promoting cooperation between industries and research institutes, the law strives to create a good service environment for the transformation of technologies.
2016	Annual report on the transfer and transformation of S&T achievements of the CAS	To match the multi-level TTS better, the CAS requires an annual report on the transfer and transformation of its S&T achievements. This policy gradually becomes an important evaluation index of the performance appraisal of institutes.
2016	Guiding Opinions of the CAS on Accelerating the Transfer and Commercialisation of S&T Achievements in the New Era	Announced the establishment of the Intellectual Property Operation and Management Center, which enriched the academy-level TTS. It also advanced technology transfer by establishing funds like the Guiding Fund for the Commercialisation of S&T Achievements and other measures.
2016	Implementation Plan of CAS Special Action to Promote the Transfer and Transformation of S&T Achievements (the Implementation Plan for short)	This plan outlined how the CAS headquarters should work together to promote the transfer and transformation of S&T achievements, clarifying how the academy-level TTS works.
2016	Measures for Incentive Administration of Leaders in the CAS on Part-Time Employment and Transformation of S&T Achievements	The two policies detailed measures for staff in different levels of the CAS transferring technologies by entrepreneurial activities, reflecting the governing role of the academy level in the TTS.
2016	Interim Measures for the Administration of S&T Personnel Leaving Their Posts to Start Businesses	
2016	Measures for the Administration of Key Special Projects in the CAS to Transfer S&T Achievements (the Hongguang Project for short)	This project responds to the Implementation Plan. It outlines how the academy-level TTS should transfer significant S&T achievements to meet the major needs or economic growth of China.
2018	Some Measures to Promote the Transfer of S&T Achievements of the CAS in Beijing	A measure made jointly by the Bureau of Science & Technology for Development (academy level), the Beijing branch (branch level), and the Administrative Commission of Zhongguancun Science Park (one of the local agencies). This is one of the typical policies reflecting the influence of the multi-level TTS on CAS's technology transfer activities.
2020	Administrative Measures for Intellectual Property Rights of Institutes Affiliated to the CAS	This policy perfects one of the most important channels for technology transfer at the institute level.

3.3 The academy-branch-institute-level TTS of the CAS

Due to the institutional setting and historical background above, the CAS adopts a multi-level TTS (i.e., an academy-branch-institute-level TTS) to transfer the technology. Specifically, actors within the academy-level TTS, such as the academy headquarters, are mainly responsible for connecting with relevant national departments. They put forward general guidance and top-down design as well as construct academy-wide platforms. Actors within the branch-level TTS take the responsibility of cooperating with local governments or local enterprises and promoting technology transfer based on local resource endowment. Actors within the institute-level TTS are in charge of the transfer and commercialisation management of specific technologies, as well as providing various support services. Figure 2 shows the different functions and roles of each level in the TTS of the CAS.

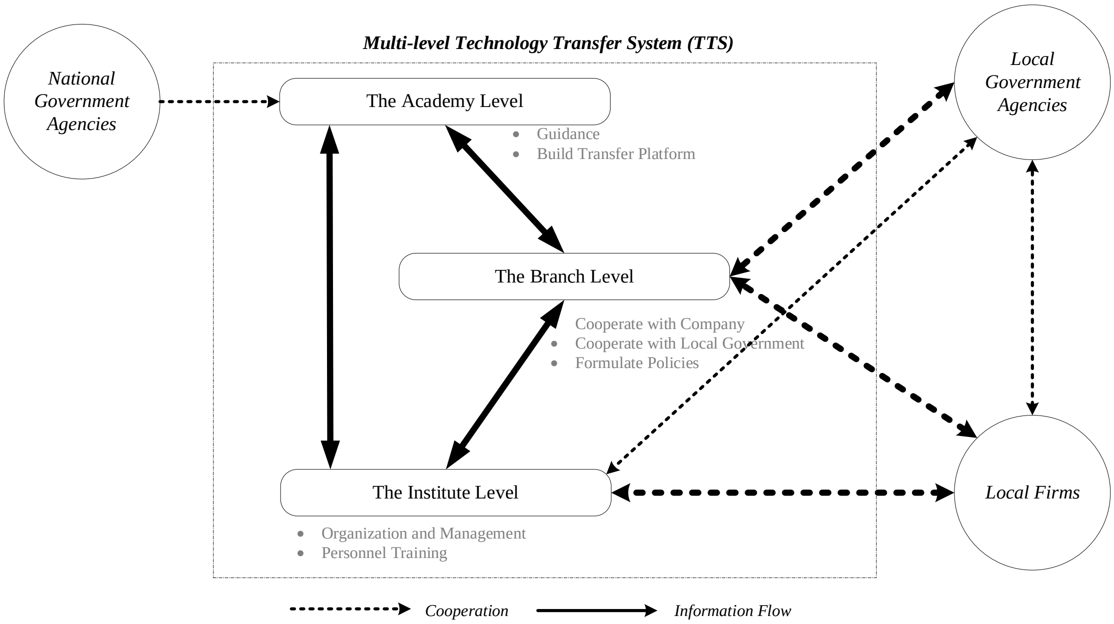

Figure 2. The multi-level technology transfer system of the CAS

3.3.1 Academy-level TTS

Actors within the academy-level TTS include one hub organisation—the Bureau of Science & Technology for Development (BSTD)—and many support organisations (as shown in Figure 3). The BSTD is responsible for directly regulating technology transfer activities in the CAS, while the other organisations are in charge of providing supports for the top-down design. These interconnected organizations work cooperatively to promote and advance technology transfer from the CAS. Such an ecosystem of academy-level actors plays a vital role in making technology transfer policies, programmes, or strategies, thereby facilitating technology transfer activities. For example, many technology transfer tasks were launched by the Implementation Plan of CAS Special Action to Promote the Transfer and Transformation of S&T Achievements (2016), and most tasks were assigned to the BSTD. The BSTD is equipped with one subordinate body (the Intellectual Property Management Division) and two platforms (the Intellectual Property Operation and Management Center and the Science and Technology Industry Website of the CAS). They cooperate with one another to accomplish the tasks. In addition, the Bureau of Personnel provides support for human resources, the Bureau of Facility Support and Budget contributes to developing innovative carriers, and CAS Holdings Co., Ltd. (CASH) is in charge of commercialising technologies (as shown in Appendix B). These academy-level actors and the BSTD work cooperatively by accomplishing their own tasks, thereby implementing the plan and effectively promoting the transfer of technologies.

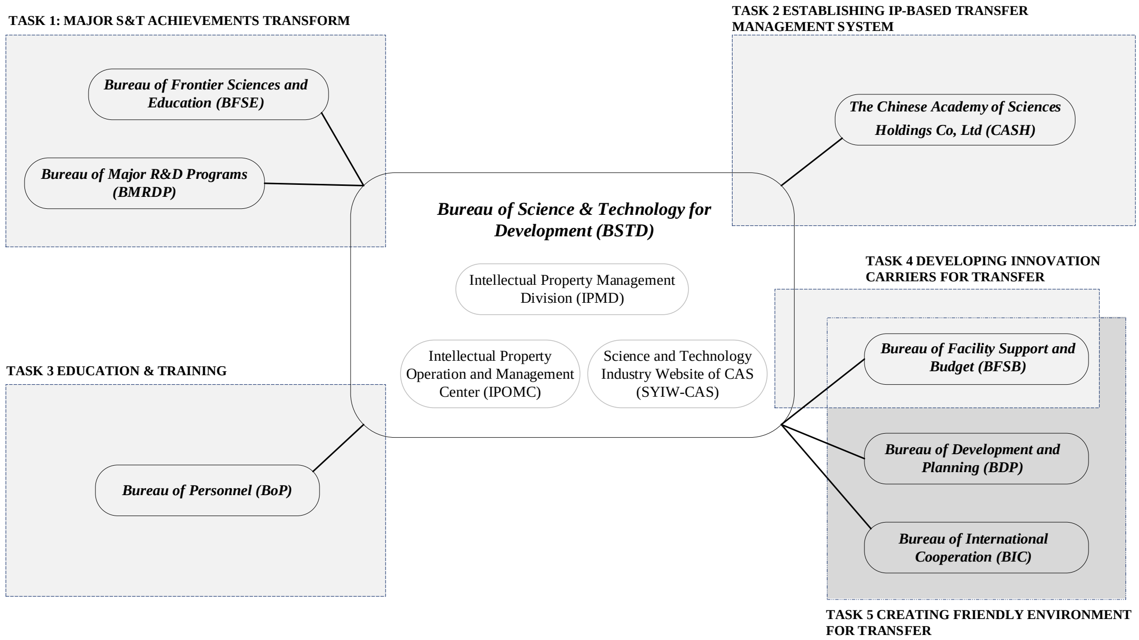

Figure 3. The organizational structure of the academy-level TTS

(Source: *The Implementation Plan of CAS Special Action to Promote the Transfer and Transformation of S&T Achievements, 2016)*

3.3.2 Branch-level TTS

Actors within the branch-level TTS include branches and their TTOs, TTCs, and incubation centres. At present, there are 12 branches that act as the agencies of the academy headquarters, managing research institutes in a given region. The distribution and jurisdictional areas of the branch-level TTS are illustrated in Figure 4.

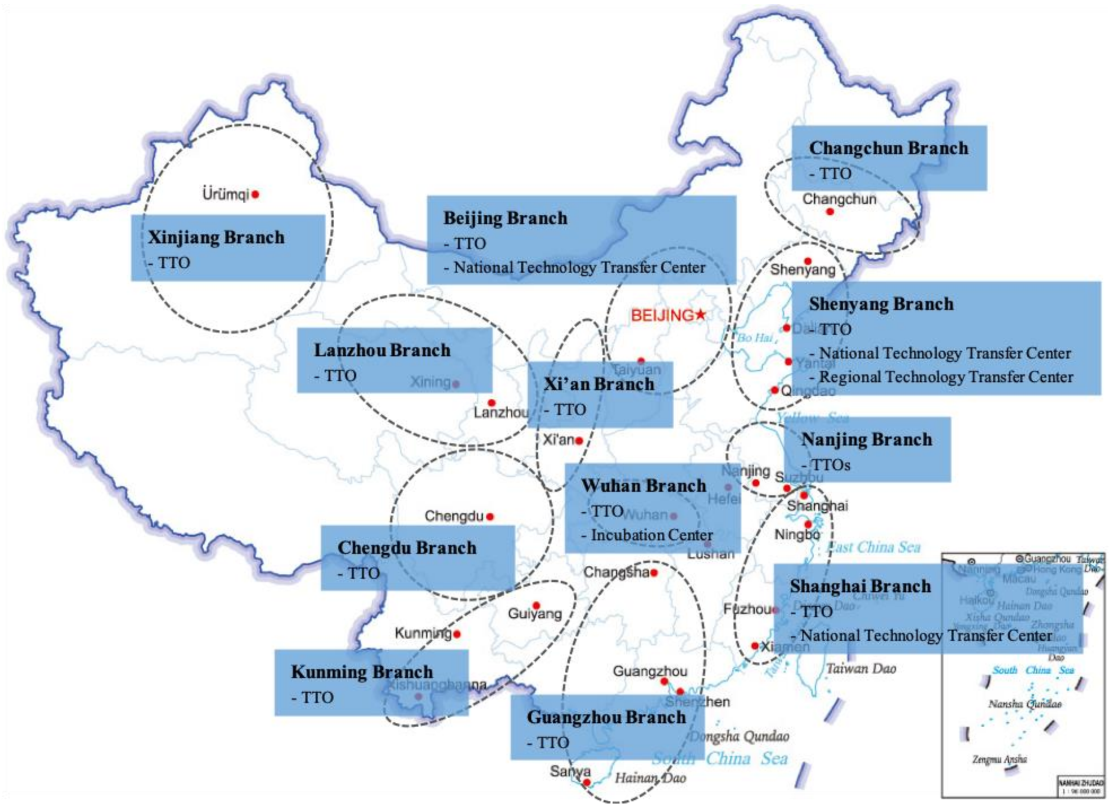

Figure 4. The distribution and jurisdictional area of the branch-level TTS.

(Source: *Modified from the official website of the CAS*, http://english.cas.cn/institutes)

In general, the roles of branches are reflected in three main aspects. First, as the regional agencies of the CAS headquarters, the branches are responsible for implementing and propelling the CAS-region cooperation programmes released by the academy-level regulatory authority. Second, the branches are responsible for promoting collaboration between research institutes and enterprises in their jurisdictional areas. They are knowledgeable about the advantages and disadvantages of the research institutes in a particular scientific and technological domain, and also have close connections with the enterprises. Therefore, they can reduce the gap between the technologies provided by the institutes and those desired by the enterprises. The branches usually work with local governments to establish technology transfer platforms or cooperation networks to perform this duty. Third, the branches are entitled to participate in the drafting of technology transfer policies with local governments (Yearbook of Chinese Academy of Sciences, 2019). In addition, the functions of branches correspond with local characteristics that are determined by the differences in resource endowment and economic social environment across regions. For example, owing to the special natural ecological environment in western China, the Lanzhou branch has developed distinct disciplines and regional characteristics in glaciology, frozen soil science, desert science, plateau ecology, and other research fields, thereby promoting the technology transfer in the western regions.

Finally, some critical technologies of research institutes in a given region have the potential to be transferred to other regions or even the entire country. In this case, transferring such technologies to other regions is beyond the ability of a single branch. Accordingly, the branches collaborate with one another to support the above-mentioned style of technology transfer for realising mutual development. An effective way to fulfill this duty is to jointly construct a technology transfer centre. For example, the Beijing, Shanghai, and Shenyang branches jointly established the National Technology Transfer Center. Another example is the Regional Technology Transfer Center that was co-established by the Guangzhou branch, Changchun branch, and local governments. Such practices have significant implications for further improving the TTS of the CAS.

3.3.3 Institute-level TTS

Actors within the institute-level TTS include research institutes and their technology transfer departments. As an all-round player on the whole innovation chain, the research scope of research institutes covers various fields. For this reason, different institutes have various ways of transferring technologies in accordance with their research fields. In addition, the research institutes of the CAS are independent legal entities, allowing them to establish a functional department dedicated to promoting technology transfer. Compared with the technology transfer departments at the academy and branch levels (such as TTOs or TTCs), those at the institute level are better acquainted with commercialising technologies. Similar to the technology transfer office in universities, such technology transfer departments could provide various support services for scientific researchers in research institutes (e.g., Phan and Siegel, 2006; Siegel et al., 2003; Xu et al., 2011) to break through the information barrier to the enterprise in the technology transfer process (Siegel et al., 2007).

3.4 Summary of the characteristics of the multi-level TTS

We conduct an intra-level comparison to summarise the characteristics of the multi-level TTS. As shown in Table 4, the three levels (academy, branch, and institute) are distinct from one another in terms of actors and duties. The effective interaction between the actors within or across the three levels of the TTS could enhance the functions of integration management, S&T resource allocation, and public R&D. Actors within the academy-level TTS are generally responsible for the top-down design. The BSTD and other academy-level actors (e.g., bureaus and companies) work cooperatively to design, support, and implement technology transfer policies. Actors within the branch level are in charge of bridging research institutes with the academy-level TTS, regional governments, local companies, and other technology transfer stakeholders. Thus, the collaboration between the actors within or across the academy and branch levels of the TTS perform the functions of integration management and resource allocation. Besides, actors within the institute-level TTS consist of research institutes and their technology transfer departments, and mainly perform the function of public R&D.

Table 4 Intra-level comparison in the multi-level TTS

Level	Academy	Branch	Institute
Actors	The BSTD; Support organisations	Branches; Technology transfer organisations	Research institutes; Technology transfer departments
Duties	(1) Making policies for top-down design; (2) Guiding the missions and goals of branches and institutes; (3) Providing a friendly environment for technology transfer;	(1) Implementing the policies released from academy level; (2) Formulating plans based on their missions, goals, and regional characteristics; (3) Bridging institutes with local governments and firms; (4) Cooperating with other branches to transfer	(1) Technology transfer through various media (e.g., spin-offs, patent licencing, collaboration with industry, etc.); (2) Implementing the plans formulated by the branch to which they belong;

	(4) Responsible for transfer of technologies to meet the major needs of the country; (5) Reporting technology transfer performance of the CAS annually.	technologies to meet the need of regional economic growth; (5) Collecting the reports of institutes' technology transfer activities and submitting them to the academy level.	(3) Participating in the construction and running of S&T infrastructures; (4) Collaboration with local governments; (5) Reporting its performance on technology transfer to th branch; (6) Responsible for some duties of branches (particular institutes only).

To reveal the uniqueness of the multi-level TTS in the CAS, this study conducts an international comparison with the TTSs of other countries' NRIs (as shown in Appendix A2). This uniqueness is reflected in three main ways. The first way concerns the ecosystem of academy-level actors. Within the ecosystem, the BSTD is the hub organisation responsible for regulating technology transfer activities in the CAS. Other bureaus and companies are the support organisations that bring their institutional superiority into full play and work cooperatively to facilitate technology transfer. The second way concerns the existence of branch level. In contrast to the branches in the RIKEN and RAS, the branches in the CAS are more like executive organisations than research units. As mentioned, the branches exist for the convenience of overall management and serve as a bridge between the academy level and the institute level. In addition, the branches are also channels for research institutes or academics to connect to local governments or companies. The third way concerns the relatively independence of research institutes. As legal entities, the research institutes of the CAS are independent organisations, allowing them to transfer technology according to their own incentives. However, they are required to report their transfer work to the branches. The branches will summarize the reports of the institutes and report them to the academy. The dual role of research institutes in the CAS is distinct from those in other NRIs.

4. Technology transfer modes beneath the multi-level TTS

Due to the differences in regional resource endowments and the research fields, the CAS research institutes located in different regions have chosen different technology transfer modes. The classification of these modes is helpful for deepening the understanding of technology transfer from the CAS. A key related topic is the formation and development of diverse technology transfer modes. Another topic is concerned with the role of the multi-level TTS played in the formation and operation of these modes. Different technology transfer modes have different demands for technological cognition and resource allocation capability, which can be satisfied by the co-specialised interaction among the three levels of the TTS at the CAS.

4.1 Identifying technology transfer modes: a thematic synthesis approach

To identify the technology transfer modes of the CAS, we employ a thematic synthesis approach to systematically extract, analyse, and synthesise useful information from the text materials related to technology transfer from the CAS, such as reports, literature, and official websites. The thematic synthesis approach is composed of three stages: the coding of text 'line by line', the development of 'descriptive themes', and the generation of 'analytical themes' (Thomas and Harden, 2008). This methodology has been widely used in the literature (e.g., Jones et al., 2011; Rijmenam et al., 2019; Steyn and Sewchurran, 2019; Symeonidou and Bruneel, 2017; Tan et al., 2021; Thomas et al., 2014). Following these studies, we first clarify the direction of data collection through multiple rounds of discussion among the research team members and conduct a search for relevant information. Thereafter, on the basis of the thematic synthesis approach, we develop a text data extraction and coding frame, and then perform data extraction and coding for all included materials (as shown in Appendix C). In addition, we adopt expert discussions to clarify the reliability of the data and the accuracy of the classification.

4.1.1 Selection strategy and information sources

By looking through the text materials related to the technology transfer modes of the CAS (e.g., Yang et al., 2018), we come to an understanding of technology transfer from the 115 research institutes of the CAS and then select ten institutes with outstanding performance for a preliminary investigation. We screen the cases from the selected institutes by taking into account the characteristics of technologies and regions, the representatives of institutes, and the effectiveness of technology transfer modes. We invite experts to confirm the case selection and finally identify six cases, namely, the Suzhou Institute of Nano-Tech and Nano-Bionics (SINANO), the Nanjing Institute of Advanced Laser Technology (NIALT), Fujian Institute of Research on the Structure of Matter (FIRSM), the Xi'an Institute of Optics and Precision Mechanics (XIOPM), the Hefei Institutes of Physical Science (HIPS), and the R&D Centre of Xuyi Palygorskite Applied Technology (R&DC-XPAT). Then, a large-scale survey focused on these six research institutes is conducted for subsequent analysis. The information sources include relevant reports, official websites, interviews with experts in relevant fields, and academic literature.

4.1.2 Data extraction and data coding process

The thematic synthesis approach proceeds through three steps. In the first step of coding, the descriptions related to technology transfer are extracted line by line. The key phrases are coded through the independent work of the research team members and are classified and summarised to develop descriptive themes. Then, analytical themes were developed through a closer examination on the symbolic meanings of and the relationships between the descriptive themes (Tan et al., 2021). In order to make the synthesis more rigorous, each member of the research team code independently, and then group discussions are held repeatedly until sufficient abstract themes that could effectively summarise the extracted technology transfer features have been formed. Finally, all included text materials are critically appraised to evaluate the quality of the evidence. We organise a group of experts to discuss and validate the reliability of the data sources, the scientificity of the coding process, and the accuracy of the classification results. According to the experts' feedback, the revision was repeated until the experts reached a consensus, and the results were then confirmed (The coding process is presented in Appendix C).

On the basis of the analytical themes, three typical technology transfer modes are identified. The first concerns the CAS-region cooperation mode. Although the collaboration with local governments is a general feature of most CAS research institutes, the CAS-region cooperation mode still has distinctive features, namely, making full use of local resources and promoting local economic development. The second concerns the construction of an incubation centre or a system to encourage spin-offs, which is defined as the incubation ecosystem mode. The third concerns the construction of platforms to promote research-industry cooperation, which is called the platform-driven mode. The cases of the HIPS and the R&DC-XPAT are typical of the first mode, the cases of the FIRSM and the XIOPM represent the second mode, and the SINANO and the NIALT typify the third mode. Although we mainly focus on these six research institutes as examples, further analysis has been conducted on other institutes to see whether these three modes also occur in other institutes, by which we have verified the validity of the classification of the three modes. It is worth noting that some institutes adopt two or three of these modes simultaneously for technology transfer.

4.2 Three technology transfer modes in the CAS

The three technology transfer modes in the CAS follow an evolutionary sequence from the CAS-region mode, to the incubation mode, and to the platform-driven mode. The first is the CAS-region cooperation mode, which dates back to the beginning of the establishment of the CAS, and this mode has regained attention since the S&T system reform. With the acceleration of S&T system reform in China and the development of S&T in the CAS, the incubation ecosystem mode emerged in the early 21st century. Owing to the improvement of the scientific and technological progress law, the upgrading of industrial structure, and the development of technologies with high exaptation, the platform-driven mode has emerged over the past decade. The evolution of these three modes mirrors the progress of the S&T system reform in China as well as the mission repositioning of the CAS, as reflected in the six cases (as shown in Appendix D).

4.2.1 CAS-region cooperation mode

In 1985, the Decision of the Central Committee of the Communist Party of China on the Reform of the Science and Technology System was enacted, marking the beginning of the

S&T system reform (Motohashi and Xiao, 2007). Since then, the CAS has adjusted its mission of devoting itself to serving national economic and social development, with the aim of advancing regional development (Xue, 2018). Consequently, the academy-level, branch-level, and institute-level actors in the CAS have initiated or participated in a series of cooperative projects with local governments and enterprises. To promote the development of local industries and the economy, the CAS-region cooperation mode came into being when the CAS research institutes are required to create public knowledge and provide related technologies for local governments or industries. This mode strengthens the cooperative relationships between local governments and enterprises, which is conducive to filling the gap between research and industry.

In this mode, research institutes transfer their technologies to promote regional economic development by carrying out cooperative projects, establishing science centres, building joint laboratories, or implementing other measures jointly with the region. In the case of HIPS, the research institute, the People's Government of Anhui Province, and the Hefei Municipal Government jointly established the Hefei Comprehensive National Science Center. The centre not only promoted the economic development of Anhui province, but also had a positive spillover effect on other provinces or cities in central China. The HIPS also built joint laboratories with local enterprises, such as those with Hefei Cosource Pharmaceuticals Inc., Anhui Yingliu Electrome Chanical Co., Ltd., and Anhui Chaoyuan Information Technology Co., Ltd. Apart from cooperation with Anhui province, the HIPS also established a series of TTCs and joint laboratories with other regions to promote their economic growth.

The research institutes in this mode also transfer their technologies by making full use of the region's resource endowment and carrying out related R&D activities. A typical example is the establishment of R&DC-XPAT. Xuyi County in Jiangsu Province is quite abundant in palygorskite clay ore; its reserves account for approximately 48% of the world's total reserves and 74% of domestic reserves. The county urgently needs palygorskite technologies to take advantage of resources and obtain high returns. However, the best palygorskite research team is in Lanzhou Institute of Chemical Physics (LICP), located in Lanzhou City, Gansu Province.

In this case, the Nanjing and Lanzhou branches, which have jurisdiction over the research institutes in Xuyi County and Lanzhou City, respectively, have promoted cooperation between Xuyi and LICP for the transfer of palygorskite technologies. In 2010, they jointly established the R&DC-XPAT and succeeded in producing a series of high-end palygorskite products. Since then, the annual value of palygorskite production has increased from less than 400 million RMB in 2010 to more than 2 billion RMB in 2017.

The CAS-region cooperation mode is mainly advanced by the branch-level TTS, owing to its high resource allocation capability. It is supervised and administered by a specialised academy-level organisation, namely, the Bureau of CAS-Region Cooperation. In the case of R&DC-XPAT, the Nanjing and Lanzhou branches played a significant role in the cooperation between Xuyi County and LIPC. Subsequently, the academy-level headquarters further advanced this cooperation with more research units, such as the Ningbo Institute of Materials Technology & Engineering, Guangzhou Institute of Energy Conversion, and Changzhou University, aiming to create a new pattern for the innovation development of palygorskite in Xuyi County.

4.2.2 Incubation ecosystem mode

In the 1990s, technology transfer from the CAS was impeded by institutional barriers resulting from the defective S&T system at that time, such as the unreasonable management of state-run assets or the absurd ownership of resources (belonging to enterprises or research institutes) (Motohashi and Yun, 2007). To break such institutional barriers, in 1999 the General Office of the State Council enacted a policy (Guobanfa [1999] No. 18) to reform the governing system of NRIs for accelerating the establishment of an enterprise-centric national technology innovation system. As a result, the CAS pushed ahead with restructuring itself and allowed the infusion of social resources, triggering the emergence of the incubation ecosystem mode. Meanwhile, with the acceleration of S&T reform, the CAS advanced the process of socialisation of the institute-invested enterprises' shareholding rights in 2003, which further enhanced acceptance of the incubation mode. Moreover, as the CAS played a critical role in the NIS, more technical science that was too hard for enterprises to introduce or absorb was gradually developed by CAS research institutes. Consequently, the research institutes adopted the incubator ecosystem mode to provide support for enterprises with potential beneficial interactions with investors, thereby facilitating the technology transfer.

The distinguishing feature of this mode is the construction of a relatively complete incubation system. Such a system guarantees that the research institutes adopting this mode can achieve self-absorption from R&D to commercialisation, thereby leading to high-efficiency technology transfer. For example, the FIRSM is a national key laboratory that not only conducts basic research on the S&T frontier but also develops applied technologies to meet industrial needs. Since the FIRSM engages in all types of the R&D activities, it prefers incubate technology rather than engage in direct licencing or trading. Similarly, the XIOPM has focused on the whole process of technology transfer and built an ecological incubation network to improve the efficiency of incubating enterprises, resulting in a network made up of an angel fund—Xike Angel Fund—an optoelectronic industry incubator, and a hard technology entrepreneurship training camp, which improves efficiency in technology transfer.

In this mode, higher technological cognition and more adequate financial support are the most fundamental factors that help incubation. Actors within the institute level play a dominant role in this mode since they have the highest cognition of technologies. The academy and branch levels are supposed to allocate resources but the beneficial interaction between technologies, capital, researchers, and research institutes reduces the demand for external resources. In the case of the XIOPM, the research institute builds the whole incubation network within which the angel funds succeed in solving the financing difficulties related to technology transfer, and becomes the keystone player in the incubation ecosystem. Accordingly, actors within academy and branch levels play less significant roles in this mode. This is because the institute-level actors are more familiar with the conditions and resources required for the transfer of related technologies and can better provide targeted supports. Under these circumstances, the academy-level and branch-level TTS, with relatively lower technological cognition and less familiarity with the path of commercialisation, generally provide some resources and policy support as basic conditions.

4.2.3 Platform-driven mode

In 2007, the Law of the People's Republic of China on Scientific and Technological Progress was revised to improve Chinese scientific and technological legislation (Richard, 2015). This revision added a new clause that encouraged public research institutes to open their infrastructures to enterprises. As a result, the CAS attempted to create technological platforms that are often organised around large research infrastructures to facilitate collaboration with enterprises. It applies in particular when industry-research cooperation becomes mature. In addition, with the economic development of China, its upgrading industrial structure requires an increasing amount of advanced technical know-how, equipment, and services. Accordingly, the CAS and its research institutes are building technological platforms and taking advantage of those platforms to cooperate with firms, thereby satisfying the corresponding demands from the industry. Moreover, technologies with higher potential exaptation have been continuously developed by the CAS and its research institutes in recent years. These technologies, such as nanotechnology, laser technology, or 3D prints, often have multiple latent functions and a strong capacity for adaptation (Beltagui et al., 2020), and can often be used in various application scenarios by constructing service platforms. CAS research institutes with such technologies are inclined to diffuse their technologies by establishing platforms to accelerate technology proliferation, forming platform-based innovation ecosystems, and advancing industry-research cooperation.

The most prominent feature of this mode is the technological service platform. To facilitate the transfer of nanotechnology, the SINANO built an open system of technology service platforms that provide equipment resources, research sites, and technical services. The platforms not only transfer technologies from the SINANO directly through licencing or contract, but also act as an application service community that attracts research achievements, enterprises, and research institutes to boost technology transfer. Similarly, the NIALT built a public technology platform and public technology service platform for laser processing technology, providing technical services for enterprises to meet the needs of laser processing. The second most prominent feature is the formation of industrial clusters around these research institutes. Public service platforms provide open S&T resources and infrastructure, which not only improves the technological innovation environment in a given region but also increases the S&T outcomes, thereby contributing to the formation of industrial clusters (Bikard and Marx, 2020). Evidence from the SINANO case supports this argument. A large number of nanotechnology enterprises were attracted by the platforms provided by the SINANO, and these enterprises devoted themselves to developing products, making the Suzhou Industrial Park one of the largest nanotechnology industry clusters in the world.

In this mode, the platforms provide shared technological resources and information, which requires a high cognition of technologies for successful operation. Actors within the institute-level specialise in R&D on technologies and consequently has a comprehensive understanding of the latent functions of technologies. This contributes to the efficient sharing of information and resources. For example, the NIALT is aware of the exact demands of the local government for laser processing technology and has therefore created a public technology service platform to assist in the development of regional laser infrastructure. Similarly, on the basis of its high cognition of nanotechnology, the SINANO has established service platforms to meet various needs of industry. This mode also has a certain demand for resources to establish platforms, where the academy-level or branch-level actors play a critical role in allocating resources. The case in the SINANO illustrates this point. The Nanjing branch established the Technology Service Network (STS) Suzhou Center to enhance communication between the SINANO and localities, and the CAS and the Suzhou Industrial Park Management jointly constructed the Suzhou Incubation Center[2] to promote technology transfer by building a nano-science city.

[2] Suzhou Industrial Technology Innovation and Incubation Center of CAS.

4.3 Summary of the characteristics of the three modes

The three modes of technology transfer differ in cooperation orientation due to their specific missions. They demand different for technological cognition and resource allocation capability that can be satisfied by the co-specialised interaction among the three levels of the TTS at the CAS.

Specifically, the CAS-region mode is oriented towards the collaboration between the CAS research institutes with the local governments and local companies, thereby improving regional development. The incubation ecosystem mode tends to be market-oriented, carrying out technology transfer from basic research to applied research and then to spin-off enterprises. The platform-driven mode is characterized by its public welfare orientation, in which the research institutes provide infrastructures or provide technological platforms for public use. The three modes have different demands for technological cognition and resource allocation capability, and actors across the three levels of the TTS make co-specialised interaction to meet the demands above. Specifically, the academy-level actors carry out the macro-level control of S&T resources, the branch-level actors have the capability to allocate S&T resources to facilitate cooperation between CAS research institutes and regions, while the institute-level actors are primarily responsible for completing the cooperation projects. Among the three technology transfer modes, the CAS-region cooperation mode has a greater demand for resource allocation capability, which is mainly satisfied by the branch level and sometimes met by the academy level. By contrast, the incubation and platform modes have greater demand for the technological cognition capability of TTS. Therefore, actors within the institute level of TTS play a dominant role in those two modes, while those within the academy and branch levels of TTS provide operational support.

It is worth noting that the three technology transfer modes of the CAS are not distinctive. The modes of the NRIs in other nations are also operated through similar technology transfer channels mentioned earlier in the article, such as technology licencing, technology trading, and spin-offs. In addition, there are also some other technology transfer modes with characteristics of the CAS, such as industrialisation based on national strategic demands and large research infrastructures.

5. Conclusions and discussions

5.1 Conclusions

Technology transfer from NRIs has become increasingly important in promoting the development of NISs. However, the issues regarding the TTSs and modes of NRIs, especially the ones in emerging economies, have not been fully explored in the extant literature. To fill the research gap, this paper explores the formation and development of the multi-level TTS and modes using the CAS as a case, and provides three key findings.

First, we find that institutional factors, such as the multi-layered organisation structure or the particular roles in NIS, influence the formation of the multi-level TTS in the CAS. The evolution of TTS is driven by the dynamics of policy-making process for the construction of NIS and the repositioning of the CAS's missions. The actors within the each level of the TTS have developed their own structures to perform their duties, and work cooperatively to facilitate technology transfer. Specifically, actors within the academy level are responsible for the top-down design, actors within the branch level are responsible for bridging the academy and institute levels with the industry, and actors within the institute level are responsible for facilitating and managing the specific technology transfer process. Compared with the TTSs of NRIs in developed countries, the multi-level TTS of the CAS demonstrates three different aspects: 1) two kinds of academy-level actor, namely, bureaus and companies, bring their institutional superiority into full play and work jointly as an ecosystem; 2) the CAS branches are more like executive organisations than research units to support the smooth operation of TTS; and 3) the research institutes enjoy considerable autonomy in managing technology transfer.

Second, we identify and illustrate three typical NRI technology transfer modes of the CAS. The evolution of these three modes exhibits a time sequence from the regional mode to the incubation mode and to the platform mode, following the progress of Chinese S&T system reform and the repositioning of the CAS mission. The first mode is the CAS-region mode, which dates to the beginning of the structural reform of the S&T system. This mode aims to promote collaboration between research institutes with local governments and local enterprises. The second mode is the incubation ecosystem mode, which occurred in the 1990s. This mode is aimed at constructing a relatively complete incubation system to promote self-absorption from R&D to commercialisation. The third mode is the platform-driven mode, which has emerged over recent decades. This mode is designed for accelerating technology proliferation, forming platform-based innovation ecosystems, and advancing industry-research cooperation.

Third, we find that different modes have diverse demands for technological cognition and resource allocation capability, which can be satisfied by the co-specialised interaction among the three levels of the TTS. The actors within the institute level have the highest technological cognition, while academy-level and branch-level actors are more powerful in resource allocation. In the three modes, the CAS-region cooperation mode has an urgent need to mobilise external resources through resource allocation, which is met by the branch and academy levels. The incubation ecosystem mode relies more on technological cognition to facilitate incubation, which is met by the institute level. The platform mode is mainly led by CAS research institutes to meet the need for high technological cognition, and sometimes can be advanced by the academy or branch levels of TTS for resource allocation.

5.2 Implications

5.2.1 Theoretical implications

Theoretically, this study attempts to extend the current studies on technology transfer by exploring the TTSs and modes of NRIs in the context of emerging countries. Our study has three theoretical implications.

First, this study contributes to the development theory of NIS by illustrating the dynamic response of TTSs to the structural transformation of NIS in emerging countries, and extends the research on the formation and development of the TTSs. Previous studies have argued that NRIs co-evolve their roles or functions with changing nature of the NIS where they operate (e.g., Intarakumnerd and Goto, 2018). This study further indicates that NRIs should develop their TTSs to fit the nature and level of development of their underlying NISs. Our study demonstrates that the CAS employs a multi-level TTS to fulfill its functions of supporting the construction of the Chinese NIS, to implement a multi-level governing system for its multi-layer organisational structure, and to respond to the impacts of other institutional factors. This study also suggests that the development of multi-level TTS is driven by the evolution of technology transfer policies, following the dynamic government interventions under the restructuring of NISs. However, the theoretical linkage between the TTSs and NISs has been not fully examined so far. Further investigations should be conducted to deepen the understanding of the formation and dynamic mechanisms of TTSs in the different national contexts.

Second, this study advances our understanding of the inherent dynamics of TTSs' responses to promoting technology transfer from NRIs by investigating the operational mechanisms of a multi-level TTS. Prior research primarily focuses on examining the performance of centre-dominated TTSs (e.g., Belitski et al., 2019; Bengtsson, 2017; Lee and Jung, 2021), company-dominated TTSs (Buenstorf, 2009), or other types of TTS in NRIs. However, the issue of how TTSs operate to promote technology transfer is not explicitly investigated in the literature. The findings of this research imply that actors within each level work cooperatively to accomplish a common mission, and actors across different levels collaborate with one another to meet various requirements for technology transfer. These findings confirm the necessity for developing a more-nuanced theory of organisational collaboration that attends to the mechanisms and conditions by which the actors within or across the three levels work cooperatively. It is particularly fruitful to provide specific propositions regarding causal relations among variables for testing the theory empirically.

Third, this study reveals the evolutionary dynamics of the modes in China and clarifies the roles of TTSs in operating technology transfer modes. Technology transfer modes in China exhibit an evolutionary sequence from regional, to incubation, and to platforms, following the process of the S&T reform in China and the mission positioning of the CAS. This evolutionary dynamics account for what triggered each successive step in China and might also be tenable explanations for the evolutionary sequence of the modes in other emerging economies. Besides, although some studies have been conducted on technology transfer modes that consist of various channels such as IP management, technology transfer alliance, or spin-offs (e.g., Link, 2019; Upstill and Symington, 2002), little is known about how TTSs work in conjunction with these modes. The findings of this study suggest that the multi-level TTS could take advantage of the co-specialisation of all its three levels to meet the particular demands of technology transfer modes for technological cognition or resource allocation. However, whether and how does the multi-level TTS continue to play a significant role in promoting technology transfer during the emerging industrial revolution? This topic warrants further attention. Future studies should further deal with this topic by further articulating the relations among TTSs, technology transfer modes, and technology transfer performance to guide technology transfer from NRIs.

5.2.2 Managerial implications

This study also has several managerial implications. First, the TTS and modes of NRIs should be designed to serve the national and regional socio-economic development. Our research findings show that a multi-level TTS and diversified modes are beneficial for comprehensive NRIs, such as the CAS, in promoting technology transfer. This suggests that NRIs could develop suitable TTSs or modes according to their own organization structure, R&D activities, or other institutional settings, thereby fitting the nature and level of development of their underlying NISs. Our research findings also show that actors within the branch-level TTS have promoted collaboration between research institutes and local enterprises to support the economic development of certain regions. This suggests that the technology transfer from NRIs are required to meet the development of regional economic growth. The TTSs of NRIs should be designed in accordance with the regional resource endowments, regional innovation systems, and other influence factors.

Second, the success stories of technology transfer from the CAS suggest that the efficient management of technology transfer needs an effectively collaboration between actors in some TTSs. The findings of our research suggest that actors within the academy-level TTS are conducive to the overall planning and management of technology transfer; actors within the branch-level can strengthen the cooperation between research institutes and regions; and actors within the institute-level are responsible for public R&D management and choosing a suitable mode to effectively transfer the technology according to the institutes' R&D activities and regional resource endowments. Moreover, the findings of our case study show that the academy-level and branch-level actors play significant roles in the CAS-region cooperation mode, but only serve in an auxiliary role in the other two modes. On the contrary, the institute-level organisations play a more significant role in the incubator and platform modes than the regional mode. This suggests that the co-specialised interaction among actors within each level guarantees the smooth operation of various technology transfer modes. If NRIs adopted the multi-level TTS without such an interaction, they would be confronted with some managerial issues. For example, duplication of resource allocation, unclear authorities, and ambiguous responsibilities among organisations at each level. Therefore, the duties and functions of each level need to be explicit and carefully communicated to each other for making an effective use of a multi-level TTS.

Third, governments should play an active role in guiding the development of the TTSs and modes of NRIs. The policy-driven evolvement of the multi-level TTS shows that the Chinese government plays a critical role in restructuring NIS which then drives the CAS to further refine its TTS and modes. Policy makers should therefore introduce a series of regulations such as for building a national TTS to perfect the Chinese NIS or creating a friendly environment for technology transfer services. The CAS should introduce a set of regulatory programmes to advance the effective collaboration among actors within and across different levels of TTS. Besides, the government should evaluate technology transfer output and performance at NRIs so as to improve the effectiveness of a certain TTS, technology transfer mode, or technology transfer policy.

5.3 Limitations and future work

Although this study provides an important insight into the TTSs and modes of NRIs in the context of China, it also suffers from some limitations. Future research can explore these further. First, our research sample is limited to several representative research institutes affiliated with the CAS. To illustrate the panoramic feature of TTSs and modes of NRIs in China, future studies can conduct a long-term and large scale sample survey to extend our study in order to generalise our findings. Second, there is still a gap in fully analysing the effectiveness of the TTSs and modes of the CAS. For example, how to evaluate the effectiveness of the TTS and modes of the CAS from the perspectives of the central government or local research institutes? What are the determinants of the success of technology transfer from the CAS? To what extent the multi-level TTS or the modes of the CAS can promote technology transfer? These important issues need further exploration. Moreover, a cross-country comparative analysis on the effectiveness of the TTSs and modes of other NRIs is also a promising line of research. It not only gives us a global understanding of the TTSs and modes of NRIs, but also provides a guidance to the best practices of TTSs and modes. Third, this study mainly focuses on the formation and development of the TTSs and modes in the context of China. However, a comparative analysis in the context of other countries with different NISs may be more important. It can reveal a cross-country difference in the formation and development mechanisms, and dynamics of the TTSs and modes of NRIs. Additionally, it can provide national experiences in the design of TTSs and modes, which may give directions for NRIs to choose appropriate TTSs or modes to cope with or adopt to the development of their underlying NISs.

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Appendix A1. An overview of typical national research institutes (NRIs)

Country	NRIs	Introduction	Mission and Goals	Types of R&D activity
U.S.	National Institutes of Health (NIH)	NIH is a part of the U.S. Department of Health and Human Services. It operates 21 institutes and 6 centers.	NIH's mission is to seek fundamental knowledge about the nature and behavior of living systems and the application of that knowledge to enhance health, lengthen life, and reduce illness and disability.	Basic research
Germany	Max Planck Society (MPG)	The MPG took over the mandate of its predecessor, the Kaiser Wilhelm Society, to foster basic research after German reunification. It has evolved into one of the mainstays of the science landscape of Germany. The MPG operates 86 institutes and 20 centers, mainly funded by the federal and state governments.	The MPG regards its primary task as working on areas that are highly relevant and promising scientifically and, above all, to move into newly emerging areas of research that lie outside the established disciplines or at the boundaries between them (Annual Report Max Planck Society, 2019).	Basic research
France	French National Centre for Scientific Research (CNRS)	The CNRS is an interdisciplinary public research organization under the administrative supervision of the French Ministry of Higher Education and Research. It has approximately 1,100 laboratories located throughout France. Most are joint research units (UMR) operating in association with a university, a higher education establishment, or another research institution.	The French state has entrusted the CNRS with the role of advancing knowledge for the benefit of society. The organization seeks to accomplish a five-pronged mission, of which technology transfer is just one.	Basic research
Japan	RIKEN	RIKEN is Japan's largest and most comprehensive research organization in a diverse array of scientific disciplines. It was an independent administrative institution under the Japanese Ministry of Education, Culture, Sports, Science and Technology. Now, it has acquired a new status as a National Research and Development Institute. About 23 centers or labs can be found on its website.	As RIKEN has essentially been established with the mission to promote the advancement of Japan's developing industries, contributing to society has always been in its blood. Therefore, transforming discoveries and breakthroughs into applications that contribute to a better society is central to RIKEN's mission.	Basic and applied research
Russia	Russian Academy of Sciences (RAS)	The RAS, the successor of the USSR Academy of Sciences, is the highest scientific institution and biggest non-profit research entity in Russia. The RAS includes 3 regional branches, 13 branches (by fields of science), more than 400 scientific centers, and about 100 representative offices.	The aim of the academy's activities is to ensure the continuity and coordination of fundamental scientific research and exploratory research carried out in the most important areas.	Basic and applied research
U.K.	NRIs in UK Research Councils	NRIs in UK Research Councils are the main driver of UK public research. They are supervised and funded by councils, which are independent and self-governing. Most of them rely on universities, and therefore, are	As non-department public bodies, the councils fund NIRs for high-level basic and applied research.	Basic and applied research

		affected by the universities in business management and choice of research field.		
Japan	National Institute of Advanced Industrial Science and Technology (AIST)	The AIST is one of the largest public research organizations in Japan. Its predecessor is the Agency of Industrial Science and Technology. It transformed from a government agency to an independent legal entity in 2001. Since then, the AIST has been supervised by the Ministry of Economy, Trade and Industry. It operates 25 institutes and 16 research centers.	The mission entrusted to AIST and its staff is to develop science and technology that complement society and the environment. It focuses on the creation and practical realization of technologies useful to Japanese industry and society, and on bridging the gap between innovative technological seeds and commercialization.	Applied research
Germany	Fraunhofer-Gesellschaft (FhG)	The FhG is the world's leading applied research organization. It was established shortly after World War II to accelerate German economic reconstruction and improve the level of German applied research. Founded in 1949, the FhG currently operates 75 institutes and research institutions throughout Germany.	The FhG, headquartered in Germany, is the world's leading applied research organization. Its focus is on developing key technologies that are vital for the future and enabling the commercial exploitation of this work by business and industry,	Applied research
Australia	Commonwealth Scientific and Industrial Research Organization (CSIRO)	The CSIRO is the successor of the Council for Scientific and Industrial Research, the organization in charge of conducting research to assist the Australian Defense Forces. Nowadays, the CSIRO is responsible and accountable to the Commonwealth. Its direction is set by the CSIRO board and the CSIRO executive team. It now operates 55 sites across Australia and 3 sites overseas.	As one of the world's largest mission-driven multidisciplinary science and research organizations, the CSIRO focuses on the issues that matter the most: quality of life, the economy, and the environment. By focusing on the big things that really matter, Australian science and technology can solve seemingly impossible problems, and create new value.	Applied research
U.S.	National Laboratories	According to a clause in the Bayh-Dole Act, national laboratories are government owned. Some of them are contractor operated and others are government operated (Link et al., 2011). The national laboratories are administered by government departments, like the DoE, NASA, and DoD.	The laboratories serve national strategic goals, undertake cutting-edge basic research, and carry out the transfer of new and high technology. Much of the technology transfer activities in the U.S. begin here. Congress has deemed it the responsibility of each federal laboratory to establish an office as well as mechanisms to transfer its technology (Link and Scott, 2019; Link et al., 2019).	Basic and applied research
Europe	European Organization for Nuclear Research (CERN)	CERN is run by 23 member states, each of which has two official delegates to the CERN Council. The CERN Council is the highest authority of the organization and has responsibility for all important decisions. The Council is assisted by the Scientific Policy Committee and the Finance Committee. The Director-General, appointed by the Council, manages the CERN Laboratory.	The CERN provides a unique range of particle accelerator facilities that enable research at the forefront of human knowledge. It performs world-class research in fundamental physics. It unites people from all over the world to push the frontiers of science and technology, for the benefit of all.	Basic research

Note: We summarized the information on NRIs from their official websites, which are as follows: (1) NIH https://www.nih.gov/; (2) MPG https://www.mpg.de/en; (3) CNRS http://www.cnrs.fr/en/cnrs; (4) RIKEN https://www.riken.jp/en/about/; (5) RAS http://www.ras.ru/about.aspx?_Language=en; (6) AIST https://www.aist.go.jp/aist_e/about_aist/index.html; (7) FhG https://www.fraunhofer.de/en.html; (8) CSIRO https://www.csiro.au/; (9) CERN https://home.cern/.

Appendix A2. An overview of typical technology transfer systems and channels in NRIs

NRIs	Technology Transfer Systems	Technology Transfer Channels
NIH	The Office of Technology Transfer at the NIH headquarters is in charge of the Intramural TT Portfolio Management Unit and License Compliance & Administration. The latter unit is also in charge of the Monitoring & Enforcement Unit and the Royalties Administration Unit[1].	License agreements.
MPG	Max-Plank-Innovation GmbH is responsible for the technology transfer from the Max Plank Institutes. Operating under the motto “Connecting Science and Business,” the MPG subsidiary acts as a partner to scientists and business alike. It provides advice and support in evaluating intellectual property, registering patents, and establishing start-ups based on technologies developed at a Max Plank Institute.	License agreements, Spin-offs, Incubators (Annual Report Max Planck Society, 2019).
CNRS	For innovative technology’s pre-maturation stage, the system has been set up jointly by CNRS Innovation Office (DGDI) and its industrial partners to increase emerging technologies’ level of maturity and help them access the market. For those in maturation stage, the 14 regional technology transfer companies (14 SATTs) of the CNRS play a role. It is a public limited company and subsidiary of CNRS and Public Investment Bank France (BPI France) whose mission is to transfer innovative technologies from CNRS-linked laboratories to industry[2].	A partnership model for technology transfer, Start-up companies, IP management (protection strategies or patent portfolio), Contracts.
RIKEN	The RIKEN Cluster for Science, Technology and Innovation Hub and the RIKEN Venture system are main components of RIKEN’s TTS. After 2019, the TTS became dominated by RIKEN Innovation Co., Ltd[3].	Technology licensing, Start-up companies, Collaboration projects, Co-creation with industry[4].
RAS	For a long time, the activities of the RAS were directed toward research as part of the overall state plan for science and technology development and it was not responsible for the commercialization of research. Instead, the task of technology transfer was passed on to the industrial research and production centers. With the transition to a market economy, the centers disappeared and a joint production venture with foreign partners appeared (Ozerin, 1998).	The mission of the center is to commercialize knowledge and technology developed by the research institutes of RAS. Projects developed in the center can apply for RUSNANO’s co-financing, and to seed and venture capital funds. Joint center of technology transfer (e.g., RAS-Rusnano).[5]
NRIs in UK Research Councils	The councils require the NRIs they administer to transfer technologies but have no requirement for the IP rights. Therefore, each NRI has its own way of transferring. Some institutes transfer their technologies through IP management and technology transfer companies (e.g., Babraham Commercialization Services, Plant Biosciences Ltd.), and others choose to do it themselves[6].	Patent assignment and license, Start-ups, Collaboration with industry.

AIST	AIST established a new department, named the Innovation Center for Startups (INNCS), which integrates the two functions of technology licensing and start-ups, executing the commercialization reliably by emphasizing the characteristic feature of the technology[7].	Multi-applied Joint IP—designed for use in many fields and companies; Specialized Joint IP in co-owner's business—can be exclusive use by a co-owner upon negotiation.
FhG	Fraunhofer's IP department is responsible for developing appropriate IP strategies in partnership with the institutes. Other organizations, like the 17 high-performance centers, or methods, like the Fraunhofer Tech Transfer Fund, also play an important role in Fraunhofer's TTS[8]. The two complementary partners – the European Investment Fund as an expert in fund structures and Fraunhofer as Europe's largest application-oriented research institution – want to bridge the gap in early commercialization phases and grow more high-tech start-ups in Germany and Europe.	Contracts, Spin-offs, Licensing, Collaboration with industry, and so on[9] (Fraunhofer Annual Report, 2018).
CSIRO	The advisory committees make policies for technology transfer and the technology transfer centers in each unit implement those policies[10].	Non-commercial transfer (e.g., staff exchanges and training), Commercial transfer (e.g., collaboration with industry, contracts, consulting, licensing and sale of IP, technical services), and New company generation (spin-offs, technology transfer companies)[11] (Upstill and Symington, 2002).
National Laboratories	The National Technology Transfer Center (NTCC), Regional Technology Transfer Center (RTCC), Federal Laboratory Consortium for Technology Transfer, FLC), and other organizations.	Cooperative Research and Development Agreements (CRADAs) between Federal R&D laboratories and private companies (Rogers et al., 1998; Link, 2019; Link et al., 2011), Spin-offs from laboratories (Rogers et al., 2001).
CERN	Knowledge Transfer group: Business Development Section, IP Management and KT Policies Section, Medical Applications, and others (GAO, industrial relations, entrepreneurship, etc.)[12].	IP management, Entrepreneurship, Funding for CERN personnel, Collaborations and networks.

Note: The sources of NIRs' technology transfer systems and channels are as follows: 1. https://www.ott.nih.gov/about-ott/org-chart; 2. http://www.cnrs.fr/en/innovation; https://in2p3.cnrs.fr/en/some-examples-technology-transfer-cnrs; 3. https://www.innovation-riken.jp/en/about/; 4. https://www.innovation-riken.jp/en/about/; https://www.riken.jp/en/collab/; 5. http://www.ras.ru/about/cooperation/internalcooperation.aspx; 6. http://www.babrahamcs.co.uk/; http://www.pbltechnology.com/; 7. https://unit.aist.go.jp/inncs/en/overview.html; 8. https://www.wipo.int/wipo_magazine/en/2017/02/article_0002.html; 9. https://www.wipo.int/wipo_magazine/en/2017/02/article_0002.html; https://www.barrier.fraunhofer.com/en/offers-for-industry/technology-transfer.html; 10. https://research.csiro.au/qcat/facilities/technology-transfer-centre/; 11. https://kt.cern/about-us/organisational-chart.

Appendix B. Part of division of key tasks in the *Implementation Plan of CAS Special Action to Promote the Transfer and Transformation of Science and Technology Achievements*

No.	Key Tasks	Task Decomposition	Leading Department
1	Promote the production and commercialization of a number of major science and technology achievements.	Promote the transfer of a number of major achievements and start the deployment of a number of R&D projects with clear application routes in combination with the deployment of the Strategic Priority Research Program of Type A and the construction of an Innovation Research Institute.	Bureau of Major R&D Programs
2		Further strengthen the forward-looking layout of the industrial applications of the deployed Strategic Priority Research Program of Type B, strengthen the cohesion of departments in the newly deployed R&D projects, and jointly support the transfer and application of expected results.	Bureau of Frontier Sciences and Education
3		Persistently promote the Science and Technology Service (STS) Network Plan and accelerate the popularization of practical technologies.	Bureau of Science and Technology for Development (BSTD)
4		Set up the "Special actions for the transfer and commercialization of scientific and technological achievements" and implement about 10 special tasks.	BSTD
5	Establish a governance system for science and technology achievements with intellectual property rights as the core.	Establish the IP Operation and Management Center of the Chinese Academy of Sciences.	BSTD
6		Establish the Achievement Commercialization and Intellectual Property Operation Fund of the Chinese Academy of Sciences.	The Chinese Academy of Sciences Holdings Co, Ltd (CASH)
7		Establish a reporting system for the transfer and transformation of science and technology achievements under hierarchical management.	BSTD
8		Establish a unified science and technology achievements information service platform for the whole CAS.	CASH
9	Educate and train professionals in the transfer of science and technology achievements.	Persistently dispatch deputy science and technology professionals and enterprises' science and technology professionals.	BSTD
10		Establish the Project to Support Research-Industry Talent.	Bureau of Personnel
11	Develop innovative carriers to promote the transfer and commercialization of science and technology achievements.	Arrange STS regional centers to serve regional industrial development.	BSTD
12		Strengthen the development of national engineering laboratories, engineering (technological) research centers, and other generic technology research bases. Develop specialized Makerspace, and improve the ability to provide services to industries and industrial sciences and technologies.	BSTD
13		Strengthen the development of open and sharing service platforms for large infrastructure and improve the support system.	Bureau of Facility Support and Budget (BFSB)
14		Establish industrial technology innovation platforms with big science centers as the core, and serve the transfer and commercialization of science and technology achievements through technology spillover.	BFSB
15		Strengthen the construction of the National Alliance of the CAS and organize technological breakthroughs by serving the development of regional industries.	BSTD
16		Strengthen the construction of field station alliances, promote interdisciplinary integration, and serve national needs.	BSTD
17		Strengthen the construction of the China Botanical Park alliance and open up the channel for processing biological resources into biotechnology products.	BSTD

18	Create an environment and atmosphere conducive to the transfer and commercialization of science and technology achievements.	Formulate and issue the "Guiding opinions of the CAS on accelerating the transfer and commercialization of science and technology achievements" and supporting policies and institutions of personnel and evaluation.	BFSB
19		Implement classified evaluation and assessment, improve the evaluation system of major output-oriented research institutes, and promote the reform and management innovation of resource allocation, project evaluation, personnel evaluation, etc.	Bureau of Development and Planning
20		Rely on established science and education cooperation institutes, transfer applicable science and technology achievements overseas.	Bureau of International Cooperation

Appendix C. Case classification and coding process

	Free Code	Descriptive Themes	Analytical Themes
Suzhou Institute of Nano-Tech and Nano-Bionics (SINANO)	Open up and share; construct public support system; public technology service center; open equipment resources; open research sites; open talent; open technology.	Public service platform	**Platform-driven mode**
	Core platform of nanotechnology; platform community for nanotechnology application services; industrial agglomeration effects.	Agglomerate platform community	
	Nanofabrication platform; establish close cooperation with related enterprises and research institutes; provide support and services; act as a bridge between enterprises as well as enterprises and research institutes; technology processing platform; talent training base; equipment opening service; technology development service; commissioned processing service; process OEM service.	Public service platform	
	Nano-Bio-Chem Center;a one-stop R&D service agency for biology, medicine, and chemistry; provide professional and reliable hardware infrastructure, technical services, and human resources for high-tech companies, academic institutions, and medical centers around and beyond the local area; establish itself as a hub for biomedical resource sharing and technology transfer between the academy and industrial sector; provide a high-profile and easy-to-access incubator platform for biomedical SMEs with great user experiences.	R&D service platform	
	Platform for Characterization & Test; sharing system of resource and information on scientific instruments; provide testing, consulting, and training services for research institutes and enterprises; integrate testing and analysis resources in Suzhou and surrounding areas, and unite the institute's nanofabrication and engineering platforms to build a public sci-tech service platform; provide characteristic nano-testing and analysis services for surrounding enterprises and units; develop distinctive sets of testing and analysis equipment for research and industrial demands and to realize industrialization.	Public service platform	
	Technology Transfer Center; implement relevant policies for technology transfer and achievement of transformation at all levels; plan, organize, and participate in various exchange activities; explore new mechanisms and models for technology transfer and achievement of transformation.	Technology transfer center	
	Incubation Center; National Mass Entrepreneurship and Innovation Demonstration Base; promote the construction of industrial community for mass entrepreneurship and innovation.	Innovation and entrepreneurship base	
	Platform driven; talent agglomeration; industrial development.	Platform-driven development	
Nanjing Institute of Advanced Laser	Public technology platform for intelligent laser; exert generic technical functions of laser processing technology; conduct technological R&D for enterprise's technical requirements; propose complete solutions for products with special needs;	Public technology platform	

Technology (NIALT)	provide process development services for enterprises; conduct transformation of sci-tech achievements at a certain R&D stage; information sharing platform; open laboratory.		
	Public service platform for laser precision detection; accept commissioned R&D projects; joint development; joint project declaration; market oriented and enterprise oriented; customized technical service for enterprises.	Public service platform	
	Secondary development mode; incubate the prototypes in the laboratory into the product used by enterprises; develop technologies for industrialization; form laser industrial clusters.	Industrial cluster effect	
	Incubator; cultivate high-tech enterprises; focus on industrial technology R&D, technology transfer and transformation, and business incubation; the total turnover of enterprises incubated by the institute exceeded 310 million yuan in 2019.	Enterprise incubation platform	
	Public technology service platform; technical support; innovation engine of the laser industry.	Public service platform	
Fujian Institute of Research on the Structure of Matter (FIRSM)	National innovation platform; key laboratory; organic interaction among scientific frontiers, strategic high technology and engineering.	Oriented to the frontiers of science	**Incubation ecosystem mode**
	Establish an open sci-tech innovation system of Haixi Innovation Group-Regional R&D Center-Strategic Emerging Industry; realize coordinated development from basic research, original innovation to applied research, and engineering industrialization.	Whole-chain innovation	
	Haixi Incubation Center; cultivate more than 10 high-tech enterprises; production and research cooperation.	Oriented to industrial development	
Xi'an Institute of Optics and Precision Mechanics (XIOPM)	New convergence development modes of "technology + finance, technology + service, technology + market, technology + society"; full-chain incubation carrier of "crowd innovation space + incubator + accelerator"; soft incubation environment of "research institutes + angel investments + incubator services + popular science and education"; improve the transfer and transformation efficiency of science and technology; build an ecological network system of science and technology entrepreneurship with the integration of "research institutes + angel funds + incubators + entrepreneurship training".	Ecological network systems for science and technology entrepreneurship	
	Xike Angel Fund; industrialization of hard sci-tech achievements; funding at the initial stage of incubation.	Self-created fund	
	The first optoelectronic industry incubator; hard sci-tech entrepreneurship camp; encourage scientific research personnel to start a business; entrepreneurship training.	Entrepreneurial talent incentives	
	Form four major industrial clusters: high-end equipment manufacturing, photonic integrated chips, people's livelihood and health, and civil-military integration; industrial alliance; unite enterprises to construct jointly; enhance independent innovation capability; promote breakthroughs in key technologies; establish the alliance model of "industry–university–research–service"; build a technical exchange platform.	Construction of industrial alliance	

	High-tech industry incubation; national science and technology business incubator; venture capital incubation platform for hard science and technology; the first batch of national specialized crowd innovation spaces.	Business incubation platform	
	Hefei Comprehensive National Science Center was jointly established by the People's government of Anhui Province and the Chinese Academy of Sciences; HIPS is one of the core construction units of the Hefei Comprehensive National Science Center.	CAS-region co-construction	
	Transformation platform; approval of licenses, transfers, and equity purchases; management of crosswise technology contracts; sign cooperation agreements with enterprises; invest in new firms.	Commercialization approach	
	Large scientific facility; national innovation and entrepreneurship demonstration base; key laboratory; large-scale experimental platform.	Oriented to the development of science and technology	
Hefei Institutes of Physical Science (HIPS)	Hefei Institute of Technology Innovation; jointly constructed by HIPS and the Hefei Municipal Government; a collaborative innovation system with enterprises as the main body, the market as the orientation, and the combination of industry, universities, and research institutes; encourage the team of scientists to establish project companies through partial monetary investments and attracting social capital to carry out market-oriented operation of sci-tech achievements; actively help the project company to obtain government funds; entrepreneurship service and counseling; construct a financing system of "equity investment + government funds + social capital + industrialization special funds".	Co-construct transformation platform	**CAS-Region cooperation mode**
	Anhui Institute of Innovation for Industrial Technology; "research center + company" mode; encourage scientific researchers to establish technology companies and incubate sci-tech achievements.	Entrepreneurial talent incentives	
	Wanjiang New Industry Technology Development Center; jointly established by HIPS, the Chinese Academy of Sciences, Tongling Municipal People's Government, and the Department of Science and Technology of Anhui Province; promote the engineering R&D and industrialization of scientific research achievements with market potential.	Promote local development	

	Zhongke Bengbu Technology Transfer Center; jointly established by HIPS and the Bengbu Municipal Government; make full use of the location, resource, and industrial advantages of Bengbu City; oriented by the demand of high-quality sci-tech development in Bengbu City; promote the transfer and transformation of sci-tech innovation achievements of the Chinese Academy of Sciences in Bengbu; accelerate the adjustment of Bengbu's economic structure and the transformation of the development mode; promote the sustainable development of the regional economy and society.	Promote local development	
R&D Center of Xuyi Palygorskite Applied Technology (R&DC-XPAT)	Industry–university–research mode with "advantage complementarity, benefit sharing, and common development"; operation mode with upstream and downstream interactions of "applied research – pilot scale-up – product production"; promote industrial development.	Oriented to industrial development	
	Carry out innovative applied research; focus on the high-value utilization of attapulgite; promote the development of the attapulgite industry; build "the Attapulgite Capital of China".	Featured resources	
	The People's Government of Xuyi County and the Lanzhou Institute of Chemical Physics, Chinese Academy of Sciences signed a co-construction agreement to establish a director responsibility system under the leadership of Lanzhou Institute of Chemical Physics and the guidance of Management Committee.	CAS-region co-construction	

Appendix D. Histories of the three modes

Mode	Research Institute	Center/Incubation/Platform	History of Development
CAS-Region Cooperation Mode	HIPS	Hefei Institute of Technology Innovation Engineering Institute of Applied Technology	The HIPS was established on *June 17, 2003*, replacing the canceled Hefei Branch of the CAS to perform branch functions. On *June 25, 2014*, in order to promote the industrialization of HIPS high and new technology, combined with the urgent needs of Hefei City's innovation-driven development, the Hefei Institute of Technology Innovation Engineering was co-established by HIPS and Hefei City. On *December 29, 2014*, to further serve the local economic development, a new innovation research unit - the Institute of Applied Technology was established by integrating the existing advantageous industrial directions of HIPS and the technology transfer innovation service platform of Anhui province.
	R&DC-XPAT	R&D Center of Xuyi Palygorskite Applied Technology, Lanzhou Institute of Chemical Physics	Based on the principle of complementing advantages, the government of Xuyi county and Lanzhou Institute of Chemical Physics of the CAS signed an agreement on jointly building the R&D Center of Xuyi Palygorskite Applied Technology, Lanzhou Institute of Chemical Physics on *June 12, 2010*.
Incubation Ecosystem Mode	FIRSM	Haixi Incubation center	Haixi Incubation Center was established in 2011 and officially registered as a technology business incubator in *2013*. Relying on the scientific and technological resources of FIRSM, the incubation center has carried out the transfer and commercialization of technologies and achievements and cultivated a series of scientific and technological enterprises.
	XIOPM	CASSTAR Incubator	*In 2013*, XIOPM established the first national incubator for hard science and technology in China - the CASSTAR Incubator and established the first angel fund focusing on the industrialization of scientific and technological achievements in Northwest China - the Xike Angel Fund. By 2019, the incubator has cultivated more than 230 hard technology enterprises with a market value of 20 billion *yuan*.
Platform-driven mode	SINANO	Nano Fabrication Facility	The First-Class Nano Platform of Fabrication and Engineering - Nano Fabrication Facility was open on *January 09, 2009*, for R&D of semiconductor devices and fabrication processes.
		Platform for Characterization & Test	The earliest traceable year is *2012*.
		Nano-Bio-Chem Centre	The earliest traceable year is *2018*.
	NIALT	Public technology service platform for intelligent laser manufacturing	NIALT was established in 2013, joined Jiangsu Industrial Technology Research Institute in 2015, and became the first batch of new R&D institutions registered in Nanjing in 2018. It is mainly engaged in technology R&D and transfer, with an established open laboratory and public service platform to provide equipment platform and technical training for other enterprises, universities, and research institutes, to realize resource sharing and technical exchange.