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Institution, Cognitive and Network: A Sociology Analysis of the European Big Science Market

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Abstract

The cooperation between big science organizations (BSOs) and industrial organizations (IOs) is considered to be the key to promoting industrial development and realizing economic and social benefits of big science infrastructures (BSIs). This study takes the European big science market (EBSM) as a case and analyzes its construction based on institution-cognitive-network framework of the sociology of markets. The findings are as follows: (1) The EBSM supports the establishment of cooperative relations between BSOs and IOs. (2) The big science market (BSM) is not an abstract or a priori existence, but a concrete form jointly constructed by European governments, BSOs and IOs. (3) Governments are not mere funding providers, but are a dominant player through making big science industrial policies and establishing various institutions. Finally, this study puts forward countermeasures and suggestions for the cooperation between BSOs and IOs.

Keywords

Big science market; Big science organization; Industrial organization; Big science infrastructure; Sociology of markets

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1. Introduction

Big science infrastructures (BSIs), also known as "major scientific and technological infrastructures" or "research infrastructures", refer to large facilities that are completed through large-scale investment and engineering construction, with important science and technology objectives to be achieved through long-term stable operation and continuous science and technology activities after completion. Different from the general scientific research instruments and equipment, the construction scale of BSIs is large. Given its technical foresight and complexity, it is necessary to develop some non-standard equipment in the construction process; and its output is scientific knowledge and scientific and technological achievements, which often requires a large amount of investment and has the characteristics of long payback period. It is precisely based on this feature of the BSIs, and objectives of promoting basic scientific research, that the Chinese government began to consider the economic and social value of BSIs (Li and Liu, 2020; Zhang, 2017; Zhang *et al*., 2018). However, the relevant policies and institutional practices in China are still in the initial stage. It is necessary to conduct exploratory research on the institutional practices of leading countries.

Research has already begun to evaluate the economic and social benefits of BSIs. Based on discussing the history and development process of big science, Myoken (2010) proposed the management challenges of current big science projects and put forward relevant suggestions. Using a Waypoints-based approach, Bianco *et al*. (2017) proposed indicators for evaluating the capability and performance of big science projects. They demonstrated the usefulness of these variables by applying them to the identification of promising projects from the International Space Station scientific database. In the context of the increasing number of users of BSIs, Hallonsten (2016) conducted research based on qualitative and quantitative analyses to provide corresponding evaluation indicators for their quality and productivity. Ortoll *et al*. (2014) proposed a set of parameters for scientific cooperation in big science projects. They demonstrated the usefulness of these parameters through a comparative study of two big science projects. Florio *et al*. (2016) created a set of cost-benefit analysis models, which mainly included technology externalities, human capital, and other indicators. Hallonsten (2014) proposed to measure the output benefits of BSIs through indicators such as technical stability, competition mode of operation time, and number of achievements.

Promoting industrial development is regarded as an important way to realize the economic and social benefits of BSIs, which has received more and more attention. Andersen and Åberg (2017), taking CERN as an example, studied its impact on industrial innovation through the study of its procurement data, and then analyzed its impact on technological innovation. Castelnovo *et al*. (2018) studied the innovation efficiency and economic benefits obtained from the cooperation between industrial organizations (IOs) and big science organizations (BSOs) by analyzing the data of IOs engaged in cooperative transactions with CERN. By Comparing 14 suppliers on CERN's supplier list and analyzing their technical capabilities before and after becoming CERN suppliers, Aberg and Bengtson (2015) found that CERN had a knowledge spillover effect on its suppliers. Taking the European Space Agency (ESA) as an example, Eerme and Nummela (2019) studied how to capitalize on the knowledge acquired during the cooperation between knowledge-intensive IOs and BSOs. Puliga *et al*. (2019) studied 26 Italian IOs participating in the ITER project, and examined its financial, social, learning and innovation impacts.

It has been found that promoting cooperation between big science BSOs and IOs is an effective mode of using BSIs to promote industrial development. BSOs are composed of BSIs that receive significant funding from governments or IOs that employ a large number of scientists and technicians for research

(Solla-Price, 1963). BSOs aim to address fundamental and complex scientific research challenges that individual universities, research institutions, and even government agencies cannot solve in isolation. Anderson *et al*. (2012) showcased the different governance models of collaboration between BSOs, the private sector, and even academic institutions from public-private academic partnerships. Autio *et al*. (2004) utilized social networks, social capital, and organizational learning theories to study the knowledge spillover of industry partner companies in the dual structure of big science and industry. Autio *et al*. (1996) provided a framework for decision-makers, industrialists, and researchers to analyze the systematic technological interactions established between BSOs and IOs. Hallonsten (2016) analyzed the academic organization of the laboratory and its enduring and symbiotic relationship with user groups and commercial companies in related technology fields through case studies, which helps to understand how contemporary big science is organized and how it supports technology transfer and commercialization of research and technology.

To fully assess the diversification benefits of big science installations, a systematic evaluation framework is needed. Taking Five-hundred-meter Aperture Spherical radio Telescope (FAST) as an example, Wang *et al*. (2020) constructed a multi-dimensional comprehensive benefit evaluation index system covering the whole lifecycle of large facilities, proposed a three-dimensional evaluation framework of “evaluation stage + evaluation objective + stakeholders”, and established a complete three-level evaluation index system to reveal the realization process and composition of comprehensive benefits of large facilities. Bastianin *et al*. (2023) evaluated the net present value of the CERN HL-LHC project by constructing a cost-benefit analysis (CBA) model and using Monte Carlo simulation and found that the project had a significant positive socio-economic impact in terms of scientific research output, technological innovation, and cultural value dissemination.

Liu (2024) studied the transformation mechanism of achievements along the way of large science installations. The successful mechanisms mainly include multi-agent co-construction, device efficiency improvement, and innovative industry integration modes, which promote the transformation of achievements from different perspectives, optimize resource allocation, and enhance the level of scientific and technological innovation and industrial development. The UK's experience in cultivating science and technology industry by relying on large science and technology installations shows that measures such as setting up special funds covering the key stages of the transformation of scientific and technological achievements, jointly building incubators in frontier fields with leading enterprises, and laying out high-level new research and development institutions can effectively promote the transformation of scientific and technological achievements. The British Science and Technology Facilities Council (STFC), through the knowledge transfer from academia to industry, has developed a funding plan covering all stages of results transformation to help coordinate the commercial application of technological achievements (Meng *et al*., 2021).

Hummel *et al*. (2024) studied the cooperation process between big science and big enterprises, and proposed the “scaffolding” mechanism and the alliance reorganization mechanism. They also promoted multi-boundary crossing and knowledge sharing by gradually creating supporting technologies and organizational objects and constantly adjusting cooperative alliances. Li *et al*. (2021) analyzed five innovative models of technical cooperation, joint research and development, knowledge sharing, training and education, and policy support between European BSOs and suppliers, and argued that such cooperation not only promoted technological progress but also enhanced the trust relationship between the two sides. The governance structure between BSOs and IOs is usually a mixed governance structure, which can effectively reduce transaction costs and promote technological innovation. When the difficulty of technological innovation is high, the governance structure will be more dependent on a high degree of interdependence, thus forming a relational governance or joint organizational entity, which is conducive to technological learning and technology diffusion (Huang, 2021).

From existing research, it can be seen that cooperation between BSOs and IOs is key to promoting industrial development. However, existing literature mainly analyzes the inter-organizational cooperation between BSOs and IOs. What we are interested in is what form of practice supports the implementation of such cooperation. How was this form of cooperation constructed? Especially, as the main funding provider for BSOs, what role has the government played in the process of form construction? These are the questions that have not been explicitly answered in existing literature. Realizing industrial technology cooperation and innovation based on big science requires extensive cross-border cooperation, as well as targeted policies and a sound institutional environment to support it. The practice of promoting cooperation between BSOs and IOs through the big science market (BSM) in Europe provides an empirical example for answering the above questions. In this study, we try to introduce the analytical perspective of the sociology of markets to conduct research. From this perspective, the market is not an abstract or a priori existence, but a concrete form constructed through the joint action of the government, BSOs, and IOs. Therefore, we will construct a market sociology analysis framework consisting of three dimensions of institution, cognitive, and network, to analyze the construction practices of the European big science market (EBSM), and propose countermeasures and suggestions that are conducive to promoting cooperation between Chinese BSOs and IOs.

This paper is structured as follows: Section 1 provides an introduction and an overview of the EBSM. Section 2 explores the theoretical framework and the key institutional players involved in the EBSM. Section 3 examines the interactions between large scientific organizations and industrial sectors, with a particular focus on government involvement. Section 4 presents a detailed analysis of case studies from European countries, followed by Section 5, which discusses policy implications for China. Finally, the conclusion summarizes key findings and provides recommendations for future research.

2. Institution-Cognition-Network Framework of the Sociology of Markets

The study of the sociology of markets is based on Granovetter's theory of “embeddedness”, which sees the market as an organic part of society, a historical process that interacts with and produces many social factors (Granovetter, 2018). From this perspective, the market is considered a socially embedded structure, which is the result of complex interactions between different actors and institutions.

The sociology of markets mainly studies the institutional factors in the formation process of the market and the mutual construction mode among participating entities from the perspective of social structure. Previous studies mainly focus on three kinds of shaping forces of the market: (1) Network embeddedness. Network embeddedness asserts that the market is embedded in the social networks, which are the social structures generated by the connections between market participants. On the one hand, social networks maintain a relatively stable market state by establishing trust mechanisms and avoiding uncertain factors and opportunistic behaviors. On the other hand, the characteristics of network relationships affect the social status and social capital of market participants, thus determining the distribution and flow of market resources (Barberb, 1995; Uzzib, 1999). (2) Cultural embeddedness. Culture is a “context-constrained rationality” that has long been endogenous or exogenous to the market and internalized by market actors (Zelizerva, 1988), which plays a regulatory and shaping role in the market. (3) State embeddedness. As the defender of market order, the state changes the market game order by constructing property rights, governance structure, and exchange rules. In the absence of state intervention and control, markets will fall into Hobbesian disorder (Polanyik, 2001).

Currently, in sociology of markets, institution, cognition, and network are the three main perspectives for explaining and understanding market phenomena. (1) From the institutional perspective, it is believed that institutions will support or constrain the behavior of market actors, and various new markets are formed within a predetermined set of institutional backgrounds (Fligstein and Mara-Drita, 1996). (2) From the cognitive perspective, it is believed that networks or institutions themselves do not directly affect behavior, where the key lies in the meaning and decisions made by market actors to these networks or institutions. The stability of market order depends on the common cognition and collective identity of actors towards the market (Fourcade, 2007). (3) From the network perspective, the market is composed of a network of relationships between actors embedded in the market, which enables the market to play a role, such as facilitating private resource sharing and price acquisition (Uzzi, 1999). In the real world, the formation and development of markets are usually the result of the interaction of multiple factors such as institutions, cognition, and networks. Therefore, the comprehensive use of the triple perspective for market analysis is the main trend in the research of sociology of markets (Fourcade, 2007).

As a general theory of modern social organization, the field can be seen as a configuration of the objective relations that exist between various positions, consisting of the following three characteristics: the behavior of the actor embodied as routine and convention, the set of principles used by the actor to explain his situation and the social relations that can or cannot be perceived by the actor (Fligstein, 2001). According to the previous elaboration, these three characteristics correspond to institution, cognition, and network respectively. Therefore, most contemporary comprehensive perspectives interpret the market as a special field shaped by the interaction of institutions, cognition, and networks. Since the actor's behavior selection preference comes from a specific field, economic behavior is embedded in the field structure of the market (Chen, 2013). Thus, the field becomes the main theoretical framework for integrating the three perspectives (see Fig. 1).

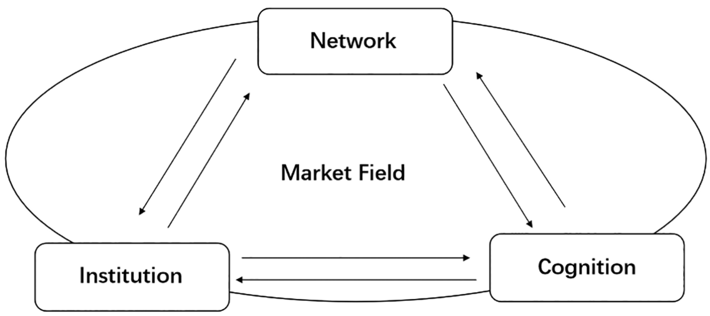

Fig. 1. A framework of sociology of markets.

We believe that the EBSM is a market field for achieving cooperation between BSOs and IOs. We have collected public information from the European Commission, European BSOs, and industry liaison officers, including policy texts, news reports, organization introductions, annual reports of BSOs, and successful cases of cooperation with IOs. Based on the analysis of these textual materials, we present a panoramic view of the construction of the EBSM from the ICN framework.

3. Construction Practice of the European Big Science Market

The government plays a crucial role in the EBSM by facilitating collaboration between scientific organizations and industrial sectors. At the initiation stage, government institutions are responsible for setting the regulatory framework and providing funding. As the project progresses, government agencies may take a more supervisory role, ensuring that the collaboration aligns with national or regional priorities. Moreover, government policies are critical in maintaining the long-term sustainability of these collaborations by establishing clear institutional frameworks and offering continuous support. The government's role varies throughout the collaboration, as different stages may require different forms of support. For instance, during the initial stages, financial backing and policy guidance are pivotal, whereas, in the later stages, the government's role may shift towards facilitating market integration and commercialization.

3.1. Institutional construction for promoting cooperation between BSOs and IOs

The institutional perspective of the market points out that the behavior of market actors is supported or constrained by institutions while existing institutions make it possible to construct new markets. The concept of the "European Big Science Market" is not proposed in a vacuum, but is embedded in the existing institutions of European BSOs, and these institutional practices have provided the basis for the construction of the relationship between BSOs and IOs. The EBSM is embedded in the institution of the EU Single Market Project. The EU has 27 member states, and nearly 450 million people, accounting for 6% of the world's population. To facilitate the free movement of people, goods, capital, services, and knowledge, the Single Market Project was formally implemented in 1993. The implementation of the EU Single Market Project has removed trade barriers among member states and facilitated internal trade and international trade. According to statistics, since the implementation of the EU Single Market Project, internal trade in Europe has increased by more than 30%, and the growth of European foreign trade is also higher than the world average. It has also promoted the division of labor and cooperation within the EU and increased the competitiveness and innovation capacity of IOs. To support and strengthen the governance and effectiveness of the Single Market Project, the EU will provide 4.2 billion euros between 2021 and 2027 to support a series of actions in this project.

In the context of the Single Market Project, many EU policies promote partnerships between BSOs and IOs. In order to fully mobilize resources from various countries throughout the EU and achieve cooperation between BSOs and IOs, the EU has formulated a series of policies in areas such as facility sharing, technology transfer, and regulations.

3.1.1. Establishing organizations to promote cooperation between BSOs and IOs

In order to promote the cooperation between BSOs and IOs, the EU has established the European Strategy Forum on Research Infrastructures (ESFRI), the European Research Infrastructure Consortium (ERIC), the European Intergovernmental Research Organization (EIRO), the Association of European Level Research Infrastructure Facilities (ERF-AISBL) and other organizations.

ESFRI is responsible for developing research infrastructure roadmaps and developing plans for 55 BSO projects in Europe. Among them, 37 have been implemented, driving nearly 20 billion Euros in investment (Table 1 shows some of the BSOs that operate these infrastructures). ERIC is a legal entity specifically composed of technology infrastructure regulations. The inclusion of infrastructures in this plan can simplify their governance structure and enable economic activities to be carried out according to their own procurement rules (ERIC, 2020).

Table 1

Some of the BSOs implemented through the route diagram.

Name	Route map planning time	Start of operation year	Construction cost (millions of Euros)	Operating cost (million Euros/year)
European Synchrotron Radiation Facility	2016	2023	128	80
European Spallation Source	2006	2025	1.8	140
European X-Ray Free-Electron Laser	2006	2017	1.5	118
Facility for Antiproton and Ion Research	2006	2025	/	234
Square Kilometre Array	2006	2027	1	77

EIRO is responsible for integrating the resources, facilities, and professional knowledge of its member organizations to promote interaction among governments, BSOs, and IOs. Its member organizations are BSOs from various countries, such as the European Organization for Nuclear Research and the European Molecular Biology Laboratory, etc. In 2010, members of the organization founded the Thematic Working Group on Innovation Management and Knowledge/Technology Transfer (IMKTT), dedicated to promoting facilities, technologies, and specialized knowledge beyond core scientific applications. After more than 8 years of cooperation, IMKTT has successfully established a solid cooperative relationship among its members, promoting technology transfer from BSOs, while emphasizing the protection and utilization of intellectual property rights, supporting IOs, and better-benefiting industry (EIRO, 2020).

ERF-AISBL aims to promote collaboration between BSOs and external researchers. ERF-AISBL's infrastructures are open at the international level, including national infrastructures as well as the European Network and Research Infrastructure Alliance. Every year, ERF-AISBL serves more than 20,000 academic and industrial users from the EU and around the world (ERF-AISBL, 2023).

3.1.2. Making policies to promote cooperation between BSOs and IOs

To ensure the smooth progress of technology transfer and cooperation, the European Commission has formulated a series of institutions. For example, detailed institutions for various collaborations related to BSOs are developed, including a list of admission prices and a list of intellectual property conditions for each admission. In terms of admission prices, different charging standards have been established based on the different purposes of using equipment, which is generally divided into four types: pure academic research (free), industrial-academic research, project-based collaborative research groups, and proprietary research (full cost). To protect innovative achievements, a series of intellectual property policies have been introduced, making the ownership and transfer of innovative achievements more comprehensive and transparent.

In addition, attention is paid to the cultivation of human capital. To improve the capability of IOs to cooperate with BSOs, a series of training systems have been tailored for IOs, and a group of researchers who have a better understanding of BSOs and research infrastructures have been trained to better meet the development needs of the EBSM. European small and medium-sized enterprises (SMEs) are also often involved in the process of technology research and development and transfer of BSOs. EU authorities have developed proprietary preferential policies for SMEs, which can provide companies with access to the EU's rapid financing mechanism, such as the SME Tool or "Fast Track to Innovation".

The BSOs of different countries in the EU also have their industrial policies, taking the European Organization for Nuclear Research (CERN) as an example. CERN is an international BSO established in 1953, with 23 member states and 9 associate member states. CERN has developed its procurement models and process, admission qualifications, industrial policies, and intellectual property system for establishing cooperative relationships with member countries and their IOs. For example, CERN's procurement is mainly carried out through bidding and tendering, with a separate electronic bidding management platform and IO database established. As CERN's funding is mainly provided by its member countries, its procurement targets mainly IOs of member countries. Based on the investment and return situation of member countries, the number of participating IOs of different member countries will be further determined to help each member country achieve balanced industrial returns in big science investment. Meanwhile, CERN has also formulated specialized industrial policies for big science, encouraging SMEs to actively participate in CERN's procurement activities.

3.1.3. Increase financial support for promoting cooperation between BSOs and IOs

Adequate funding is an important guarantee for supporting the cooperation between BSOs and IOs. In terms of public investment, the EU mainly invests in BSOs and IOs through three channels: Horizon Europe, European Structural and Investment Funds, and European Fund for Strategic Investments (Su, 2018). Among them, Horizon Europe is the funding program with the highest proportion, the largest intensity, and the widest coverage. Since 1984, the European Commission has been implementing the Framework Programme as an important policy tool to support technological innovation. The Framework Programme is the largest public financial research funding program in the world to date, and also the most important research funding program in the EU. It took a total of 30 years from the First Framework Programme to the Seventh Framework Programme. The starting time and funding amount of previous Framework Programs are shown in Table 2, which shows the development of the EU's investment in research and innovation increasing year by year. The latest phase of the framework is named "Horizon Europe", which outlines the funding budget for the timespan from 2021 to 2027 and a new Framework Programme.

Table 2
Successive EU funding schemes.

Name	Annual	Total budget (100 million Euros)	Important task
Framework Programme1	1884–1990	32.71	(1) Building the European Research Area (ERA); (2) Maintaining excellence in science and technology; (3) Enhancing the competitiveness of IOs; (4) Addressing economic and social challenges.
Framework Programme2	1987–1995	53.57	
Framework Programme3	1991–1995	65.52	
Framework Programme4	1995–1998	131.21	
Framework Programme5	1999–2002	148.71	
Framework Programme6	2003–2006	192.56	
Framework Programme7	2007–2013	558.06	
Horizon 2020	2014–2020	770	The first 4 points are the same as above; (5) Economic growth; (6) Expand employment
Horizon Europe	2021–2027	955	

The budget for scientific and technological innovation planned by the European Union from 2021 to 2027 is 100 billion Euros, of which the total budget for Horizon Europe is approximately 95.5 billion Euros, accounting for about 10% of the entire EU government budget. The purpose of this plan is to strengthen Europe's technological strength, enhance its competitiveness, help address global challenges, promote open cooperation, and enhance the decision-making and implementation of scientific research achievements in the EU (European Commission, 2020). The core of this plan mainly includes three parts: open science research, global challenges, industrial competitiveness, and open innovation. The specific allocation of funds is shown in Table 3.

Table 3
Horizon Europe specific allocation.

Three strategic priority areas	Total budget amount / 100 million Euros	Action plan	Single budget amount / 100 million Euros
Open science research	258	European Research Council	166
		Marie Skłodowska-Curie actions	68
		European Research Infrastructures	24
Global challenges and industrial competitiveness	527	Health and Hygiene	77
		Inclusive and Secure Society	28
		Digital and Industry	150
		Climate, Energy, and Transportation	150
		Food and Natural Resources	100
		The Joint Research Centre (JRC)	22
Open innovation	135	European Innovation Council	105
		European Institute of Innovation & Technology (EIT)	30
Strengthening the European Research Area	21	Sharing Excellence	17
		Reform and Strengthen the European Research and Innovation System	4

The "Horizon Europe" funding program has laid a solid financial foundation for cooperation between BSOs and IOs in terms of talent training, technology development, and industrial development. The CERN has received funding support of 74 million Euros and 110 projects through the Horizon 2020 program, with 80% of the projects and 85% of the funding coming from the Excellence Science Program. Over 100 young scientists and engineers from different fields have gained valuable training and work experience through the Marie Skłodowska-Curie action. In addition to obtaining funding and project support, the Horizon 2020 program also provides support to the CERN in areas such as industrial innovation and technology transfer. Through this program, the CERN collaborates with 800 partners from 57 countries, including 487 academic organizations and 223 industrial companies. According to CERN (2021), it will continue to participate in the Horizon Europe Program (CERN, 2021).

3.2. Network construction for promoting cooperation between BSOs and IOs

The implementation of transactions or the allocation of resources depends on the existence of trading networks. Therefore, some studies suggest that “the market is the network”, which means that for a real market, the network is not a pre-existing action structure, but a result of the construction of actors (Fligstein and Mara-Drita, 1996). For the EBSM, we believe that the construction of an innovation ecosystem and the EU industry liaison officer institution are important institutions for building a trading network between BSOs and IOs.

3.2.1. Establishing the big science business network

The European Commission established the Enterprise Europe Network in 2008, which is funded through the Single Market Project and implemented by the European Innovation Council and the SMEs executive agency of the European Commission, to assist IOs in innovation and development on an international scale. This network is active in various European countries, bringing together experts from member organizations known for their excellent business support. The member organizations mainly include chambers of commerce, regional development organizations, universities and research organizations, innovation organizations, etc., forming a big science business network. Although individual enterprises cannot become network members, they can enjoy the services provided. This network sets up contact points in each country and region, and IOs can choose contact points close to their business locations to seek help. These contact points can provide advice, support, and international cooperation opportunities for IOs (EEN, 2022). At the same time, the Enterprise Europe Network has a contact point section on its official website, where IOs can search for nearby contact points and obtain geographic information and contact information to seek help.

Since 2008, the Enterprise Europe Network has helped 2.9 million SMEs achieve international innovation and development. The Enterprise Europe Network launched partnerships and consulting services in 2008, provided tailored innovation support to IOs in 2014, expanded its targeted service scope in 2017, and moved towards a more sustainable, digital, and resilient network in 2021. During this process, 785,000 business matching activities were provided to SMEs, promoting their international growth through training and information support. The Enterprise Europe Network has become the engine room for cooperation between BSOs and IOs, which has nearly 80 network members, including multiple industry experts from large scientific laboratories and university research departments in Europe. Its goal is to accelerate the social and economic impact of federal and pan-European research programs, and it also provides many opportunities for IOs to collaborate with BSOs. For example, Danish advanced materials company CTS provided a case study of so-called “upstream innovation”. Since 2014, it has been collaborating with the CERN Particle Physics Laboratory near Geneva to jointly develop a customized piezoelectric actuator series. Due to this innovative partnership, CTS is now the preferred supplier of CERN.

3.2.2. The application of Industry Liaison Officer institution

Under EBSM, all stakeholders should have a better understanding and awareness of the existing potential for cooperation. The role of professional intermediaries and specialized cooperation mechanisms and tools is necessary to strengthen cooperation between innovation institutions and industry, as well as between innovation institutions themselves. The increasingly uncertain situation faced by intermediaries in supporting the innovation process of their network participants leads to a high degree of complexity in their roles and activities. Intermediary agencies are very diverse: industry liaison officers, procurement officers, knowledge and technology transfer offices, industry consulting committee experts, etc.

The Industry Liaison Officer (ILO) is a formal institution used in Europe to construct the technology trading networks of big science. The embryonic form of this institution was first founded with the establishment of the Institute of Industrial Development (DSIR) in 1916. In the early 1950s, the United States conducted a survey of 221 companies in Manchester to test the hypothesis that British industry was too slow to absorb new scientific knowledge. The conclusion was that the most urgent need was better connections, not better science. Other surveys have shown that many small companies have solutions to the problems they face. To help the industry find these industrial development opportunities, DSIR decided to establish eight regional information centers in 1957. In 1958, the Royal College of Science and Technology in Glasgow established a technical liaison office consisting of two part-time officials who had retired from senior positions in industry and administration. From February to October 1963, the DSIR in Scotland appointed relevant personnel and held separate negotiations with the Ministry of Education, providing financial support for the introduction of ILO services to England. This institutional arrangement has continued in Europe to this day.

The organizational members of the ILOs are mainly composed of BSOs and government officials from European countries. Their main task is to provide key information and advice for domestic IOs to cooperate with BSOs, and to contribute to the organized and planned formation of a more complete and prosperous big science market in Europe. The main functions of the ILOs are to maintain and develop a database of companies that cooperate with or are interested in collaborating with BSOs, conduct market analysis to determine suitable bidding companies, identify new companies, and establish relationships through departmental activities or on-site visits to IOs, organize activities to raise awareness or introduce companies or BSOs to specific buyers, and ensure that the company understands the procurement rules and understands the support they can receive from ILOs, etc.

To build a better pan-European network, the European Commission has established the ENRIITC project, which is composed of ILOs from different countries and BSOs. The establishment of this network enables IOs to better collaborate with BSOs, whether as suppliers, users, or co-creators. The establishment of this network provides a platform for communication and cooperation between ILOs of various countries and BSOs, enhancing mutual interaction and demand flow. Meanwhile, regular seminars and exchange activities will be held to provide more opportunities for cooperation between BSOs and IOs. Table 4 lists some of the activities organized by ENRIITC to promote cooperation (ENRIITC, 2022).

Table 4
Some of ENRITC's activities and contents.

Activity name	Main content
Infrastructure and industry engagement - fostering innovation in Europe	Introduce supplier development plans, share cooperation experiences, and discuss industrial cooperation models
How basic science and big science can become the seeds of future needs	Bringing together BSOs, IOs, and stakeholders to discuss the future needs of big science
The role of the big science industry in facing new healthcare challenges	Share the needs of the medical community and ongoing projects; Promote the transfer of technology and science, and bring new opportunities to industry
Webinar	Share the efforts and successful cases of industry liaison officers in reducing barriers to enrich other parts of the network through collaboration and new services
Application and industry and basic science - who should get research infrastructure?	How to maintain openness and provide support for IO research

BSOs also have a large and effective network of ILOs, which can transform the demand for technology and instruments from scientific research organizations into supply bases. Thus, the ILOs play a crucial role in improving the innovation capabilities of scientific research organizations and their ecosystems. In addition, specialized innovation platforms have been established in some countries to promote scientific and industrial cooperation in neutron and X-ray fields, such as Denmark's LINX Association and Sweden's LINXS, which complement the role of the International Atomic Energy Agency. The efficiency and effectiveness of ILOs in improving industrial returns, including returns to their commercial companies, in member countries of the pan-European BSOs have been fully demonstrated. Networking these international professional organizations around each infrastructure or broader thematic area is a good practice that should be promoted.

3.3. Cognitive construction for promoting cooperation between BSOs and IOs

The cognitive differences caused by information asymmetry between BSOs and IOs are an important factor hindering their cooperation. Therefore, cognition construction is particularly important in BSOs. In the process of cognitive construction between BSOs and IOs, seminars, popularization, and communication are commonly used as means of disseminating scientific knowledge in the EBSM.

At the European level, EU Industry Days is the most important industrial annual event held in Europe, jointly created by European authorities and their industrial partners. The EU Industry Days provide a platform for stakeholders to engage in inclusive dialogue with a wide range of partners, discuss industrial challenges, and jointly develop opportunities and policy responses. This also helps to ensure that policies at the national, regional, and local levels in Europe work together, enabling European industry to provide employment, growth, and innovation. The 2021 EU Industry Days event was held from February 23rd to 26th. It gathered 6,500 participants and held approximately 4,500 exchange activities during the conference. This conference featured many eye-catching speeches, viewpoints, and opinions from over 200 other speakers, social opportunities, digital exhibitions, and dedicated podcasts (European Commission, 2021). As an important complement to EU Industry Days, EU Industry Week is a broader framework, and as part of EU Industry Days, these events are held in other regions of the EU and cover a wider range of topics. For those who want to participate in the event, they can search by theme, region, and time on their official website and choose the right seminar to participate in.

3.3.1. Showcasing business opportunities of BSOs

The Big Science Business Forum (BSBF) is one of the forms of cognitive construction for the EBSM. The BSBF is a business-oriented forum that serves as an important platform for European IOs to understand the future investments of European BSOs. Take BSBF 2022 as an example. BSBF 2022 attempts to construct the following cognition: Big science investment contains business opportunities, and EU countries can establish the EBSM to achieve these opportunities. On the one hand, BSBF 2022 showcases the investment value and trading methods of the EBSM through two plenary sessions. The topic of the first plenary session is "The investment potential of Europe's Big Science Market". The senior speakers of the BSOs will showcase their organization from the aspects of development status and future vision so that participants have a general understanding of the basic situation and investment potential of the EBSM. Table 5 shows the organization and speech content of the speakers for the first plenary session. The topic of the second plenary session is "How to do business with Big Science Organizations from an industrial perspective". The session provides an explanation of business development methods from an industrial perspective and uses specific examples to demonstrate every step in the process from business opportunity search to contract signing and intellectual property application.

Table 5
Speakers and related briefings at the first plenary meeting of BSBF 2022.

Serial number	Spokesman	Position and organization	Speech content
1	Carlos Alejaldre Losilla	Director General, CIEMAT	Operation Status of Neutron Source Infrastructure DONES
2	Frederick Bordry	Technical Director, CERN	Current and Future High Energy Accelerators of CERN
3	Edith Heard	Director General, EMBL	EMBL's Vision and Future Plans
4	Johann-Dietrich Wörner	Director General, ESA	Introducing ESA
5	Professor Xavier Barcons	Director General, ESO	ESO Provides Projects and Opportunities for Industry
6	Dr. Francesco Sette	Director General, ESRF	Implementation of ESRF Extremely Bright Light Source Project
7	Professor John Womersley	Director General, ESS	From Construction to Operation: Continuous Business Opportunities Brought by ESS
8	Professor Robert Feidenhans'l	Chairman of the Management Committee, XFEL	Introduction to the XFEL
9	Jörg Blaurock	General Manager, FAIR	The Universe in the Laboratory
10	Johannes Schwemmer	Commissioner, F4E	Participation and Integration of EU Industry in the ITER Project
11	Helmut Schober	Director General, ILL	ILL - Serves the Changing Society through Neutron
12	Professor Philip Diamond	Director General, SKAO	SKAO: Challenges and Opportunities for the Next Global Research Infrastructure

Note: The table is made by the author based on the content of BSBF 2022. For more details, please see https://www.bsbf2020.org/Speakers.

On the other hand, BSBF 2022 showcases the reasons why big science technologies can become a business field through 15 parallel sub-forums - European BSOs jointly engage in technology procurement with European IOs, resulting in the aggregation and scale effects of big science technology.

3.3.2. Enhance IOs' understanding of the commercial value of big science

BSBF 2022 has established a sub-forum on "Key Aspects of SMEs' Participation and Procurement" specifically for SMEs. BSBF 2022 selects around 20 European SMEs while ensuring an appropriate balance among countries, technology, and SMEs' scale.

BSBF 2022 believes that SMEs are very suitable for the BSM because compared to large IOs, SMEs can provide greater flexibility in the development of specific technological fields and the manufacturing of a few particularly innovative components, thereby better adapting to the specific technical requirements of BSOs. What's more, BSBF has also set up the "SME Track" with two purposes: (1) To demonstrate that investment in the BSM can become a growth model for SMEs and enable knowledge transfer to other sub-markets; (2) To provide opportunities for SMEs with specialized technologies and capabilities required for the BSM, enabling them to connect with the technical leaders of BSOs and explore collaboration and business opportunities together. This indicates that investment in the BSM can become a growth model for SMEs and provide business opportunities for SMEs with the specialized technology and capabilities required for the BSM.

Based on the above analysis of the construction of EBSM, we use Fig 2 to show a panorama of big science market construction practice in Europe.

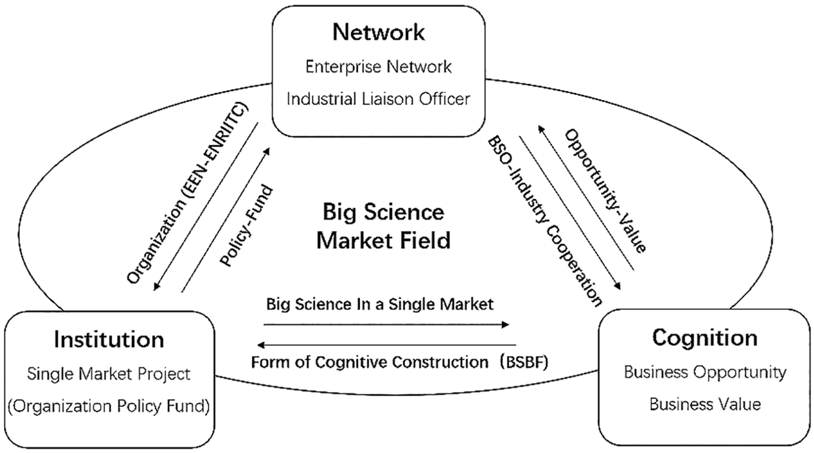

Fig. 2. A panorama of the practice of building big science market institution.

4. Discussion and Policy Implications

This study aims to contribution to the understanding of how large-scale scientific collaborations—specifically in the context of big science projects—can drive technological innovation and industrial transformation. A key insight from this research is the need for a more integrated approach to the governance of big science projects, one that facilitates dynamic interactions between government, scientific organizations, and industry. This approach challenges existing assumptions that the role of government in big science projects is primarily financial or regulatory. Instead, our findings suggest that government involvement must be more proactive, particularly in facilitating the transformation of scientific research into tangible industrial applications. This calls for a shift in the policy landscape toward more flexible, adaptive governance models that can respond to the changing needs of collaboration throughout the project lifecycle. The study also highlights the importance of multi-stakeholder frameworks, which are often underemphasized in traditional models of big science governance. The findings show that successful collaboration not only requires institutional support but also necessitates the creation of trust-based networks between research institutions and industries. This finding challenges traditional linear models of innovation and emphasizes the need for relational governance mechanisms, as suggested by Huang (2021), which are especially important when technological challenges are complex and require sustained collaboration.

One of the key findings of this study is the importance of continuous support for big science projects at each stage of the innovation process. This aligns with Liu (2024), who emphasized the role of multi-agent cooperation and innovation in optimizing resource allocation. Drawing on the experiences of the UK's Science and Technology Facilities Council (STFC), which has successfully integrated funding and innovation incubation throughout the lifecycle of its projects (Meng *et al*., 2021), we recommend that China implement a similar system. Specifically, China should establish specialized funds that not only support initial research but also facilitate the commercialization of scientific outcomes through dedicated innovation hubs and industry collaborations. This approach would reduce the time lag between discovery and industrial application, enhancing the overall socio-economic benefits of big science projects. Our findings suggest that a hybrid governance model, combining hierarchical control with network-based collaboration, is essential to reduce transaction costs and foster innovation. This is particularly relevant in the Chinese context, where top-down governance is common but needs to be complemented by more flexible, relational governance models to promote greater interdependence between industry and academia. This recommendation draws on the work of Li *et al*. (2021) and Hummel *et al*. (2024), who argue that mixed governance structures are particularly effective in promoting knowledge sharing and technological learning. China, with its state-driven innovation model, could particularly benefit from governance structures that allow for more adaptive and collaborative problem-solving, especially in high-tech industries and frontier research areas. This study emphasizes that big science projects are inherently international, with technological and knowledge boundaries often crossing national borders. Therefore, China should seek to establish more robust international partnerships, modeled on the CERN collaborations, to both access global knowledge networks and contribute to international scientific advancements. Our research supports the findings of Bastianin *et al*. (2022), who argue that cross-border cooperation is critical for maximizing the impact of big science projects. In practice, this means not only participating in global scientific collaborations but also establishing frameworks for knowledge sharing, intellectual property management, and joint development initiatives that involve international industrial partners. An overarching theme in our findings is that big science projects must align with broader national innovation goals to ensure their long-term success. This involves creating a policy environment that encourages not just short-term economic returns but also long-term, sustainable development in technology and industry. In contrast to Europe, where big science projects are often evaluated based on their contribution to scientific discovery and technological diffusion (e.g., the CERN HL-LHC project's socio-economic impacts), China's policies should place equal emphasis on the transformation of research outputs into practical, industrial applications. This could involve enhancing public-private partnerships, creating innovation ecosystems, and aligning scientific discovery with market needs.

4.1. To establish an institutional environment conducive to the cooperation of BSOs and IOs

4.1.1. Leading role of governments in building a platform for big science cooperation

The success of the cooperation between the BSOs and IOs in the EU lies in the following aspects: (1) With the countries (including the international organizations such as the European Commission) as the leading actors, the BSOs and IOs have built a trading and cooperation platform. (2) The national action promotes the formation of the EBSM. On the one hand, BSOs in Europe carry out centralized procurement activities from IOs and non-standard components that are difficult to mass produce from economies of scale here. On the other hand, IOs cooperate with BSOs to obtain technology transfer. (3) The procurement access qualifications of members of BSOs and the implementation of supportive policies for IOs, especially SMEs, are emphasized.

Therefore, it is necessary to provide a high-level exchange and cooperation platform for BSOs and IOs and formulate procurement policies with IOs (especially SMEs) as a priority, so as to build a sustainable big science market. The establishment of this market is not only conducive to improving the technical capabilities of IOs but also conducive to improving the level of research and development of scientific research instruments.

4.1.2. To establish cross-institutional procurement models

The BSOs in the EU belong to different member states or joint bodies of member States, which apply different procurement procedures and rules, and thus form different procurement models. However, these diversified procurement models from different countries and even international institutions coexist in the EBSM and help IOs from different countries to reach deals and cooperate with BSOs by providing clear instructions on procurement procedures and processes. This indicates that the multi-procurement model does not restrict the cross-institutional cooperation between BSOs and IOs.

Therefore, a unified procurement model is not a necessary condition for the establishment of a BSM, while multiple procurement models can coexist. On the one hand, BSOs should formulate clear procurement rules and procurement strategies as soon as possible, and publish them on their respective portals for relevant organizations to inquire and understand. On the other hand, in the regular open activities held by the big science platform, procurement guidelines are formulated to centrally publish the procurement needs and procurement models of various BSOs, to facilitate the transaction between BSOs and IOs.

4.1.3. To provide a holistic financial support institution

In terms of financial support, holistic financial support can ensure output and promote cooperation between BSOs and IOs.

(1) To coordinate public funding channels. The different funding of BSIs provided by different departments will lead to different fund management methods, resulting in problems of incoordination and incompatibility. Thus, it needs to combine with the different lifecycles of BSIs and strengthen the effective connection and coordination among the funding support system of government departments to meet the funding needs of various links. Besides, the coverage of the fund should be further expanded.

(2) To expand the multi-party funding system. The construction and operation of BSIs have the characteristics of a long construction period, high cost of capital, and long return period. Therefore, sufficient funds are one of the key elements to ensure the success of the operation of the BSOs. It is worth considering referring to the EU's "public construction and private operation" model, which can expand the sources of funds, mobilize the enthusiasm of different actors (such as governments, financial institutions, private capital, etc.), and establish cost and risk sharing mechanism, to provide an adequate financial guarantee for the cooperation of BSOs and IOs.

(3) To strengthen funding for the IOs' use of BSIs. The IOs are less involved in the construction and use of BSIs, the EU model provides us with good references, and its funding program for SMEs provides conditions for cooperation between BSOs and IOs. It is worth learning from the approach of the EU and strengthening financial support for the users from IOs. It is suggested that the government should establish special funds to attract IOs to use BSIs for R&D.

4.2. To build a big science business and innovation eco-network with multi-actors

4.2.1. To establish a science and technology intermediary institution

Information asymmetry is an important reason that affects the establishment of cooperative relations between BSOs and IOs. The ILO is a science and technology intermediary institution adopted to promote the transaction and cooperation between BSOs and IOs in the EU. The main task of ILO is to provide national IOs with key information and advice on cooperation with BSOs to contribute to the formation of a more prosperous EBSM in an organized and planned way. The EBSM is targeted at different countries in the EU. Despite the institutional differences and geographical distances among countries, IOs can still establish business cooperation networks with BSOs in different countries, which is an important contribution of the ILO. Therefore, as an institutional arrangement and innovation to reduce the transaction cost of a big science market, ILO has important reference value for the exploration of constructing a BSM and the promotion of effective cooperation between BSOs and IOs.

4.2.2. To establish a network of enterprises based on BSOs

The establishment of the Enterprise Europe Network has been an important platform for the establishment of cooperation between BSOs and IOs and provided an important reference for other countries. Government can build enterprise networks by taking the following steps:

(1) To build a dedicated enterprise network group. This group can be composed of government officers from science and technology departments, members of BSOs, science and technology intermediaries, etc. They can meet regularly to discuss policy development and support for IOs to better understand their needs and challenges.

(2) To set up enterprise network offices in various places. Through this initiative, IOs can be helped to solve the inconvenience caused by geographical location. These offices can provide advice and support to local IOs, as well as networking and communication.

(3) To conduct a survey of the major technology needs of BSOs. It is suggested to establish a database of major technology needs and conduct a statistical survey of relevant IOs in order to provide a platform for BSOs and IOs to find cooperation opportunities. This can help governments better understand current technology needs, so as to better coordinate policies and resources, and provide business and technology opportunities for IOs.

(4) To provide advice and assistance. The government can provide advice and assistance to IOs, helping them to obtain government funding support, finding partners, and so on. The government can also provide IOs with advice and support on technology transfer and legal provisions to better promote their development.

4.2.3. To establish an industry promotion department to coordinate cooperation

Based on the study of EBSM, it is argued that the establishment of an industry promotion department is an important factor in encouraging cooperation between BSOs and IOs. The industry promotion department should be led by the government and be responsible for promoting exchanges and interactions, coordinating resources, and creating a good environment for cooperation between BSOs and IOs.

It is necessary to give full play to the publicity and guidance role of the industry promotion department in the cooperation between BSOs and IOs. This department should help IOs to solve technical problems and enhance mutual understanding between BSOs and IOs. According to the needs of all parties, the industry promotion department should coordinate BSOs to reasonably allocate the application of BSIs in industry and scientific research and provide sufficient opportunities for IOs to use BSIs for R&D. Furthermore, the industry promotion department can help to build an innovation and entrepreneurship service platform, provide financial support, as well as other services such as site, law, intellectual property rights, and commercialization analysis to solve the worries of IOs.

4.3. To strengthen the cognitive construction of IOs on the commercial value of big science

4.3.1. To strengthen the publicity of big science to IOs

In the cooperation between BSOs and IOs, from experimental instruments for basic research to industrial application research for IOs, there are many segments separating BSOs from IOs, which make IOs lack knowledge of BSOs. Thus, targeted publicity and user training measures are crucial. Publicity can solve the cognitive gap between potential users of IOs and BSOs, and increase the interest and understanding of IOs on BSOs. These measures can include lectures, exhibitions, media coverage, etc. Comprehensive considerations in terms of planning, hierarchy, and pertinence are needed. Outreach efforts should go to a variety of online and offline channels, as well as a combination of traditional and new media. Between different communication purposes and subjects, it is necessary to adopt personalized approaches and form an effective mechanism. Especially for promotional activities to promote industrialization, it is necessary to provide more opportunities for IOs to get to know BSOs.

4.3.2. To establish a better open and sharing institution for BSOs

To improve the way BSOs operate BSIs. By changing the utilization mode, more IOs are provided with the opportunity to use BSIs for R&D, and some preferential conditions are provided, to improve the attractiveness of cooperation between IOs and BSOs. The government and BSOs should develop a sound opening institution for IOs, and realize the sustainable development of BSI operation and management. Meanwhile, it is necessary to formulate a support, incentive, and supervision institution to promote cooperation between BSOs and IOs, to form a sustainable open and sharing institution. Furthermore, it is suggested to reform the evaluation indicators of BSOs, incorporating the output of cooperation with IOs into the evaluation system, which should serve as an important basis for the renewal and funding support of BSOs.

5. Conclusion

By using the field theory to integrate three perspectives of sociology of markets to build an institution-cognitive-network framework, this study analyzes the construction practice of the EBSM and obtains useful policy implications from it. The theoretical contribution of this paper lies in its extension of the governance and innovation systems frameworks, particularly in the context of big science collaborations. While existing literature on big science often focuses on either the institutional or network aspects of innovation, this study integrates both dimensions to provide a more comprehensive view of how large-scale scientific projects can foster cooperation between scientific organizations, industries, and government bodies. Our findings also propose a new framework for understanding the role of government in facilitating these collaborations, not only as a funding body but also as an active participant in the knowledge-sharing and commercialization processes. This theoretical extension challenges existing models of innovation that treat government and industry as separate, autonomous entities, instead proposing a more integrated model of governance that is more responsive to the evolving needs of big science projects. The findings are as follows:

(1) The EBSM supports the establishment of cooperative relations between BSOs and IOs.

(2) The Big science market is not an abstract or a priori existence, but a concrete form jointly constructed by European governments, BSOs, and IOs.

(3) Governments are not mere funding providers but are a dominant player through making big

science and industrial policies and establishing various institutions.

Under different institutional contexts, China’s big science policies should balance localization with insights from international practices. For instance, the EBSM emphasizes cross-border collaboration and consortium-building to enhance regional integration. Building on its existing top-down governance model, China could adopt more flexible, network-based governance structures to promote cross-sector cooperation and technology diffusion. Additionally, while the EBSM benefits from the institutional support of the EU Single Market Project, China may address the disparities in regional economic development by designing multi-level, multi-sector coordination mechanisms to ensure the efficient operation of its BSIs. This analysis underscores that big science projects are not only catalysts for technological innovation but also critical tools for institutional reform and economic transformation. By considering its institutional context, China can explore tailored pathways for constructing a big science market, advancing technological, industrial, and societal progress in a coordinated manner.

Based on the above findings, this study believes that China can learn from the institutional construction practice of the EBSM, explore the establishment of China's big science market, and put forward countermeasures and suggestions from three aspects: institutional environment construction, business and innovation network construction and cognitive construction. We believe that the establishment of a big science market is in line with China’s current policy practice of implementing the innovation-driven development strategy and building a unified national large market.

There are still some limitations in this study. On the one hand, this study tried to present a panoramic view of the institutional practice of the EU in promoting cooperation between BSOs and IOs, but some specific practical details still need to be further analyzed. For example, the European Single Market Project is the institutional foundation for the construction of the EBSM, but their relationship is not analyzed in detail in this study. On the other hand, although the EBSM is a representative example, it is necessary to compare its institutional practice with similar institutional practices in other countries, which can help to better understand the similarities and differences between the institutions that can promote cooperation between BSOs and IOs. In future research, we will try to take some specific BSOs as the research cases, and further analyze the construction mechanism of the EBSM in detail. Furthermore, we will try to compare the EBSM with the national laboratory system in the United States, to increase our understanding of the institutional basis on which BSOs and IOs can establish effective partnerships.

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