A Comparison of Open Access Models for Major Scientific and Technological Infrastructures Abroad and Their Implications for China (Postprint)

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Abstract

Open sharing of major scientific and technological infrastructure plays a pivotal role in the open science ecosystem and is of great significance for promoting scientific and technological development, enhancing innovative cooperation, and improving national comprehensive competitiveness. This article systematically reviews four open sharing modes of major scientific and technological infrastructure from the two dimensions of resource scarcity and resource sustainability: public welfare sharing mode, market-responsive sharing mode, intensive guarantee sharing mode, and strategic cooperation sharing mode. By selecting representative foreign cases and conducting multi-case comparative analysis, the article further elaborates on the basic characteristics of different open sharing modes. Finally, based on in-depth analysis of these modes, it explores experiences and insights that can be referenced for promoting open sharing of major scientific and technological infrastructure in China.

Full Text

Preamble

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Comparison of Open Sharing Modes of Foreign Large-Scale Scientific Facilities and Implications for China

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Abstract

The open sharing of large-scale scientific facilities plays a pivotal role in the open science ecosystem and is of great significance for promoting scientific and technological development, enhancing innovation cooperation, and boosting national comprehensive competitiveness. From the two dimensions of resource scarcity and resource sustainability, this article systematically identifies four open sharing modes for large-scale scientific facilities: public inclusive sharing mode, market-responsive sharing mode, intensive guarantee sharing mode, and strategic cooperation sharing mode. Through multi-case comparative analysis of representative foreign cases, the article further elaborates on the basic characteristics of different open sharing modes. Finally, based on in-depth analysis of these modes, the article discusses experiences and implications that can inform China' s efforts to promote the open sharing of large-scale scientific facilities.

Keywords: large-scale scientific facilities, resource scarcity, resource sustainability, open sharing modes, case comparison

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Open science is flourishing, and the open sharing of key elements in scientific activities—such as scientific and technological infrastructure, scientific data, and scientific journals—is driving extensive cooperation and innovation in scientific research. The open sharing of major scientific and technological infrastructure (hereinafter referred to as "major facilities"), as an important component of open science, refers to opening up large-scale complex scientific research devices or systems to society to provide services for high-level research activities. Since the 21st century, developed countries in Europe and America have regarded investment in and construction of major facilities as crucial measures to enhance national scientific and technological capabilities. For example, the United States has built more than 60 major facilities in fields such as physics, astronomy, life sciences, and information technology; the United Kingdom has over 40; Germany more than 60; and France nearly 60. While possessing numerous major facilities, these countries and regions have accumulated rich experience in promoting scientific cooperation, optimizing resource allocation, and enhancing research efficiency through the open sharing of major facilities.

As of June 2022, China had approximately 57 major facility projects under construction or in operation, with 32 already completed and operational, some of which have reached the global "first echelon" in comprehensive performance. As a major country in terms of major facilities, China has consistently adhered to the principle of open sharing to improve resource utilization efficiency and promote scientific output. However, compared with international advanced levels, there remains a certain gap in China' s open sharing of major facilities, particularly in terms of unclear project selection priorities, lack of sustained funding, and low open sharing service capacity. Drawing on the experiences of Europe, America, and other regions in open sharing of major facilities can help improve and enhance China' s practices in this field and develop open sharing modes for major facilities that align with the concepts and practices of open science.

Current academic research on the open sharing of major facilities is relatively limited. Existing studies have mainly focused on discussing the output benefits, comprehensive benefit evaluation, and evaluation mechanisms of major facilities, with few summarizing and comparing foreign open sharing modes. To address this research gap, this article adopts an international comparative perspective, focusing on resource scarcity and sustainability to deeply analyze typical practices and experiences in foreign major facility open sharing, summarize different open sharing modes, and provide decision-making support for China to formulate policies and improve management practices for major facility open sharing.

1 Classification of Open Sharing Modes for Large-Scale Scientific Facilities

Major facilities provide shared services that are important scientific and technological resources with quasi-public goods attributes: non-excludable but rivalrous in use. That is, facility sharing services cannot simultaneously satisfy every researcher in need. Therefore, from the demand perspective, major facility sharing exhibits resource scarcity. From the supply perspective, the construction and operation of major facilities require high construction costs and maintenance expenses, raising the question of how to ensure the sustainable provision of high-quality shared services, which faces constraints of resource sustainability. This article attempts to explore open sharing modes for major facilities from the two dimensions of resource scarcity and sustainable resource supply.

1.1 Resource Scarcity

Scarcity refers to the condition where demand for resources always exceeds available supply under limited resource conditions, requiring allocation decisions based on priority. Resource scarcity in major facilities means that services to support research and development activities are limited and far from meeting scientists' demands, necessitating choices about which scientists or research activities to serve.

According to the level of resource scarcity, allocation strategies and priorities for major facility open sharing services differ. When resource scarcity is high—that is, when shared services are in severe short supply—priority should be given to resource utilization efficiency, concentrating major facility allocation on users or projects that can maximize research output. Accordingly, facility resource managers set selection criteria to prioritize professional users who are highly dependent on resources and can achieve high output. Conversely, when resource scarcity is low and shared services are relatively abundant, the scope and targets of major facility services can be more relaxed and diversified. Lower supply-demand pressure allows managers to consider diversity and fairness in resource allocation more extensively—on the basis of satisfying professional users, more resources can be opened to general users to promote research diversity and knowledge popularization. Therefore, from the perspective of resource scarcity, major facility allocation strategies show differences: when resource scarcity is high, efficiency and professional user needs are emphasized; when resource scarcity is low, fairness and popularization are considered more.

1.2 Resource Sustainability

Sustainability refers to maintaining well-being over long periods, possibly indefinitely. Resource dependence theory suggests that attention should be paid to what action strategies an organization adopts to obtain sustainable resources critical to its continued operation. When discussing open sharing modes for major facilities, cost compensation for open sharing services must be considered.

Regarding open sharing services for major facilities, cost compensation relies on one hand on government payment without market participation, and on the other hand on obtaining market-based income through paid services. Without market participation, government provides stable funding and necessary resources such as professional talent for major facilities through direct investment and scientific project funding. Long-term stable government support covers the operating costs of major facilities, ensuring they can continuously provide open sharing services. With market participation, market entities provide additional economic security for facility operation, maintenance, and upgrading by purchasing services. Market participation not only increases economic sources for facility operation but also optimizes resource allocation through price mechanisms and strengthens connections between scientific research and industry, promoting technological innovation and knowledge transfer. Therefore, from the perspective of resource sustainability, major facility open sharing distinguishes between two scenarios: without market participation, government support ensures sustainability; with market participation, paid services provide economic compensation and promote utilization efficiency.

1.3 Classification Model of Open Sharing Modes

Comprehensively considering the two dimensions of "resource scarcity" and "resource sustainability" and employing typological methods, this article proposes four open sharing modes for major facilities (Figure 1 [Figure 1: see original paper]).

1.3.1 Public Inclusive Sharing Mode In scenarios with low resource scarcity and no market participation, the focus of major facility resource allocation and utilization is to ensure broad user groups can equally access major facilities to promote democratization of research activities and global cooperation, forming a public inclusive sharing mode characterized by open access strategies. In this mode, major facilities have fewer usage restrictions, can provide usage opportunities for a wide range of scientists, but rely primarily on government funding for operation and maintenance. In addition to ensuring continuous operation and upgrading of major facilities, the government also guides facility managers to develop a set of evaluation and approval processes to ensure open sharing aligns with scientific value and social benefits.

1.3.2 Market-Responsive Sharing Mode In scenarios with low resource scarcity and market participation, major facilities open facility usage rights to users willing to purchase services according to market demand and value creation, forming a market-responsive sharing mode characterized by market mechanisms and cost compensation. Users pay fees to obtain access to or usage rights of major facilities, and facility operators improve resource utilization efficiency through partial marketization. In this mode, shared services are transformed into market products provided to users with demand and willingness to pay. The charging mechanism transfers part of the facility' s operating costs to users, while the price reflects the market' s valuation of the facility' s shared services. Through paid services, government and market cooperate to operate and maintain major facilities, achieving long-term operation and scientific support capacity.

1.3.3 Intensive Guarantee Sharing Mode In scenarios with high resource scarcity and no market participation, the focus of resource allocation is to ensure user groups with strategic significance or undertaking critical research tasks can obtain stable and continuous resource support, forming an intensive guarantee sharing mode characterized by centralized management and refined allocation. In this mode, users are required to submit detailed research proposals for conducting research at major facilities, and management institutions implement user selection and priority ranking to ensure limited resources serve projects with the greatest research potential and urgency. The intensive guarantee sharing mode emphasizes the government' s key role in resource guarantee, maintenance, and upgrading. Although users may bear partial costs, the overall funding, maintenance, and upgrading of major facilities mainly rely on government financial support and policy guidance.

1.3.4 Strategic Cooperation Sharing Mode In scenarios with high resource scarcity and market participation, there is a need both to select users to ensure efficiency in major facility resource allocation and to guarantee sustainability of facility usage through government and market channels, forming a strategic cooperation sharing mode characterized by establishing strategic partnerships. Due to resource scarcity, major facilities mainly provide shared services to selected user groups with research capabilities; to compensate for operation and maintenance costs, they tend to select users with payment capacity. Major facilities establish strategic partnerships with selected users who rely on the facilities for long-term collaborative research. The strategic cooperation sharing mode is a strategic choice to ensure sustainable operation and improve open sharing efficiency under resource scarcity constraints.

2 Typical Cases of Open Sharing Modes for Large-Scale Scientific Facilities

Based on the above classification model, this article selects typical cases of foreign major facility open sharing, analyzes and compares the operational characteristics of different modes, and summarizes relevant experiences.

2.1 Public Inclusive Sharing Mode–CERN Open Data Platform

Located near Geneva, Switzerland, the European Organization for Nuclear Research (CERN) is the world' s largest particle physics laboratory, composed of partner organizations from 12 European countries, primarily dedicated to high-energy physics research exploring the origin and nature of fundamental particles and the universe. CERN has built and operates important facilities including the Large Hadron Collider (LHC), Super Proton Synchrotron (SPS), and Proton Synchrotron (PS). To meet extensive data demands, CERN launched the Open Data Portal, providing public access to its experimental data, including datasets from multiple experiments and research projects, as well as data from different detectors, to ensure experimental data is preserved and opened to broad audiences.

Major facilities can generally be divided into two categories: "hard facilities" as technology platforms and "soft facilities" as data platforms. CERN' s Open Data Platform serves as a typical "soft facility" adopting a public inclusive sharing mode for the public. Regarding resource scarcity, the establishment of the open data platform reduces the scarcity of experimental data in the high-energy physics field. Due to the non-exclusive nature of experimental data —allowing multiple users to simultaneously access the same dataset without causing supply shortages—whereas previously these high-value data were mainly used for internal CERN research and its partners, ordinary public and non-collaborating researchers had difficulty obtaining access. From the perspective of resource sustainability, CERN' s Open Data Platform does not rely on market funds to maintain its operation. Government funding support is sufficient to ensure the platform' s openness and continuous updating, thereby achieving sustainable data use.

Through accessing the open data platform, users can freely obtain experimental datasets generated by facilities to meet research needs without paying usage fees. Notably, CERN' s open data platform follows specific time regulations and policies for public data release; for example, LHC data must be retained in data storage centers for three years before being made public. Under the public inclusive sharing mode, intellectual property rights for experimental data are completely open, and users can freely use these data for analysis, verification, and research. Additionally, CERN' s Open Data Platform provides users with additional resources such as relevant metadata, documentation, software, and analysis tools to help users understand data background, experimental design, and processing methods, supporting their work in data analysis and interpretation.

2.2 Market-Responsive Sharing Mode—German Electron Synchrotron (DESY)

Founded in 1959, the German Electron Synchrotron (DESY) in Hamburg has developed into one of the world' s leading accelerator centers. DESY is equipped with advanced large-scale accelerator facilities such as the Positron-Electron Tandem Ring Accelerator (PETRA) and the Hadron-Electron Ring Accelerator (HERA), providing critical light and particle beam resources for experimental research. In 2022, DESY's annual budget reached €230 million, with a total staff of approximately 2,300, including about 650 scientists; each year, approximately 3,000 guest scientists from over 40 countries conduct research at DESY.

DESY serves as a typical example of the market-responsive sharing mode, providing an innovative framework for close integration between scientific research and industry. Regarding resource scarcity, DESY is characterized by relative abundance and sustainability—not only supporting high-level scientific research activities but also opening its accelerator facilities to industry. Industrial enterprise users can obtain facility access by contacting relevant personnel and utilize these resources for project R&D. To address resource sustainability challenges, DESY employs a market-based income mechanism to enhance its resource sustainability. By serving industrial partners and implementing usage fee collection mechanisms, DESY provides stable funding sources for its facilities' maintenance, operation, and support costs.

DESY' s market-responsive sharing mode optimizes resource supply-demand relationships, not only improving resource utilization efficiency but also creating conditions for integration between scientific research and industrial applications. Additionally, this mode provides continuous and effective services for different user groups by encouraging scientific collaboration and technology commercialization, offering new perspectives for facility operation models. Regarding intellectual property, in the market-responsive sharing mode, rights typically belong to applicants, but research institutions may retain certain usage rights or other constraints to balance resource sustainability and innovation promotion. For example, Captor Therapeutics, a biopharmaceutical company, utilized DESY' s PETRA III facility to obtain critical protein crystallography diffraction data, which helped the company resolve atomic-level structures of target protein-ligand complexes to design and optimize novel targeted degradation drugs. However, these data are not shared externally and belong to joint ownership. DESY' s market-responsive sharing mode demonstrates how to optimize the supply-demand relationship of scientific research resources through market mechanisms while ensuring rational utilization of scientific achievements and management of intellectual property rights.

2.3 Intensive Guarantee Sharing Mode–National High Magnetic Field Laboratory (NHMFL)

The National High Magnetic Field Laboratory (NHMFL) is a research institution specializing in high-intensity magnetic field research, funded by the U.S. National Science Foundation (NSF) and operated in cooperation with multiple universities and research institutions. As one of the world' s largest high magnetic field laboratories, NHMFL possesses major facilities such as Electron Magnetic Resonance (EMR), Ion Cyclotron Resonance (ICR), and Pulsed Field, serving fields including physics, chemistry, biology, and materials science.

NHMFL implements an intensive guarantee sharing mode to manage and allocate magnetic field facility resources. Regarding resource scarcity, NHMFL' s high-intensity magnetic field facilities face scarcity due to limited quantity and supply, making it difficult to meet all potential user demands, manifested in limited equipment numbers, restricted usage time, and broad user needs. To address resource scarcity challenges, NHMFL employs application and scientific committee review procedures to select users, including steps such as preparing documentation, creating user profiles, submitting requests online, and reporting research results, aiming to ensure fair facility resource allocation. Regarding resource sustainability, NHMFL involves almost no market participation, focusing on government funding to support its operation and allowing selected users to use high-intensity magnetic field facilities free of charge. Through precise resource allocation, user selection, and priority setting, NHMFL improves facility utilization efficiency and ensures the durability and effectiveness of facility resources.

Under the intensive guarantee sharing mode, when users generate paper achievements using high-intensity magnetic field facilities, they own the rights to these achievements and can independently decide on publication and utilization methods. Meanwhile, NHMFL requires users to disclose data, allowing other researchers to verify research results, establish new research questions, and promote collaboration and innovation in the scientific community through public data. Additionally, NHMFL employs flexible access strategies, where users can either directly operate high-intensity magnetic field facilities for experiments and observations or remotely access them via networks for experimental control and data collection. NHMFL' s comprehensive management model includes internal scientific committees and external committees. Internal scientific committees supervise scientific research direction and quality to ensure consistency with the laboratory' s mission and objectives. External committees include user committees and external advisory committees, with user committees focusing on improving service quality and user satisfaction, while external advisory committees composed of experts from various fields provide advice on laboratory operations and strategic planning.

2.4 Strategic Cooperation Sharing Mode—Argonne National Laboratory (ANL)

The Argonne National Laboratory (ANL) is a major scientific and engineering research institution under the U.S. Department of Energy, managed and operated by "UChicago Argonne, LLC" established by the University of Chicago. As one of the earliest established national laboratories in the United States, ANL' s team includes approximately 3,500 regular employees, 325 postdoctoral researchers, and nearly 500 graduate students. ANL possesses multiple major facilities including supercomputers, neutron sources, photon sources, and ion accelerators, serving about 6,700 scientific users annually and providing critical support for research activities in nuclear energy, renewable energy, and environmental science.

ANL faces a major challenge in how to effectively manage and maximize the utilization of major facility resources. To address this challenge, ANL has adopted a strategic cooperation sharing mode aimed at fully utilizing its major facility resources by establishing stable long-term cooperative relationships with specific users. Under this mode, specific users who pay fees or provide funding support can become strategic partners, enjoying priority services and other special support. These long-term cooperative relationships transcend single projects, with the goal of jointly promoting the development and innovation of major facilities. Regarding resource sustainability, ANL participates in market activities to obtain funding while also relying on government financial support to maintain its operations.

Through the strategic cooperation sharing mode, ANL can not only meet the research needs of specific users but also promote the application and commercialization of scientific and technological achievements. For example, ANL's programs such as the Technology Expert-in-Residence Program, Corporate Voucher

Program, and Technology Commercialization Fund have facilitated cooperation with the private sector and promoted the commercialization and development of energy technologies. This market-oriented strategic cooperation approach provides an innovative and effective model for major facility resource management. ANL' s strategic cooperation sharing mode not only provides an economic foundation for the long-term sustainable development of major facilities but also optimizes the utilization and improves output efficiency of major facility resources by fully leveraging market mechanisms, effectively addressing the challenges of resource scarcity.

Overall, different open sharing modes for major facilities have their respective strengths and are suitable for different application scenarios, depending on the resource scarcity and sustainability of major facilities. In terms of user categories, degree of marketization, and intellectual property, different open sharing modes present their own characteristics and differences (Table 1).

3 Implications for China

China has achieved remarkable accomplishments in major facility construction, but the more urgent current need is how to make good use of these facilities, expand open sharing, and provide strategic foundational support for national high-level scientific and technological self-reliance. Based on the above classification model of open sharing modes and comparative analysis of typical foreign cases, this article summarizes five implications for China.

3.1 Classify and Promote Open Sharing According to Major Facility Types

Foreign major facilities have formed differentiated open sharing modes based on the two dimensions of "resource scarcity" and "resource sustainability," thereby balancing the needs of different user groups and the service capacity of major facilities to improve utilization efficiency and promote diversified development of scientific cooperation and innovation. In contrast, China' s open sharing modes for major facilities remain relatively singular, primarily based on experimental proposal applications. To maximize the utility of major facilities, it is necessary to develop differentiated sharing strategies according to the characteristics and purposes of different facility types, fully considering the scarcity levels and service functions of different facilities.

First, construct classified sharing modes. For facilities with high resource scarcity, such as nuclear fusion experimental devices or deep-sea exploration facilities, strict usage review and scheduling arrangements should be implemented to ensure major facility resources are used efficiently and professionally. For facilities with low resource scarcity, such as data storage and analysis platforms, more flexible access permissions should be provided to promote broader open sharing of scientific data.

Second, adopt differentiated service and support strategies. For academic users, intensive guarantee sharing mode or public inclusive sharing mode can be adopted, with open applications and non-discrimination principles to ensure broad availability of major facility resources. For industrial users, market-responsive sharing mode or strategic cooperation sharing mode are more suitable, meeting their specific needs through paid usage rights and additional services.

3.2 Emphasize User Selection Mechanism Design and Construct a Multi-Dimensional Evaluation System

Given the scarcity of major facility resources, user selection mechanisms are key to ensuring efficient and fair allocation of facility resources. In the management and operation of foreign major facilities, user selection mechanisms receive high attention, comprehensively considering users' backgrounds, research achievements, project innovation, and social impact to ensure fair and efficient resource allocation and maximize scientific potential and social value. Compared with mature foreign user selection systems, China has not yet formed a complete multi-dimensional evaluation system in the design and implementation of user selection mechanisms, which may lead to low resource utilization efficiency and underutilization of scientific potential. Therefore, to address resource scarcity issues, China' s major facility open sharing urgently needs to establish a differentiated selection mechanism for different user groups based on the principle of "asymmetry and emphasizing strengths," thereby adapting to the rapid changes in the research environment and diverse user needs.

First, for the selection of scientific community users, focus on evaluating expected research output. In user selection, emphasize applicants' strengths in research fields, valuing research innovation, academic background, research achievements, and potential contributions to science. Priority support should be given to research projects proposing new theories or with potential major scientific impact, as well as teams with widely recognized collaboration and research capabilities, thereby ensuring major facility resources are allocated to teams most likely to produce major scientific discoveries.

Second, for the selection of industrial users, focus on evaluating the project' s potential to promote industrial development or generate disruptive technological innovation. Assess the project' s potential to improve existing technologies or products, market application feasibility, commercial potential, and possible economic benefits, giving priority to projects expected to drive industrial technological progress or lead new market trends. This not only helps improve major facility resource utilization efficiency but also promotes economic growth and technological innovation.

3.3 Provide Pricing Guidance for Market Services to Ensure Major Facility Sustainability

Considering that the operation and maintenance of major facilities require significant capital investment, introducing market participation mechanisms—particularly through providing paid services to enterprise users—is an effective strategy to enhance the sustainability of major facility resources. International experience shows that providing paid services has become a widely adopted practice for major facilities when opening and sharing with enterprise users. However, China' s practice in this area lags behind, with a low proportion of enterprise users in major facility utilization, resulting in the potential economic and social value of major facilities not being fully realized and the market participation of major facilities not meeting expected levels. Research shows that the key to major facility resource sustainability lies in providing pricing guidance for paid services and developing reasonable and effective pricing policies that encourage broader market participation and utilization to support long-term facility operation and development.

First, adhere to cost compensation and non-profit principles. The core of paid service pricing strategy is to ensure prices truly reflect the value of major facility services. This means pricing should consider not only direct costs, operation and maintenance expenses, and personnel costs but also be based on comprehensive cost-benefit analysis to ensure user fees reasonably reflect the quality and benefits of major facility services.

Second, implement differentiated or reasonable tiered pricing. Considering the diverse payment capacities and service needs of different user groups, flexible pricing structures (such as tiered pricing, cooperative pricing, and on-demand pricing) can be used to accommodate different user needs. For example, tiered pricing applies to different levels of service demand, cooperative pricing suits long-term partners, and on-demand pricing fits specific project needs.

Third, pricing strategies should be transparent and flexible. To ensure long-term effective operation and maximize social value of major facilities, pricing structures should be transparent, enabling different users such as research institutions, enterprises, and the public to understand the principles and considerations behind pricing, which helps establish trust mechanisms. Flexibility means the pricing mechanism is not static but can be adjusted in a timely manner according to actual conditions, including fluctuations in market demand, technological progress, and policy adjustments.

3.4 Improve Open Sharing Service Capacity to Support High-Level Research Activities

In many foreign countries, facility host institutions have established mature open sharing mechanisms for major facilities, ensuring rational allocation and use of major facility resources through fair, transparent application and review processes and efficient information platforms. They also pay special attention to providing advanced experimental equipment and technical support to promote interdisciplinary cooperation. In contrast, the service capacity of facility host institutions in China urgently needs improvement in terms of constructing open sharing mechanisms and providing technical support.

First, construct fair, transparent, and efficient open sharing mechanisms. Introduce international and small peer expert review teams to establish fair and transparent application and review processes, ensuring scientific and fair resource allocation. Simultaneously, strengthen process transparency to ensure users have clear understanding of application processes and results.

Second, strengthen information platform construction and enhance platform functions and technical support. Major facilities should increase investment in equipment maintenance and upgrading, improve the professional level of technical service personnel, and provide more comprehensive and personalized user technical support, thereby improving research efficiency and depth and promoting the development of high-level research projects.

3.5 Emphasize the Public Welfare Characteristics of Major Facilities and Expand the Social Impact of Open Science

With the development of open science, an increasing number of countries have adopted inclusive and public welfare strategies to manage their major facilities, aiming to cover broader user groups and promote democratization of scientific knowledge and equalization of research opportunities through expanded open sharing. For example, in 2021, 76% of NHMFL users came from universities, 16% from government laboratories, and 8% from industry, whereas enterprise users of some Chinese major facilities account for less than 1%. In comparison, China' s major facilities still tend to serve specific "elite" groups, with inclusiveness not yet fully realized, which to some extent limits the broad application of major facility resources and the socialization of scientific and technological achievements. In the context of open science, China should pay more attention to inclusive open sharing when promoting major facility open sharing, in order to maximize the social value of major facility resources.

First, gradually lower the threshold for accessing and using major facilities while ensuring core research tasks are not affected. Provide more support especially for resource-scarce small and medium-sized research teams, independent researchers, and enterprises. Simultaneously, to promote integration and innovation in interdisciplinary and cross-field research, strengthen encouragement and support for these boundary-crossing projects to promote knowledge and technology integration across scientific fields.

Second, use digital means to break geographical usage limitations. By establishing online sharing platforms and other digital means, provide users with more flexible and convenient virtual access and remote operation capabilities, thereby improving the utilization efficiency of major facility resources.

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Note: Figure translations are in progress. See original paper for figures.