International Experience and Reflections on Promoting Open Source and Open Access of Outcomes from State-Funded Scientific Research Projects - Postprint

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Abstract

In the digital economy era, open source innovation activities have become a fundamental driver for stimulating innovation vitality from the source and are becoming an important source for the high-quality supply of digital public goods. This article focuses on the importance of promoting open source and openness of outcomes from state-funded research projects, summarizes the practical experiences and policy measures of major countries and regions globally regarding open source and openness of outcomes from national fiscal-funded research projects, and analyzes the challenges faced by China in promoting open source and openness of outcomes from government-funded scientific and technological projects. Based on this, it proposes recommendations for facilitating the construction of an open source and openness mechanism for scientific and technological achievements in China.

Full Text

Experience and Reflections on Promoting Open Source of Achievements from State-Funded Scientific Research Projects

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Abstract

In the era of digital economy, open source innovation has become a driving force for stimulating innovation vitality from the source and is emerging as an important source of high-quality supply of digital public goods. This paper focuses on the importance of promoting open source of achievements from state-funded scientific research projects, summarizes the practical experiences and policy measures of major countries and regions worldwide in promoting open source of achievements from state-funded scientific research projects, and analyzes the challenges China faces in advancing open source of achievements from government-funded scientific and technological projects. Based on this analysis, the paper proposes recommendations for establishing an open source mechanism for scientific and technological achievements in China.

Keywords: state funding, scientific research projects, open source innovation, digital public goods, scientific and technological achievements

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1 The Significance of Open Source for Achievements from State-Funded Scientific Research Projects

The era of digital economy is a transformative period filled with both challenges and opportunities. Open source models have enabled disruptive innovation and leapfrog development in information technology, which is of major strategic significance for China to achieve high-level self-reliance in science and technology. Open source communities serve as crucial channels for the development and evolution of modern information infrastructure software, while open source ecosystems represent key pathways for building and integrating comprehensive systems of data and innovation resources. These ecosystems have played vital roles in promoting the construction of software and hardware information industry ecosystems, attracting deep attention from decision-making departments.

In March 2021, the *14th Five-Year Plan for National Economic and Social Development and Long-Range Objectives Through 2035* of the People' s Republic of China proposed in its section on "Accelerating Digital Development and Building a Digital China" to "support the development of innovation consortia such as open source communities for digital technologies, improve the open source intellectual property and legal system, and encourage enterprises to open software source code, hardware design, and application services." This marked the first time that "open source" was written into national strategic planning. In February 2023, the *Overall Layout Plan for Digital China Construction* issued by the CPC Central Committee and the State Council explicitly stated that digital China construction follows the "2522" framework: consolidating the "two foundations" of digital infrastructure and data resource systems; promoting the deep integration of digital technology with economy, politics, culture, society, and ecological civilization construction; strengthening the "two capabilities" of digital technology innovation systems and digital security barriers; and optimizing the "two environments" of digital development domestically and internationally.

Against this backdrop, this paper explores the value, specific measures, and recommendations for promoting open source of achievements from state-funded scientific and technological projects to advance the construction of digital public goods systems. The findings of this study can help better coordinate the implementation of national policies for promoting open source ecosystem development, accelerate the iterative optimization of digital technologies—especially underlying software and hardware technologies—enrich innovative and exploratory scientific and technological achievements from the source, and maximize the stimulation of innovation vitality and momentum across society.

1.1 Open Source Innovation as a Key Source of Global Digital Public Goods Supply in the Digital Era

The status of open source innovation products as digital public goods has become a global consensus. In June 2020, the United Nations released the "Roadmap for Digital Cooperation" report, which for the first time publicly emphasized that "digital public goods must adopt open source forms, which is key to enhancing human well-being through the internet." The report provided the first widely accepted definition and scope of digital public goods: "open source software, open data, open AI models, open standards, and open content that comply with privacy and other applicable international and domestic laws, standards, and best practices, and do not cause harm to others." Globally, the view of open source technology as digital public infrastructure services has become a consensus, recognized by more than 20 major economies from the private sector, government, and civil society.

Open source innovation has become an important collaborative model for scientific and technological innovation, a crucial force driving global information technology development, and a typical production and supply method for digital public goods. Open source innovation can fully unleash the potential of digital technology, particularly in promoting collaborative research, development, and application of underlying basic software and hardware such as operating systems, middleware, databases, and chips. Simultaneously, open source innovation can promote open sharing of research and data, achieve collective wisdom, and facilitate research convergence and inspiration.

Open source innovation is becoming an important practice for large-scale collaboration in the information technology field. It influences new software and hardware development methods, scientific paper dissemination channels, and data access approaches, and is changing the landscape of the information technology industry and scientific publishing models. With the rapid development of new-generation information technology, open source has become crucial support for cutting-edge scientific and technological innovation, profoundly impacting the development pattern of the entire information technology industry. Open source technology supports more than 90% of internet-based information technology products and has fostered the growth of numerous small but innovative enterprises. By 2020, over 95% of mainstream IT enterprises and organizations were using open source software and technology directly or indirectly in their key solutions, making open source one of the most important technological supports in the digital era [7].

1.2 Open Source as an Important Model for Sharing Scientific Achievements and Promoting Collaborative Innovation

Open source is an important model for achieving collaborative development among industry, academia, research, and application. Through open source licenses, source code owners grant licensees the freedom to use, modify, and dis-

tribute software. Compared with closed-source software, open source software has nurtured new innovation paradigms such as crowdsourcing, open innovation, user innovation, and innovation commons, achieving tremendous success in both technological progress and commercial development. In the open source process, active participation from technology giants and the coexistence of diverse open source communities have propelled software open source innovation into a crowd intelligence integration and development stage oriented toward human-machine-thing fusion environments [8]. Open source enables technological iteration, upgrading, and survival of the fittest through crowd intelligence sharing, allowing outstanding achievements to be continuously launched and reused. This enables the entire society, including innovative enterprises, to benefit from national scientific and technological achievements generated by fiscal investment, thereby promoting high-quality economic and social development.

Open source helps advance breakthroughs in scientific research and innovation. Open science is a future frontier trend, and the practice of open science has promoted scientific development and technological progress alongside the rapid development of digital technologies. Scholars have found that knowledge generated by the public sector during research processes should be shared with the public [9]. In 2021, UNESCO synthesized opinions from 193 member states to form the *Recommendation on Open Science*, which represents an important future direction for scientific research. The participation of so many countries in completing this recommendation also demonstrates the global emphasis on open science. The construction of open science as a whole cannot be separated from the collaborative advancement of various modules, including open source software, open data, open policies, open papers, open communities, and open participation. Through collaborative construction including open source software, a solid foundation has been laid for building an innovative country.

Open source is a strategic lever for fiscal savings and efficiency. From a fiscal perspective, adopting open source pathways helps reduce redundant investment in scientific and technological projects, optimize fiscal fund allocation, ensure effective resource utilization, and achieve higher quality and more efficient outcomes while promoting economic growth. For example, a 2021 EU study on the economic impact of open source software and hardware reported that open source technology contributed €65–95 billion to the European economy. Open source can promote continuous iteration and optimization of top scientific and technological achievements or innovations, facilitating the formation of a social innovation environment characterized by co-creation, co-construction, co-governance, and sharing. Adopting open source forms for achievements from state-funded scientific and technological projects can institutionally ensure transparent use of fiscal expenditures, thereby improving public fiscal efficiency.

1.3 Open Source as an Important Means to Promote International Cooperation and Participation in Global Governance

Open source is an important pathway for China to integrate into the international innovation network. As open source ecosystem elements gradually become complete, encouraging high-quality domestic open source software and hardware projects to "go global" and attracting international top-tier open source projects to "come to China," open source will become an important way for China to integrate into the global innovation ecosystem. In November 2023, China issued the *International Science and Technology Cooperation Initiative* at the first Belt and Road Science and Technology Exchange Conference, advocating the implementation of open, fair, just, and non-discriminatory international science and technology cooperation concepts, insisting that "science has no borders and benefits all mankind,"and working together to build a global science and technology community. In May 2023, the United Nations released the policy brief *Our Common Agenda*– "A Global Digital Compact for an Open, Free, and Secure Digital Future for All," proposing specific goals for global digital public goods, including developing and managing digital technologies to promote sustainable development, empower humanity, anticipate and effectively address risks, and ensure inclusive digital cooperation that enables meaningful contributions from all stakeholders.

Open source is a new method for China and countries worldwide to achieve the UN 2030 Sustainable Development Goals (SDGs). The SDGs aim to pool global capabilities from 2015 to 2030 to address common social, economic, and environmental development problems and promote sustainable development. Open source technology has become an important method for the UN to promote the SDGs, which proposed building a "central database of open-source appropriate technologies" (OSAT) and integrated the establishment of a series of open support platforms represented by "2030 Connect," bringing together well-known partners inside and outside the UN system such as the Digital Public Goods Alliance (DPGA) and the CAS Earth Big Data Science Engineering Project (CASEarth). Open source has become one of China' s important ways to participate in international governance.

2 Policy Measures Supporting Open Source of Achievements from Government-Funded Projects in Major Countries and Regions

Open source innovation achievements are important carriers and manifestations of national scientific research results. Simultaneously, open source is an important channel and means for spreading national scientific and technological innovation influence, conducive to promoting international science and technology cooperation. Major developed countries and regions worldwide attach great importance to open source innovation and open science development [10]. This section reviews how the United States, European Union, United Kingdom,

France, India, and other countries and regions promote open source of scientific and technological achievements through top-level design, strategic layout, institutional mechanisms, and organizational structures.

2.1 Strengthening Top-Level Strategic Design to Promote Open Sharing of Scientific and Technological Achievements

The United States is an active promoter of top-level open source strategies. In February 2023, the U.S. National Science Foundation (NSF) funded the release of the "Pathways to Enable Open-Source Ecosystems" (POSE) program, which aims to harness the power of open source development to create new technological solutions for issues of national and social importance. In 2019, the U.S. Congress passed a series of regulations and policies including the *Open Government Data Act*, *Freedom of Information Act*, *Government in the Sunshine Act*, and *Federal Government Information Resources Management Policy*. These regulations and policies aim to ensure government information openness and treat open government data as important strategic assets for the federal government, partners, and the public. California launched an "Open Source and Code Reuse Policy" in 2018 to enhance government use of open source software. These regulations and policies represent historic steps for the U.S. government in open government data, as they assume by default that all government information should be open data, machine-readable, and freely reusable, bringing considerable returns to both public and private sectors in "improving government operations and serving citizens' lives." As open source software plays an increasingly important role in U.S. national security, particularly following the Log4j2 vulnerability outbreak in December 2021, Democrats and Republicans cooperatively proposed the *Protecting Open Source Software Act* in September 2022 to strengthen open source software protection. This act designates open source software as public digital infrastructure for the first time and requires the U.S. Office of Management and Budget to issue guidelines to federal agencies on the secure use of open source software.

The EU promotes open source software as digital public goods. In November 2020, the *Open Source Software Strategy (2020–2023)* was released, proposing to establish world-class public services, encourage greater use of open source software for construction, and promote sharing and reuse of software, applications, data, information, and knowledge, aiming to contribute to a knowledge society through shared source code. Based on this, the report *Software Helping Businesses, Innovators, and the Public Interest* was formed to further promote open source software as digital public goods.

France has written data openness into government acts. In 2016, the French government promulgated the *Digital Republic Act*, which requires opening public research data and elevates open government data to the national legal level. According to this act, government information should be in machine-readable formats and open to the public by default without harming privacy or security [10].

The UK promotes open source and data interoperability standards. In 2017, the UK released the *Guidelines for Opening and Using Open Source Code*, which holds that code needs to be made public and open source technology should be used to improve transparency, flexibility, and accountability. The 2019 *Digital Service Standards* require government departments to open source all new code under appropriate licenses. The UK government also led the establishment of the "Digital 5" intergovernmental coordination mechanism to promote open standards, open source, open markets, and open government. In January 2022, the *UK Open Government National Action Plan (2021-2023)* was released, proposing to establish interoperability standards for health data and encourage government collaboration with open source communities to address unclear and non-transparent health data issues.

India builds an open source industry ecosystem based on its software outsourcing service advantages. In 2015, India proposed the "Digital India" initiative, striving to adopt open source software in all e-government systems implemented by Indian government organizations as the preferred option compared to closed-source software. The initiative calls on open source developers, technology entrepreneurs, and Indian startups to submit implementable open source product innovations that could be applied to government technologies in health, education, agriculture, urban governance, and other fields. The vision of the "Digital India" initiative is to expand and adopt Indian open source platforms globally, achieving inclusive global growth. The Indian government announced that all its software services and applications would mandatorily adopt open source software, and many Indian startup technology companies have been established using free or open source software.

2.2 Establishing Specialized Agencies to Execute and Optimize Open Source Operation Mechanisms

The United States leads the world in establishing specialized agencies to operate open source mechanisms. To promote the utilization and transformation of funded project research results, U.S. government departments require funded research projects to disclose their scientific research results and relevant supporting data within specified timeframes. This requirement is implemented and enforced by the U.S. White House Office of Science and Technology Policy (OTSP). Guided by OTSP' s memo on *Increasing Access to the Results of Scientific Research*, the National Oceanic and Atmospheric Administration (NOAA) released the *NOAA Plan for Increasing Public Access to Research Results* in February 2015, which clearly states that publications and environmental data funded by taxpayer money should be made public in a timely manner. For research articles published in restricted journals, the embargo period should not exceed 12 months before being made freely available to the public. The U.S. government also stipulates the applicable scope of funded projects in the plan.

Europe has proposed standards and cooperation mechanisms for open source operations. For example, in 2018, the EU' s report on *The Impact of Open Source*

Software and Hardware on EU Economic and Technological Independence, Competitiveness, and Innovation called for establishing an EU open source software office to serve as an official management institution that complements market-based management mechanisms for digital infrastructure and comprehensively serves digital infrastructure development needs, though this has not yet been implemented. The UK' s Cabinet Office Central Digital and Data Office (CDDO) leads digital, data, and technology-related work to create better conditions for the UK government' s digital transformation. The UK has also established the Government Digital Service (GDS), which formulates and implements technical standards for government digital services, including open source-related policies, digital service standards, open standard principles, and technical practice codes, while also coordinating and regulating open source communities such as the Linux Foundation, World Wide Web (WWW) Consortium, and Unicode Consortium on behalf of the UK government.

2.3 Establishing National Open Science Action Plans Across Multiple Departments

The United States advances the implementation and promotion of open source scientific tools through the "Year of Open Science" initiative. In 2023, the U.S. launched the "Year of Open Science" commemorative activity, a multi-agency initiative across the federal government aimed at engaging in open science through various activities and promoting the adoption of open, equitable, and secure science. Relevant open source activities include NASA' s "Open Source Science Initiative," NOAA' s "Unified Forecast System," and NIH' s "Software Tools for Open Science." Combining open source work with other open science activities of government departments can make open source work more grounded and concrete.

Major European countries actively promote national open science strategies. For example, in July 2021, the French government released the *National Open Science Plan (2022-2024)*, which requires that research data, algorithms, and source code supported by public funds should be disseminated and shared through open licenses. This plan builds upon France' s first national plan released in 2018, expanding its scope to include research-related source code and designating open source as a key component of scientific research that needs to be recognized and supported to ensure that source code and software generated in French public research can be developed, maintained, and applied. In 2022, the Dutch government launched the NPOS (National Open Science Program) project, which sets four vision goals for 2030: strengthening cooperation among knowledge communities (including research institutions, government departments, and enterprises); conducting scientific activities (such as quality assurance, communication, and evaluation) in an open, effective, and transparent manner; building open academic exchange communities to eliminate barriers to accessing and reusing scientific research achievements and sustainably acquiring and benefiting from knowledge; and sharing knowledge creation achievements

(such as data and software) in FAIR ways—Findable, Accessible, Interoperable, and Reusable. These four goals explicitly integrate open source scientific research achievements with other plans to strongly promote their sharing and utilization services.

3 Challenges Facing China in Promoting Open Source of Achievements from Government-Funded Scientific and Technological Projects

Compared with major developed countries and regions worldwide, China started relatively late in building open source ecosystems. The supply capacity and diversity of digital public goods through social channels for open source innovation are relatively insufficient. Therefore, China needs to promote the open source of achievements from government-funded scientific and technological projects to facilitate the full utilization and effective transformation of scientific and technological achievements by the whole society, thereby making greater contributions to promoting high-quality economic and social development. Currently, China' s open source ecosystem construction is mainly driven by industry-leading enterprises, such as Huawei' s HarmonyOS ecosystem and Alibaba' s cloud-native platform ecosystem, while collaboration between academia and enterprises in open source needs further strengthening. Compared with major overseas open source participants such as technology giants and open source foundations, some domestic technology enterprises are still in the initial stages of building digital economy open source ecosystems and still have certain deficiencies. To promote industry open source ecosystem construction, the government and relevant administrative departments should become important promoters of industry open source ecosystem development, encouraging multi-party integrated innovation, avoiding technological monopoly and closure, and creating a market environment for fair competition. However, China still faces severe challenges in promoting open source of achievements from government-funded scientific and technological projects, mainly reflected in the following four aspects.

3.1 Relatively Insufficient Proactive Innovation Capability in Core Open Source Technologies

China' s proactive innovation capability in core open source technologies is relatively insufficient, specifically manifested in insufficient reserves of original open source technologies, limited involvement in international open source standard systems, and insufficient proficiency in applying open source rules. China' s originality in underlying key common technologies for open source software and hardware is relatively low, particularly in basic software and hardware technologies such as operating systems, industrial software, and underlying chips that are regarded as digital public goods in the digital economy era. This results in China's overall insufficient participation in the formulation of international standards for key technologies and data based on open source ecosystems and insufficient understanding of the different participation rules of various open source

communities involving technological innovation sources [7]. Consequently, integration with global open source communities is relatively difficult—China still lacks internationally influential "star" open source projects, which is not conducive to China's future transition from a peripheral node to a more central position in the global open source innovation network.

3.2 The Multi-Party Deep Collaboration Pattern in the Open Source Ecosystem Has Not Yet Formed

In the field of open source innovation ecosystems, the collaborative model among enterprises, government, and society has not yet formed an organic interactive situation. Domestic universities, research institutes, industrial organizations, large enterprises, and startups have not yet found open source models suitable for achievement transformation. Although China is gradually building a relatively complete new-generation information technology system through participation in open source innovation models, compared with the social-enterprise-government ternary collaborative model formed by international open source innovation [12], China's open source field, projects, and communities are relatively fragmented, lacking "star" projects and major demand traction, making it difficult to gather open source ecosystem forces. This is not conducive to building open source communities and also disadvantages Chinese market entities in participating in the construction of global open source innovation networks. Additionally, there are certain institutional risks for government departments or state-owned technology enterprises to participate in open source, such as the risk of state-owned asset loss involved in donating source code by state-owned enterprises.

3.3 The Social and Cultural Atmosphere for Advocating Open Source Innovation Needs Strengthening

China has not yet formed a social and cultural atmosphere that advocates open source innovation, and social forces lack continuous financial investment and talent injection into open source governance activities. From a micro perspective, existing research shows that the community culture of Chinese open source innovation participants exhibits complex and contradictory characteristics [13]. In open source communities, participants both share and cooperate while competing with each other, demonstrating a pattern of "competitive mutual assistance and cooperation." Meanwhile, regarding open source project management and the functions of project leaders, Chinese open source communities show both various efforts toward equality and democracy and strong "personality cult" characteristics, displaying "centralized" and "concentrated" features different from international open source culture's "bottom-up," "distributed collaborative democracy," and "decentralization." This "centralization" leads to a certain degree of "dictatorship," but this "dictatorship" is often necessitated by practical circumstances. Chinese 本土 open source participants contribute less and use more, lacking subject consciousness and being accustomed to leadership-

centered systems, which better guarantees project efficiency and progress [13]. However, from the perspective of innovation development laws, relying solely on centralization cannot achieve crowd intelligence convergence and multi-subject participation.

3.4 Management of Open Source Achievements from State Financial Funding Is Not Yet Perfect

China currently lacks management norms for the collection of open source funded achievements. For the management of open access literature resources, China successively released the *Policy Statement on Open Access to Research Papers Funded by Public Research Projects of the Chinese Academy of Sciences* and the *Policy Statement on Open Access to Research Papers Funded by Projects of the National Natural Science Foundation of China* in 2014. For scientific data, China issued the *Scientific Data Management Measures* in 2018, and relevant departments have also issued corresponding departmental policies. However, there is currently no unified management method for open source software scientific and technological achievements, which directly affects the classification, collection, and open sharing of these achievements. Additionally, many achievements from state-funded scientific research are frontier exploratory, highly specialized, and narrowly applied. Without collection and standardized management, these achievements would cause great difficulties for the overall layout and sustainable development of national scientific and technological work.

4 Recommendations for Promoting Open Source of Scientific and Technological Project Achievements in China

According to the *Notice on Further Strengthening the Coordinated Management of National Science and Technology Program Project Initiation*, since 2022, the Ministry of Science and Technology has required some major projects to indicate "promoting the open source of breakthrough achievements or some components and functional modules, with open source code volume not less than 25% of the total project code volume." To expand the sources of open source scientific and technological achievements on a larger scale, it is recommended that relevant national departments further clarify policies and procedures for the public welfare donation of state-owned assets involving software code, institutionally guaranteeing the market promotion and industrial application of scientific and technological achievements through open source, saving national fiscal investment, and improving the utilization efficiency of fiscal funds. Based on actual research, China has not yet formed institutional constraints on open source of achievements related to national science and technology projects. Therefore, four recommendations are proposed.

4.1 Establish Government Agency Source Code Repositories and Shared Operation Platforms

First, strengthen top-level design. Internally, integrate and guide national resources; externally, engage in multi-party coordination and actively participate in and contribute to global governance work on SDGs. In the scientific research field, jointly participate in the overall construction of open science and consolidate China' s digital scientific research infrastructure for future intelligence. Second, encourage and guide software development work in state-funded projects to be organized based on open source platforms originating from China, promoting open source sharing of source code for independent functional service modules. Build professional open source institutions and source code repositories to widely attract social forces to participate during the research and development process of science and technology projects, allowing project undertakers to enjoy the benefits of open source during the R&D process. Third, introduce policies and procedures for the public welfare donation of software code state-owned assets. Institutionally guarantee the open source of state-developed or scientific and technological achievements. From multiple aspects, promote all social sectors to actively embrace open source, build shared operation and maintenance networks, leverage respective advantages, promote the coupled development of underlying technologies and service modules, and jointly promote the construction of open source innovation ecosystems.

4.2 Build a National Open Source Platform for Operating Scientific and Technological Achievements

First, strongly support exploration of open source models. Strengthen research on the internal mechanisms, theoretical methods, and technical principles of open source ecosystems, and recommend that technology enterprises, research institutes, and universities establish open source offices to standardize the use of open source technology and actively participate in and contribute to open source communities. Second, build core asset libraries for open source software ecosystems. Promote multi-party participation in open source construction by the government, large technology enterprises, small and medium-sized startups, research institutions, and higher education institutions, and recommend that the Chinese Academy of Sciences take the lead in jointly creating an open source platform for sharing scientific and technological achievements with relevant parties. Third, establish public open source support platforms. Promote the construction of open source tools and community mechanisms suitable for the characteristics and collaboration habits of Chinese software developer groups. Fourth, support the establishment of multiple Chinese-language open source communities. Provide continuous technical support for open source ecosystem construction. Fifth, strengthen open source software talent cultivation. Encourage researchers to actively participate in open source activities, break down barriers between enterprises and research institutions, establish industry-academia-research-application collaborative open source practice plat-

forms, and activate the market value and social value transformation of scientific and technological achievements. Sixth, actively strengthen international cooperation. Integrate into the joint construction and promotion of global digital public goods, so that more Chinese digital achievements can be recognized and applied.

4.3 Incorporate Open Source Innovation Contributions into the National Science and Technology Evaluation System

First, build a new evaluation and reward system for open source technology talents. Collaborate with business-related parties to jointly build open source innovation exchange communities and "ecosystems," gradually forming a good open source situation with stable demand, mature markets, complete evaluation systems, sufficient talent, and flexible collaboration. Enrich the connotation of scientific and technological achievement recognition and evaluation, and include important open source software and hardware in the scope of representative scientific and technological achievements. Second, make open source an important reference standard for the acceptance of national science and technology projects. Relevant departments such as the Ministry of Science and Technology, National Development and Reform Commission, Ministry of Industry and Information Technology, and Ministry of Education should collaborate fully to include requirements in the project initiation guidelines or bidding documents for state-funded science and technology projects that explicitly require the promotion of technical architecture and technical document openness, advocate for the openness and transparency of key basic algorithms, and for software achievements, require that under the premise of not endangering national security, the proportion of open source code should reach a certain level, such as no less than 20%. For hardware equipment and experimental environments, mechanisms need to be designed to open them to the whole society. Third, establish a long-term tracking mechanism. Conduct continuous tracking of open source scientific and technological project code achievements and evaluate actual effects through "look-back" methods to avoid formalism. Fourth, promote the transformation of ownership of software and hardware achievements from state-funded science and technology projects toward digital public goods and advance the construction of digital public infrastructure. Institutionally eliminate researchers' concerns about the ownership of open source achievements, especially by explicitly stipulating that research and development achievements involving basic software and other underlying technologies are owned by the whole society. Simultaneously, encourage scientific research achievements to be hosted and evolved on domestic open source platforms from the infrastructure level to prevent the loss of achievements from state-funded projects. Fifth, incorporate investment in and contributions to open source ecosystems into the science and technology evaluation and assessment system. Include evaluation indicators such as code contributions, algorithm services, coding testing, education and popularization, technical training, and case promotion, similar to papers and patents, into China' s future innovation capability evaluation index.

Encourage research institutes, universities, and central state-owned enterprises to increase investment in open source and vigorously promote the development of open source software and hardware industries.

4.4 Promote the Promotion and Application of Open Source of National Science and Technology Project Achievements

Promote the open source application and promotion of science and technology project achievements through various means to build a community "ecosystem." First, accelerate research on laws and regulations for open source intellectual property recognition to provide precedents for effectively handling legal issues such as open source software copyright ownership and code intellectual property. Second, attempt to guide the market-oriented and scaled transformation of open source solutions through government procurement. Starting with promoting the open source of national scientific research project achievements, drive and lead the investment of human, financial, and material resources in open source activities across society, promoting open source to play a greater role in government-industry-academia-research-application collaboration and promoting the high-quality supply of digital public goods. Third, strengthen education and publicity on open source technology, concepts, and culture. Enhance open source case research and promotion to form internationally demonstrative and influential cases, providing Chinese solutions for international governance and SDGs practice. Fourth, advocate the open source of research and development project achievements with openness and public welfare characteristics. Gradually form institutional rules based on social consensus to improve the whole society' s understanding of open source. Fifth, by promoting the open source of state-funded scientific and technological achievements, gradually attract market entities such as innovative enterprises to participate in using and transforming open source achievements to better serve national economic and social development. This will facilitate the transition of scientific and technological achievements from the research stage to the commercial market stage and achieve market maturity, realizing smooth connection and deep integration of the "innovation chain," "industrial chain," "capital chain," and "talent chain," enabling state fiscal funds to play a greater leading and driving role.

5 Conclusion and Outlook

Since the 1970s, open source collaborative achievements represented by software products and services have gradually become a large-scale collaborative practice example in the information and communication technology field. The tremendous knowledge increment generated has not only produced new software products and software industry collaboration models, improving human production and lifestyle, but also nurtured open source culture, community autonomy mechanisms, crowd intelligence collaboration networks, open innovation paradigms, and innovation commons theory. The influence of open source innovation culture extends far beyond the software field to digital economy and science and

technology governance. Since the internet revolution in the early 21st century, open source innovation has gradually become a new path for national entities, various market entities, and individuals worldwide to build continuous innovation capabilities in scientific and technological innovation frontiers with high complexity and uncertainty.

Led by state-funded scientific research projects, promoting open source is strategically significant for enhancing the transparency of China' s scientific and technological R&D and funding sources, building competitive scientific centers, attracting global high-level talent, and cultivating frontier technology enterprises. The point-like achievements emerging through open source, through integrated innovation and technology combination to build technology stacks, play important roles in transforming into different technology products and industrial support. Open source innovation is not only an effective way for China to address constraints on core key technologies but also a possible path for China to achieve leadership in the new round of scientific and technological competition. Therefore, the construction of software and hardware open source innovation paradigms requires high attention, objective assessment, and rational decision-making.

The construction of open source innovation ecosystems is a long and arduous task, and it is necessary to accelerate the shaping of China' s open source innovation social and cultural environment. With the successive establishment of domestic open source organizations such as the OpenAtom Foundation and the Open Source Development Committee of the China Computer Federation, the rapid growth of domestic open source projects like OpenHarmony, the continuous development of activities such as the open source chip "One Student, One Chip" program and the open source software supply chain "Lighting Plan," and the diversified development of alliances such as the China Open Source Cloud Alliance and China RISC-V Ecosystem Alliance, good organizational guarantees and work foundations have been provided for promoting open source innovation ecosystem construction. To further promote the sustainable development of open source innovation ecosystems, it is necessary to strengthen the construction of innovation ecosystems in strategic layout, form systematic national layout and planning, support digital China construction, and promote the open source of state-funded scientific and technological achievements from the top-level design to maximize social innovation vitality and further consolidate effective supply channels for digital public goods.

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