Research on the Value Chain Management and Circulation Bottlenecks of Scientific Data Elements

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Abstract: In order to understand the practical problems of the circulation and utilization of scientific data in the value chain in China, explore and construct the theoretical model of the value chain of scientific data elements on the basis of discussing the value effect of data elements, and then reveal the bottleneck of the circulation of scientific data elements along the value chain and analyze the corresponding solutions. It is found that the circulation and utilization of scientific data in the value chain in China are facing practical bottlenecks in four aspects which are factor allocation, standard practice, privacy security, and asset security. It is found that the circulation and utilization of scientific data in the value chain in China are facing practical bottlenecks in four aspects which are factor allocation, standard practice, privacy security, and asset accounting. In this regard, China can focus on three aspects which are promoting the resource sharing of scientific data service platforms, continuing to develop and promote scientific data standards and relevant statistical systems, managing scientific data by level and classification and improving the quality of scientific data. In this regard, China can focus on three aspects which are promoting the resource sharing of scientific data service platforms, continuing to develop and promote scientific data standards and relevant statistical systems, managing scientific data by level and classification and improve governance mechanisms.

Keywords: scientific data, data elements, data value chain, circulation bottlenecks

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1 Introduction

As a core production factor in the era of digital economy, data have become an important force for economic and social progress. Among them, scientific data can provide a source of creativity for technological innovation and industrial upgrading, and is an important strategic resource for the country to realize innovation-driven development. At present, China's scientific data mainly face two problems: complex content and lack of attribute description[1] and fragmentation of standards[2] , which leads to the constraints on the value of data in practical applications. To address the problem of data attributes, scholars mainly conduct research on data sharing[3] , data center service[4] , data exchange[5] , and data platform construction[6] and so on. Regarding data standards, Xu Feng believes that scientific data standards can be subdivided into four aspects, namely, basic standards, public standards, technical standards and subject area standards, to promote the application of scientific data.[7] Scholars, such as Rocca-Serra et al.[8] , Hu Lianglin et al.[9] , and Jiang Tian et al.[2] , have carried out research on expanding the idea of data standards development. From a comprehensive point of view, the existing studies analyze the measures and methods to strengthen data management from the technical level, but lack the consideration of application scenarios, especially how to unleash the multiplying and stacking effects of scientific data from the perspective of the value chain.

The value of data is realized in the process of circulation and utilization[10] . Only by allowing scientific data to circulate smoothly along the value chain can the potential value of scientific data be stimulated, thus injecting a steady stream of data empowerment for relevant subjects to promote innovation activities. The Outline of the Fourteenth Five-Year Plan and Vision 2035 for National Economic and Social Development of the People's Republic of China proposes to "promote the further opening of national scientific research platforms, scientific and technological reports, and scientific research data to enterprises." Accelerating the circulation and open sharing of scientific data is not only a realistic move for scientific research organizations and the enterprise sector to enhance the momentum of innovation, but also an important hand for China to grasp the opportunities of the new round of scientific and technological revolution. In this regard, this paper will explore and construct a theoretical model of the value chain of scientific data elements on the basis of discussing the value effect of data elements, and then reveal the bottlenecks in the circulation of scientific data elements along the value chain and analyze the corresponding solutions.

2 Value effect of data

According to the definition of the Organization for Economic Cooperation and Development (OECD), data is a quantitative, objective symbol that is used to store and transmit facts[11] . The all-round penetration and deep integration of the new generation of information technology into all fields of the economy and society has broken down the traditional sectoral barriers and linked up one data island after another, laying a favorable technical foundation for the circulation and utilization of data. Unlike the use of traditional factors of production such as labor and capital, which are subject to the law of diminishing margins, the value of data elements will show a trend of increasing margins with the increase in the number of times they are used. In addition, the role of data in circulation and utilization is not only reflected in the provision of innovative value for the relevant subjects, but also in the process of clustering other factors of production towards the links that promote innovative activities, realizing the rational allocation of factors and improving total factor productivity. It is also in the process of circulation and recycling that the value of data elements is constantly being tapped and developed, releasing a superimposing and multiplying effect.

2.1 Unlocking the value stack in the circulation cycle

The popularization and promotion of intelligent sensing devices has accelerated the speed of data collection, making the physical world perfectly mapped into the Internet space in the form of data. Nowadays, data can be automatically generated in the system, and the global data measurement unit has long surpassed the GB and TB levels, and is rapidly developing towards the DB and NB levels, which also forces the technical capabilities of data storage devices to be continuously upgraded. Data as a measurement symbol, its own is not given a specific meaning, different subjects analyze the same set of data may get very different analysis results. This feature also enables data to get rid of the mark of subjective consciousness, and can be disseminated and promoted among different subjects at a very low copying cost, and its scope of application has been greatly expanded. Any subject has the opportunity to extract the most favorable clues and solutions from data based on specific scenarios and their own development needs. The newer the data, the more accurately and

objectively it can reflect the cutting-edge dynamics of real issues, and then provide valuable market signals for the subject's behavior. Therefore, timeliness becomes one of the important factors affecting the value of data.

Since data have timeliness, when data are circulated and utilized between different subjects through the Internet, they can be accessed and utilized by different subjects at the same time, realizing the one-time generation of multiple values while bringing convenience to different subjects, releasing the value superposition effect of data, and realizing a new leap in the value creation of data. The global, real-time and open characteristics of data transmission make it possible for data to be accessed by different subjects in less time and at a lower cost than the point-to-point unidirectional mode of traditional information transmission, thus realizing the synchronization and coordination of value creation activities among different subjects. Data circulation brings together the original scattered data islands and releases value energy for innovation activities. The data circulation process gradually forms a stable circulation mechanism, and at the same time continuously releases the value of the superposition effect, so that each subject in the circulation network obtains the value released by the circulation of data, and the cohesion of the innovation organism is also enhanced as a result.

2.2 Unlocking value multipliers in the recycling process

The non-competitive and non-consumptive nature of data itself gives it the logical premise that it can be recycled by different subjects, but the amount of value that the subject can mine from the data depends on the ability to mine and utilize it, i.e. the algorithmic model and the basis of arithmetic power. "Data + Arithmetic + Algorithm" constitutes the driving mechanism of the smart economy, using the power of machine reason to build a management framework for data acquisition, transmission, storage and analysis, which makes the recycling of data technically feasible and promotes the gradual upgrading of the traditional relational database system (RDBMS) into a multi-tier business intelligence (BI) system, with the data source and non-consumptive data being used by different subjects. system (BI), data sources and accumulation speed have been significantly improved. Computers can work continuously and stably for long periods of time under suitable natural environments, which not only overcomes the technical errors that may be caused by human initiative, but also accelerates the frequency and cycle of data recycling, and enhances the depth of integration between data and data, and between data and other factors of

production. When the system continuously enters new data, the level of data is constantly enriched, which enables the algorithm model to continuously carry out self iteration and optimization based on new data, so that the data mining work in terms of credibility and validity has been improved. The focus of data mining is no longer limited to improving traditional activities, but can also assist in exploring new problems, developing innovative capabilities, and unlocking the value multiplier effect of data. New algorithmic models can better incorporate the real-world pain points of different subjects, discover new combinations of value based on streaming or batch processing of data, and provide reliable, trustworthy, and usable system-level solutions to problems related to procedural and non-procedural activities, respectively. The source of ideas and the design process of these solutions will be retained in the form of data, which will help provide clues and inspiration for subsequent work.

3 Scientific data value chain management

As a subcategory of data, scientific data record the original and fundamental information of scientific research activities and can provide information support for scientific research, economic development and social progress. As early as the beginning of the 20th century, developed countries such as the United States and the European Union introduced policies at the national level to strengthen the management and service of scientific data. China introduced the Measures for the Management of Scientific Data in March 2018, aiming to standardize the management and service of raw data and derived data for scientific research activities. According to the definition of the International Data Committee (CODATA), the scope of scientific data services includes activities that assist organizations in acquiring, aggregating, storing, managing, analyzing, and visualizing scientific data, as well as services that provide legal support and academic research[12] . Data flows and circulates along the value chain, and value creation, value mining and value application are accomplished step by step between different links. With the acceleration of the new round of scientific and technological revolution, it is especially necessary and urgent to improve the management and service of scientific data value chain and enhance the dynamic energy of innovation in China.

3.1 Data life cycle

Life cycle theory originated in the field of sociology and has since been gradually

expanded to psychology, management, economics and other disciplines. According to the life cycle theory, data from generation to elimination should go through six stages: collection, storage, processing, transmission, exchange and destruction (Figure 1). At different stages, the conditions for the formation of data value are very different, and the specific management strategies are also significantly different.

In the data collection stage, the value of data can be ensured by expanding the scope and channels of data acquisition, increasing the multidimensionality and plurality of data, while taking the original first-hand data as the main source of data and cooperating with pre-processing means to screen and eliminate redundant data, and improving the purity of data.

In the data storage stage, adopting the appropriate format for effective storage of data is a prerequisite for guaranteeing the realization of data value, during which attention should be paid to upgrading the hardware infrastructure and database management system in a timely manner according to the changes in the amount of data storage, and when necessary, consideration can be given to adopting a distributed storage model to alleviate the pressure of the storage of the central node.

In the data processing stage, according to the real problems and data characteristics, choose the appropriate algorithmic tools to model dynamic data and explore the potential value, so as to combine with professional theories to carry out in-depth analysis and formulate alternative solutions.

In the data transmission stage, the transmission efficiency is related to factors such as link selection and transmission mode. In order to ensure the timeliness, accuracy and reliability of data, technical means can be used to prevent the emergence of data loss, privacy leakage and other problems in the transmission process.

In the data exchange phase, the data interaction mode depends on application scenarios, communication channels and other factors, and the sender and receiver need to repeatedly test each technical detail, especially dynamic encryption, security auditing, data ferry and other security issues to be communicated in depth.

In the data destruction stage, in accordance with compliance requirements, identify potential loopholes in advance, formulate a reasonable and thorough destruction program, keep records of data destruction, and implement data destruction on a regular basis to help reduce the pressure on storage and avoid the legal risks that may be triggered by data leakage.

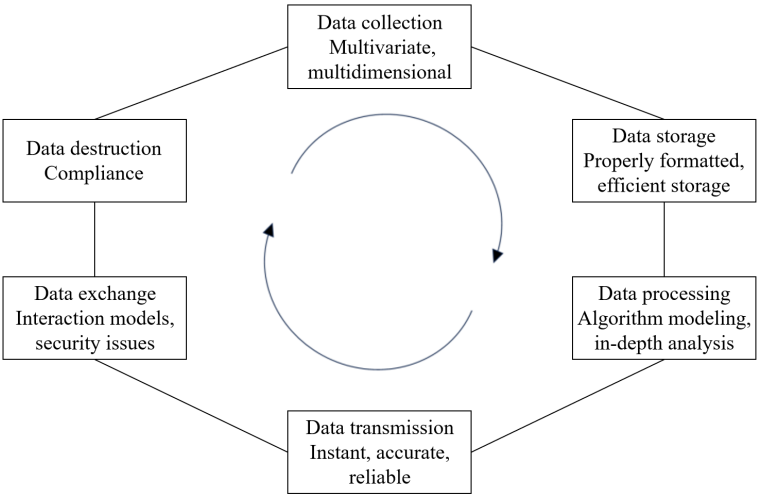

Fig. 1. Data life cycle

3.2 Scientific data value chain management

The data life cycle describes the process of value accumulation, value development, value utilization, and value promotion of data elements, on the basis of which scholars in the field of systems engineering have divided the data value chain into four consecutive links, namely, data generation, data acquisition, data storage, and data analysis, and different processing technologies will be applied to different links[13]. The Organization for Economic Co-operation and Development suggests that data value play is not just a chain process, but manifests itself as a multi-stage circular feedback cycle, i.e., after going through the four modules of datafication and data acquisition, data analysis, knowledge refinement, and decision-making drive, it ultimately promotes economic growth and social welfare[11]. In essence, the data value chain is a full-process closed-loop gain system in which data and other factors of production interact with each other to jointly create new economic value. in July 2020, among the "first batch of 108 new words for big data" collected and validated by the National Science and Technology Nomenclature Validation Committee, the Data Value Chain was recognized as a new word for big data. In July 2020, among the first batch of 108 new big data words collected and finalized by the National Science and Technology Nomenclature Validation Committee, Data Value Chain was publicly released to the whole society as a new big data word and put on trial.

Scientific data is an accurate record of the facts of scientific research activities, which needs to meet certain conditions before it can be collected, and the data sources are relatively limited. Although data can be obtained through simulation and modeling systems, these data can only be collected after repeated testing in real scenarios. According to the chain order of value addition, the scientific data value chain includes the acquisition, processing, integration, and analysis of raw data[14] . An important difference between scientific data and other data is that scientific data involves scientific and technological patents and intellectual property rights, so it has higher requirements for security, which requires encrypted protection of scientific data at different levels according to the content of the research, and this kind of protection will, to a certain extent, constrain the development, utilization and promotion of the value of scientific data, and this important difference makes it clear that the value chain of scientific data is a characteristic that distinguishes it from the data value chain. A feature that distinguishes the data value chain - the focus on data security. The strength of scientific research institutions lies mainly in the promotion of R&D projects, and they generally lack the relevant technology and experience in data security, so they need the assistance of professional organizations to do a good job in the professional management of scientific data. In addition to the basic value links such as data collection, data analysis, and knowledge refinement in the scientific data value chain, value service links are also needed to undertake technical support work in data privacy, data desensitization, and data aggregation and dispersal, so as to promote the effective circulation and recycling of scientific data, thus better releasing the value superposition and value multiplication effects of scientific data. In addition, the data value chain does not involve data destruction, but scientific data have high requirements for security, so the scientific data value chain needs to make additional considerations for data destruction, and for some scientific data that are not in need of use for the time being, they can be stored in a more secure way, or they can be directly destroyed in a compliant way.

According to the value creation characteristics, the basic value links of the scientific data value chain (Figure 2) include four links of data generation, data acquisition, data storage and data analysis, with scientific research units as the main focus, which activate various factors of production through the circulation of data to provide assistance for scientific research and release the value superposition effect of the data; and the value service links include four links of data aggregation, open source data, data mining and security maintenance, with professional organizations as

the main focus, which further explore the potential of data through data recycling to discover new problems and opportunities and release the value multiplication effect of the data. The value service link includes data convergence, data open source, data mining and security maintenance, which is mainly provided by professional organizations. Through data recycling, the data potential can be further explored, new problems and opportunities can be found, and the value multiplier effect of data can be released. As an overall system, the operation of the scientific data value chain requires that scientific research units and professional organizations participate in the value creation process, each in its own way, and each link in the value chain is interlocked, and the overall capability of the system is reflected in the synergy between each link, including the breadth and depth of synergy. Problems in any part of the system will be reflected in the entire value chain, thus affecting the creation of data value in the entire system.

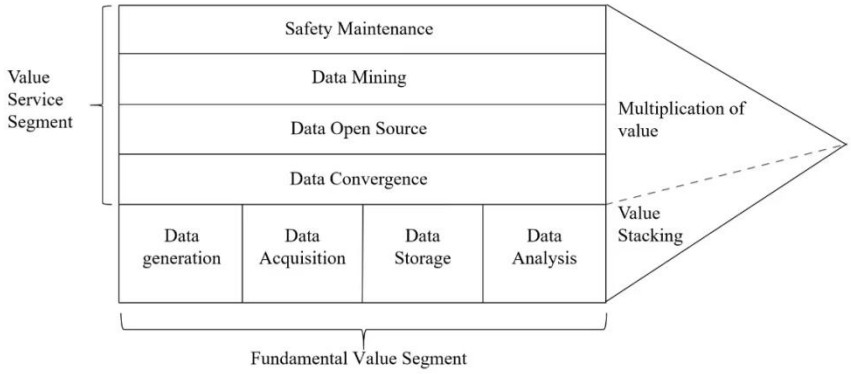

Fig. 2. Scientific data value chain

4 Circulation bottlenecks and solutions in China's scientific data value chain

The value contained in scientific data is an important source for a country to promote scientific and technological innovation. For a long time, countries have been building scientific data service platforms, striving to break down the data barriers between different scientific research units and realize the integration of the basic value link and the value service link in the scientific data value chain. The core role of scientific data

service platforms is to enhance the empowerment of data for scientific research and provide reliable technical guarantee for the basic value link in the scientific data value chain at the level of value service. At present, the more influential scientific data service platforms in the world include Scientific Data, which is organized by Nature Magazine, and re3data, which is supported by the German Research Foundation. Compared with developed countries, the construction of scientific data service platform in China started late, but the technical application and management system still need to be further improved.

4.1 Realistic bottlenecks in the flow of scientific data value chain in China

At present, China has built a number of specialized scientific data service platforms, such as the National Earth System Scientific Data Sharing Service Platform, the National Science and Technology Basic Condition Platform Portal Application System and the Science Data Bank (Science DB). However, the circulation and utilization of scientific data in the value chain in China still faces many practical bottlenecks, including the following four aspects.

(1) Allocation of scientific data elements. China is a vast country, and the economic level of development and technological base conditions vary between regions. The scientific research activities and achievements in the eastern region are obviously more than those in the central and western regions and the northeastern region, and the annual number of valid patents in the eastern region has increased from 2,178,900 to 10,179,200 during 2012-2021, an increase of 367.17%, which is obviously higher than that in the central and western regions and the northeastern region in terms of both number and increase (Fig. 3), which exacerbates the gap in the accumulation of scientific data between the regions. The gap in the reserve of professionals is closely related to the gap in the accumulation of scientific data, and the eastern region relies on the advantage of the reserve of professionals to seize new market opportunities through the excavation and analysis of data, open up breakthroughs in development, and quickly realize the transformation of the results of scientific theories into the results of economic practice, and establish new economic growth points. In addition, the circulation of scientific data elements depends on the development of infrastructure, due to the unbalanced development of infrastructure in different regions, resulting in inefficient circulation and utilization of scientific data elements among regions. In some regions, there is even the phenomenon of "data islands",

which prevents some high-quality or even critical scientific resources from realizing their value.

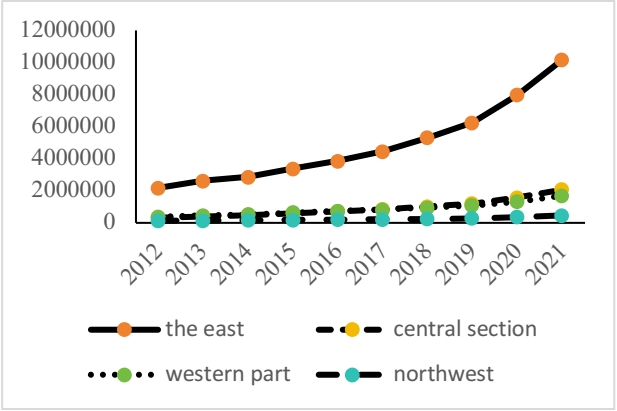

Fig. 3. Effective patents in different regions during 2012-2021

Source: China Science and Technology Statistical Yearbook.

(2) Scientific data standardization practices. Improvement in the level of data standardization helps to reduce errors in encoding and decoding between senders and receivers and promotes data exchange. China's current scientific data standards include data exchange, data storage, data publication, data citation, etc., and a series of industry standards have been introduced to supplement the national standards, but few of them are related to data analysis and data management[2] , which do not form a comprehensive coverage of the value chain of scientific data, and impede the circulation and utilization of scientific data. According to the characteristics of different disciplines and the needs of different users, China's enhancement of the articulation of data standards needs to take into account both the disciplinary attributes and the common and individual characteristics of scientific data services. In terms of specific details, the description of scientific data, content identification, classification standardization, platform association, software tools and other aspects have yet to be introduced as unified technical standards.

(3) Scientific data asset accounting. The understanding of data has long exceeded the scope of the database[15] , after the realization of scientific data assets, with the transaction attributes, the scope of application has greatly expanded[16] . However, the value of data is not only reflected in a single form of monetization, but also in the form of "non-monetary transactions" to promote economic and social development[17、

[18] , increasing the complexity of data asset accounting. It is due to the expansion of the scope of application of scientific data and changes in the form of transactions that scientific data asset accounting has become more complex, and the current statistical rules and accounting systems are not applicable to scientific data asset accounting, so China still does not have a reasonable accounting method to accurately and reasonably account for the benefits brought about by scientific data, which will reduce the ability of scientific research institutes and professional organizations to promote the active circulation and application of scientific data elements in the value chain. This will reduce the enthusiasm and initiative of scientific research units and professional organizations to promote the circulation and application of scientific data elements in the value chain.

(4) Scientific data privacy and security. Security is an issue that must be emphasized during the use of scientific data, and has a positive impact on the change of the value of scientific data[19] . However, there is no authoritative basis and implementation method for data property rights, and the data security technology and regulatory mechanism are opaque and high-risk[20] . Some organizations have limited ability to protect the privacy and security of scientific data, and are not strong enough to prevent data leakage, network attack, data tampering and other security risks that may be encountered during the circulation of scientific data, especially the lack of strong screening tools that make it difficult to detect some hidden viruses, and there are many network security loopholes and malicious backdoors in the management of scientific data, and compliance with the requirements for data acquisition, data storage, and data transmission. The compliance of data acquisition, data storage, data transmission and other work needs to be improved. Once a scientific data security incident occurs, it will lead to the loss of property, even the loss of state secrets and intellectual property rights, and China generally lacks effective remedial measures for major scientific data security incidents. Meanwhile, data use infringement and intellectual property disputes often accompany the circulation and utilization of scientific data in the value chain, which greatly affects the normal work of scientific research institutions.

4.2 Solutions to bottlenecks in the circulation of scientific data value chain in China

In view of the real bottlenecks faced by the circulation of scientific data value chain in China, the relevant departments can make efforts to solve the problem from the

following three aspects.

(1) Promoting resource sharing on scientific data service platforms and synergistic integration of basic value links and value service links. The value chain management of scientific data is aimed at the synergistic integration of the basic value link and the value service link, and with the power of the scientific data service platform, it promotes the circulation and utilization of scientific data between regions and institutions, so as to fully unleash the value superposition effect and value multiplication effect of data. As two important conditions for the formation of scientific data value, citation and utilization are directly related to the release of scientific data value. For the citation of scientific data, the platform can establish the correspondence between scientific data and academic literature, launch unified search tools, gather and share more database resources, and clearly record the data sources and the number of citations. With regard to the use of scientific data, the platform can apply new-generation information technologies, such as big data and blockchain, to trace the connection, circulation and utilization of scientific data, objectively assess the impact and efficiency of the use of the data, and safeguard the basic rights and interests of the data owners.

(2) Continuously develop and promote scientific data standards and related statistical systems. Focusing on the value chain of scientific research data, invite relevant organizations to participate in the development and revision of various data standards, especially the two links of data analysis and data management, which are seldom involved, so as to accelerate the comprehensive coverage of the value chain of scientific data. Drawing on the data standard system introduced by international organizations such as the International Organization for Standardization and the World Data System, and based on the characteristics of China's development and practical problems, we will establish unified reference standards in combination with the characteristics of disciplines, and build a diversified standards management mechanism, so that the scientific data value chain can be improved and the scientific data value chain can be enhanced and strengthened. Based on the characteristics of China's development and practical problems, we will establish unified citation standards in accordance with the characteristics of disciplines, build a diversified standard management mechanism, break through the standard barriers in the value chain of scientific data, and explore and improve the data-related statistical system.

(3) Graded and classified management of scientific data and improvement of governance mechanisms. According to the attributes of scientific data and the

corresponding security risks, implement a hierarchical classification management method based on the active construction of a hierarchical classification system, and adopt protection technologies corresponding to the encryption level for scientific data of different security levels. Construct a systematic and structured security system based on the links of the value chain of scientific data and its characteristics, formulate solutions to security risks in advance, reduce losses after security accidents, and improve the governance mechanism. On the basis of the Data Security Law of the People's Republic of China, the Network Security Law of the People's Republic of China, the Personal Information Protection Law of the People's Republic of China and other existing laws and regulations, we have improved the implementation rules of data rights and data governance, and strengthened the supervision and control of violations and infringements of scientific data.

5 Conclusion

Nowadays, data-driven research methods have become the fourth paradigm of scientific research after Empirical, Theoretical, and Computational modeling. As early as the beginning of the 20th century, the United States, the European Union and other developed countries launched policies to strengthen the management and service of scientific data at the national level, and in recent years, new policies have been introduced to promote the effective circulation and recycling of scientific data. Sound management and service of the value chain of scientific data is of great significance to China's compliance with the new trend of the digital economy era and the enhancement of innovation momentum. Unlike the use of traditional factors of production such as labor and capital, which is subject to the law of diminishing margins, the value of data factors shows a trend of increasing margins with the increase in the number of times it is used, and releases the value superposition effect and value multiplication effect in the process of circulation and recycling. In essence, the data value chain is a full-process closed-loop gain system in which data and other production factors interact with each other to jointly create new economic value. According to the life cycle theory of data and the characteristics of value creation, the scientific data value chain can be divided into two parts: the basic value link and the value service link. As a system, the management of the scientific data value chain requires scientific research units and professional organizations to play their respective advantages, perform their respective roles and participate together. At

present, the circulation and utilization of scientific data in the value chain in China is facing four practical bottlenecks in the areas of factor allocation, standard practice, privacy security and asset accounting. In this regard, China can make efforts to solve the problem from three aspects, namely, promoting the resource sharing of scientific data service platforms, continuously developing and promoting scientific data standards and related statistical systems, and managing scientific data in a hierarchical manner and improving the governance mechanism.

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