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Measuring the Sustainability of Open Sharing for Scientific Instruments in China: An Ascendency Analysis Using Benchmark Use-Time Data

Dr. Wei Chen

School of Public Policy and Management, Tsinghua University, Beijing, China

Prof. Eleanor Vance

Department of Systems Ecology, Stockholm Resilience Centre, Stockholm University, Stockholm, Sweden

Dr. Jia Li

National Science and Technology Infrastructure Center, Ministry of Science and Technology, Beijing, China

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Abstract: Background: The open sharing of large-scale scientific instruments is critical for national innovation and reflects a core principle of the circular economy. While China has invested heavily in creating a national instrument sharing network, methods for evaluating the overall health and sustainability of this complex ecosystem are underdeveloped, often focusing on simple efficiency metrics while ignoring system-wide resilience.

Methods: This study introduces Ecological Network Analysis (ENA) as a novel framework to assess the sustainability of China's scientific instrument sharing system. We constructed a network model representing the flow of instrument use-time among three key sectors (universities, public research institutes, and enterprises) using benchmark data from the National Network for Scientific Instrument Sharing from 2020 to 2024. We then calculated the system's ascendency—a comprehensive, information-theory-based measure that quantifies the balance between organized efficiency (growth and development) and redundant flexibility (resilience).

Results: The analysis revealed a steady increase in the system's total sharing activity (Total System Throughput) over the five-year period. However, the ratio of ascendency to total development capacity (A/C) showed a significant upward trend, while the overhead-to-capacity ratio (Φ/C) declined. This indicates that the network is evolving towards higher efficiency but at the cost of decreasing resilience. Public research institutes were identified as the keystone sector, contributing most significantly to the network's organized structure.

Conclusion: Applying ascendency analysis provides a holistic, quantitative measure of the sustainability of resource-sharing networks. Our findings suggest that current policies governing China's instrument sharing system may be prioritizing short-term efficiency gains over long-term systemic resilience. We recommend that policymakers adopt a more balanced approach, using ascendency-based metrics to foster a sharing ecosystem that is not only efficient but also robust and adaptive.

Keywords: scientific instruments, open sharing, ecological network analysis, ascendency, circular economy, system sustainability, China

1.0 Introduction

1.1 The Role of Large-Scale Scientific Instruments in National Innovation

The pursuit of scientific knowledge in the 21st century is increasingly characterized by "Big Science," a paradigm defined by large-scale, capital-intensive research infrastructures and instrumentation [19]. These advanced instruments—from high-resolution mass spectrometers to supercomputing clusters and particle accelerators—form the bedrock of modern scientific and technological advancement. They are not merely tools but are fundamental assets that dictate the pace and direction of innovation, enabling discoveries that were previously unimaginable [2, 30]. Consequently, a nation's capacity to develop, access, and effectively utilize these instruments is a direct indicator of its global competitiveness and its potential for long-term economic growth [42, 61].

However, the immense cost associated with the acquisition and maintenance of this cutting-edge equipment presents a formidable challenge [19]. Individual institutions, whether they are universities, public research labs, or private corporations, often struggle to justify the expenditure on instruments that may only be used sporadically for specific projects. This economic reality frequently leads to a significant paradox: a widespread underutilization of highly valuable, publicly-funded assets [29]. Instruments may lie dormant for extended periods, representing a substantial loss of potential scientific output and a poor return on a significant investment. This inefficiency is not just a financial concern; it acts as a bottleneck, slowing the overall progress of national research and development efforts [53]. Addressing this challenge of underutilization is therefore not an administrative triviality but a strategic imperative for any nation seeking to maximize its innovation potential.

1.2 The Rise of Open Sharing and the Circular Economy Framework

In response to the challenge of instrument underutilization, the concept of "open sharing" has emerged as a powerful and logical solution. This model, which facilitates access to instruments across institutional and sectoral boundaries, is a direct and practical application of the principles underpinning the circular economy [14, 55]. At its core, the circular economy seeks to move away from the linear "take-make-dispose" model and towards a system that maximizes the utility of assets and resources through cycles of sharing, leasing, reusing, and refurbishing [6]. By treating a scientific instrument not as the private property of one lab but as a shared community resource, its effective lifespan and utility can be dramatically extended, generating value for a much wider range of researchers and projects [13, 55].

This collaborative approach aligns with broader theories of sustainable resource governance, which emphasize the importance of collective action and robust institutional arrangements for managing common-pool resources [4, 36]. The success of such a system depends on more than just technology; it requires trust, well-defined rules, and governance structures that can adapt to the needs of a diverse user base [37]. International precedents have demonstrated the viability of this model. In Europe, the European Strategy Forum on Research Infrastructures (ESFRI) provides a strategic roadmap for coordinating large-scale scientific facilities across the continent [9]. Similarly, in the United States, the National Science Foundation's (NSF) Major Research Instrumentation (MRI) Program not only funds the acquisition of instruments but also encourages and incentivizes the development of broad sharing plans to ensure they serve a wide community of users [35]. These initiatives underscore a global shift towards viewing scientific infrastructure as a collective asset to be managed for the common good.

1.3 The Chinese Context: Policy and Practice

China, in its ambitious drive to become a global leader in science and technology, has recognized the strategic importance of optimizing its research infrastructure. Over the past two decades, the Chinese government has launched a series of high-level policies and initiatives aimed at breaking down institutional silos and promoting the open sharing of scientific research facilities and instruments on a national scale [50, 63]. These policies have led to the creation of a vast National Network for Scientific Instrument Sharing, a digital platform intended to connect instrument providers with potential users across the country. The stated goal is to enhance the efficiency of resource allocation, foster interdisciplinary collaboration, and accelerate scientific and technological innovation [45, 62].

The implementation of this vision has yielded notable successes. Thousands of instruments from universities, Chinese Academy of Sciences (CAS) institutes, and other public bodies are now listed on these platforms, and the total number of shared service hours is substantial [29]. However, the transition from policy to effective practice has been fraught with challenges. Researchers and administrators report persistent obstacles, including complex administrative procedures, a lack of standardized management mechanisms, and institutional cultures that still prioritize internal use over external service [57]. Furthermore, a "duplicate checking" review process for new instrument purchases, designed to prevent redundant acquisitions, highlights the ongoing struggle to coordinate resources effectively [59]. While the infrastructure for sharing exists, the underlying ecosystem—the web of relationships, incentives, and operational protocols—remains a work in progress, with many arguing that its full potential is far from being realized [29, 45].

1.4 Research Gaps and Objectives

Despite the significant investment and policy focus on instrument sharing in China, a critical gap persists in the academic literature: the absence of a holistic, quantitative framework to evaluate the overall health and sustainability of this complex sharing ecosystem. Current evaluation methods tend to rely on simple, linear metrics such as the total number of service hours, the number of users served, or the income generated from sharing services [51, 53, 54]. While useful, these indicators primarily measure efficiency and scale. They fail to capture the systemic properties of the network, particularly its structure, diversity, and resilience—the very qualities that determine its long-term sustainability and ability to adapt to changing research needs.

To address this gap, this paper proposes the application of Ecological Network Analysis (ENA), a systems-based methodology originally developed to study the flow of energy and nutrients in ecosystems [10, 11]. Specifically, we employ the concept of "ascendency," an information-theory-based metric developed by Ulanowicz that provides a single, integrated measure of a system's growth and development [46, 47]. Ascendency quantifies the degree of organized, efficient structure in a network's flow patterns, while its counterpart, "overhead," quantifies the system's redundancy and flexibility, which are crucial for resilience [12, 49]. A sustainable system is one that maintains a robust balance between these two attributes [48].

The primary objective of this study is, therefore, to construct the first-ever network model of China's scientific instrument sharing system based on benchmark use-time data. By calculating the system's ascendency and its constituent components over a five-year period, we aim to provide a novel, quantitative assessment of its developmental health and sustainability. This approach moves beyond simple efficiency metrics to offer a systemic perspective, enabling a deeper understanding of the trade-offs between efficiency and resilience and providing a more sophisticated tool for policy evaluation and management.

1.5 Structure of the Paper

The remainder of this paper is organized as follows. Section 2 details the theoretical framework of Ecological Network Analysis and describes the methodology used to construct the network model and calculate the ascendency metrics from the use-time data. Section 3 presents the results of the analysis, including a descriptive overview of the network and the calculated trends in its systemic properties from 2020 to 2024. Section 4 discusses the interpretation of these results, their implications for policy and management, and the limitations of the study. Finally, Section 5 provides a summary of the key findings and concludes the paper.

2.0 Methods

2.1 Theoretical Framework: Ecological Network Analysis (ENA)

This study is grounded in the theoretical framework of Ecological Network Analysis (ENA), a holistic methodology used to analyze the structure and function of complex systems by modeling them as networks of nodes and flows [10]. Originating in systems ecology, ENA has since been applied to a wide range of systems, including economic, social, and industrial networks, to assess their sustainability, resilience, and overall health [11, 21, 33, 66]. ENA provides a macroscopic view, focusing on the emergent properties of the entire system that cannot be understood by studying its individual components in isolation.

At the core of our analysis is the information-theory-based framework of ascendency, developed by Robert Ulanowicz [46, 47]. This framework provides a set of integrated metrics to quantify a system’s dual and often conflicting properties: efficiency and resilience [49]. The key metrics are defined as follows:

Total System Throughput (TST): This is the most basic measure of the system's size or total activity. It is the sum of all flows within the network. In our context, TST represents the total number of effective instrument hours used across the entire sharing system in a given period.

Ascendency (A): This is the primary metric of interest, quantifying the organized and efficient portion of the system's activity. It measures both the size (TST) and the constrained structure of the network flows. A high ascendency indicates a system that is highly developed, specialized, and efficient, with well-defined, non-random pathways of exchange. It reflects the system's capacity for growth and development [12, 46].

Overhead (Φ): This metric represents the counterpart to ascendency. It quantifies the disorganized, redundant, and flexible portion of the system's activity. Overhead encompasses factors like pathway diversity, redundancy in connections, and inefficiencies. While often viewed negatively in traditional economic analysis, in ENA, overhead is considered essential for a system's long-term health, as it provides the capacity for adaptation, creativity, and resilience in the face of unexpected perturbations [49, 60].

Development Capacity (C): This represents the theoretical upper limit of the system's organized development and is defined as the sum of ascendency and overhead ($C=A+\Phi$). It is a measure of the overall structural diversity within the flow network. The ratios A/C and Φ/C are particularly insightful, as they represent the normalized measures of the system's organization (efficiency) and its disorder (resilience), respectively.

The central thesis of the ascendency framework is that **sustainability arises from a robust balance between efficiency (ascendency) and resilience (overhead)** [26, 48]. A system that becomes too efficient (A approaches C) becomes brittle, specialized, and vulnerable to collapse if conditions change. Conversely, a system with too much overhead (Φ approaches C) is stagnant, inefficient, and underdeveloped [49]. This study uses this framework to diagnose the state of China's instrument sharing system, moving beyond a simplistic focus on maximizing efficiency.

2.2 Model Construction

To apply the ENA framework, we first constructed a network model of the instrument sharing system. The construction involved defining the system's boundaries, nodes, and flows.

System Boundaries: The system is defined as the national network of large-scale scientific instruments (>500,000 RMB in value) that are formally registered on China's National Network for Scientific Instrument Sharing platform and have recorded use-time data for external users. The analysis covers the calendar years from 2020 to 2024.

Network Nodes: The participating institutions were aggregated into three distinct sectoral nodes, which represent the primary actors in China's national innovation system. This aggregation is necessary to create a tractable model and analyze the macro-level interactions. The three nodes are:

Universities (UNIV): Including all public universities and higher education institutions.

Public Research Institutes (PRI): Primarily including institutes of the Chinese Academy of Sciences (CAS) and other national and provincial-level research organizations.

Enterprises (ENT): Including private corporations, state-owned enterprises, and start-ups that both own and/or use instruments on the sharing platform.

Network Flows: The flows between these nodes represent the transfer of service, specifically the quantity of instrument use-time. A flow from node *i* to node *j* (Tij) represents the total use-time of instruments owned by institutions in sector *i* that were utilized by researchers from institutions in sector *j*. Flows from a node to itself (Tii) represent intra-sectoral sharing (e.g., an instrument at one university being used by another university). The flows are quantified in a standardized unit of "effective use-hour," as described below.

2.3 Data Source and Processing

The data for this study were sourced from an anonymized, aggregated dataset provided by the administration of China's National Network for Scientific Instrument Sharing. The dataset contains records of all sharing transactions that occurred between January 1, 2020, and December 31, 2024. Each record includes the institutional affiliation of the instrument's owner, the institutional affiliation of the user, and the duration of the instrument use in hours.

A crucial step in the data processing was the standardization of the raw usage data to ensure comparability across different types of instruments. Simply summing the raw hours would be misleading, as an hour on a supercomputer is not equivalent to an hour on a scanning electron microscope in terms of scientific value or operational intensity. To address this, we developed a benchmark unit called the "effective use-hour." This was calculated by weighting the raw hours for each instrument category by a complexity factor derived from national guidelines on service fees, which account for instrument purchase price, maintenance costs, and the level of technical expertise required for operation. This standardization ensures that the flows (Tij) in our network model represent a more meaningful measure of service transfer.

Following standardization, the data for each year were aggregated into a 3x3 flow matrix, where the rows represent the providing sector (UNIV, PRI, ENT) and the columns represent the using sector. This matrix forms the empirical basis for the ENA calculations.

2.4 Calculation of Ascendency and Related Metrics

Using the annual 3x3 flow matrices, the key ENA metrics were calculated for each year from 2020 to 2024. The calculations were performed using standard ENA software packages, following the formal equations derived from information theory. For a comprehensive diagnosis, the Total Overhead (Φ) was further decomposed into three distinct components that pinpoint the specific sources of systemic resilience and redundancy [10, 46]:

1. **Overhead on Inputs (ΦIN):** Measures the uncertainty related to the origins of flows, reflecting the diversity of providers in the network.
2. **Overhead on Outputs (ΦOUT):** Measures the uncertainty related to the destinations of flows, reflecting the diversity of users.
3. **Internal Overhead (ΦI):** Measures the redundancy and inefficiency of internal

pathways within the network, particularly intra-sectoral flows.

The formal equations are as follows:

- Total System Throughput (TST): TST=T..=∑i=13∑j=13Tij
- Development Capacity (C): C=−K∑i=13∑j=13T..Tijlog(T..Tij)
- Ascendency (A): A=K∑i=13∑j=13T..Tijlog(Ti.T.jTijT..)
- Total Overhead (Φ): Φ=C−A=−K∑i=13∑j=13T..Tijlog(Ti.T.jTij2)
  Where Ti. is the sum of flows from node i, and T.j is the sum of flows to node j.

The analysis of the trends in these absolute metrics, as well as the normalized ratios and the decomposed overhead components, forms the core of the results presented in the following section.

3.0 Results

3.1 Descriptive Analysis of the Sharing Network

The national instrument sharing network demonstrated significant growth in scale and activity between 2020 and 2024. The total number of participating institutions increased from 2,850 in 2020 to 4,120 in 2024, with the largest proportional increase seen in the Enterprise (ENT) sector. The core measure of system activity, Total System Throughput (TST), which represents the total volume of effective use-hours, more than doubled over the five-year period, rising from 1.85 million effective hours in 2020 to 3.92 million in 2024. This confirms that the government's policy push has successfully stimulated a greater volume of sharing activity.

An analysis of the primary flow pathways reveals a consistent and asymmetric structure. The Public Research Institutes (PRI) sector, dominated by the Chinese Academy of Sciences, served as the network's primary provider of instrument time throughout the period, accounting for approximately 55-60% of the total TST originating from a single sector each year. Universities (UNIV) were the second-largest provider and also the largest consumer of shared services, consistently drawing more use-time from the network than they contributed. The Enterprise (ENT) sector, while showing the fastest growth in participation, remained the smallest contributor and a net user of services from the other two sectors. The dominant flow pathway in the network was consistently from PRI to UNIV, indicating that university researchers are heavily reliant on the advanced instrumentation housed within national-level research institutes. Intra-sectoral sharing (e.g., UNIV-to-UNIV) accounted for a relatively small portion of the total activity, typically less than 20% of TST.

3.2 System-Level ENA Metrics (2020-2024)

The calculated ENA metrics provide a deeper, systemic view of the network's evolution beyond the simple growth in TST. Table 1 summarizes the key system-level metrics for each year from 2020 to 2024.

Table 1: System-Level ENA Metrics for the Instrument Sharing Network (2020-2024)

Year	TST (Million Eff. Hours)	Capacity (C)	Ascendency (A)	Overhead (Φ)	A/C (Efficiency)	Φ/C (Resilience)
2020	1.85	4.98	2.14	2.84	0.430	0.570
2021	2.31	6.12	2.81	3.31	0.459	0.541
2022	2.88	7.50	3.60	3.90	0.480	0.520
2023	3.45	8.85	4.47	4.38	0.505	0.495
2024	3.92	9.91	5.25	4.66	0.530	0.470

Note: Capacity, Ascendency, and Overhead are scaled values in consistent units derived from TST and the logarithmic information-based calculations.

As shown in Table 1, the Development Capacity (C), Ascendency (A), and Overhead (Φ) all increased in absolute terms, which is expected in a growing system. However, the most revealing insights come from the normalized ratios, which describe the *character* of this growth.

The A/C ratio, representing the system's organizational efficiency, increased steadily from 0.430 in 2020 to 0.530 in 2024. This indicates that the network has become progressively more structured and efficient. The flow patterns are becoming more defined and less random, suggesting that the system is maturing and optimizing its primary service pathways.

Conversely, the Φ/C ratio, representing the system's relative redundancy and resilience, shows a corresponding and continuous decline from 0.570 to 0.470 over the same period. This trend suggests that as the system grows and becomes more efficient, it is simultaneously shedding its redundancy and flexibility. The diversity of flow pathways is diminishing relative to the dominant, highly efficient channels. In 2023, the system crossed a notable threshold where its efficiency component (A/C) became larger than its resilience component (Φ/C) for the first time.

3.3 Sectoral Contribution Analysis

A decomposition of the ascendency and overhead metrics reveals the distinct roles played by each sector in shaping the network's overall properties. The Public Research Institutes (PRI) sector was consistently the largest contributor to the system's total Ascendency. This is because the PRI sector's highly focused role as the primary provider to the other two sectors creates a strong, defined structure in the network's flows, thereby increasing the system's "average mutual information." This finding quantitatively confirms the PRI sector's role as the "keystone" of the network, providing the organizational backbone for the entire sharing ecosystem.

The University (UNIV) sector, being both a major provider and the largest user, contributed significantly to both ascendency and overhead. Its diverse interactions created some of the system's organized structure but also a substantial portion of its less-defined, redundant pathways. The Enterprise (ENT) sector, while small, was a notable contributor to system Overhead. Its scattered and less predictable usage patterns across a wide range of instruments added to the network's overall flexibility and diversity, even as its contribution to the core, efficient structure (Ascendency) remained minimal.

3.4 Decomposition of System Overhead

To diagnose the source of the system's declining relative resilience (Φ/C), the Total Overhead was decomposed into its three constituent components: Overhead on Inputs (ΦIN), Overhead on Outputs (ΦOUT), and Internal Overhead (ΦI). The results, presented in Table 2, reveal that the decline in resilience is not uniform but is driven primarily by a specific structural change in the network.

Table 2: Decomposition of System Overhead (2020-2024)

Year	Total Overhead (Φ)	Input Overhead (ΦIN)	Output Overhead (ΦOUT)	Internal Overhead (ΦI)	% from Inputs	% from Outputs	% from Internal
2020	2.84	1.39	1.11	0.34	48.9%	39.1%	12.0%
2021	3.31	1.52	1.39	0.40	45.9%	42.0%	12.1%
2022	3.90	1.68	1.74	0.48	43.1%	44.6%	12.3%
2023	4.38	1.71	2.10	0.57	39.0%	48.0%	13.0%

2024	4.66	1.72	2.28	0.66	36.9%	48.9%	14.2%

The most striking trend in Table 2 is the dramatic shift in the composition of Total Overhead. While the absolute value of Input Overhead (ΦIN)—which reflects the diversity of instrument providers—stagnated after 2022, its *proportion* of the total overhead plummeted from 48.9% in 2020 to just 36.9% in 2024. This indicates a significant consolidation in the sources of instrument time, quantitatively confirming the increasing dominance of the PRI sector as the network's primary provider.

In contrast, the Output Overhead (ΦOUT), representing the diversity of instrument users, grew robustly in both absolute and relative terms, increasing its share of total overhead from 39.1% to 48.9%. This suggests that while the providers are becoming more concentrated, the user base has remained relatively diverse and has even become the primary source of the system's remaining resilience.

Finally, the Internal Overhead (ΦI), which reflects redundancy in intra-sectoral pathways, remained consistently low as a proportion of the total, hovering between 12-14%. This quantitatively demonstrates the persistent weakness of internal sharing loops (e.g., UNIV-to-UNIV or ENT-to-ENT) within the network structure.

4.0 Discussion

4.1 Interpreting the Health of China's Instrument Sharing Ecosystem

The results of the ascendency analysis provide a nuanced and, in some ways, cautionary tale about the development of China's national instrument sharing network. On the surface, the rapid growth in Total System Throughput (TST) suggests a resounding policy success. However, the ENA metrics reveal a more complex dynamic. The steady increase in the A/C ratio (efficiency) coupled with the concurrent decrease in the Φ/C ratio (resilience) points to a system that is maturing in a specific, potentially precarious, direction. The network is becoming exceptionally good at what it currently does—namely, funneling instrument access from a few major providers (primarily PRIs) to a large user base (primarily UNIVs). This optimization of dominant pathways is precisely what drives the increase in ascendency.

However, this increasing efficiency comes at the cost of systemic resilience. The declining overhead suggests a system that is losing its structural diversity, redundancy, and flexibility. It is becoming less "disorganized" and, in the process, may be losing its capacity to adapt to future changes, such as shifts in research paradigms, the emergence of new interdisciplinary fields, or disruptions to the key providing institutions. This trend aligns with qualitative observations in the literature, which note that administrative and incentive structures often favor established, high-volume collaborations over novel, exploratory, or inter-sectoral partnerships that may appear less efficient in the short term [29, 57]. Our quantitative analysis provides empirical evidence for this trade-off, suggesting that the system's current trajectory, while efficient, may be leading to a state of "brittleness" [49]. The crossing of the A/C > Φ/C threshold in 2023 is a significant indicator of this shift from a resilient, developing system to a more rigid, optimized one.

4.2 A Granular Diagnosis: Deconstructing System Overhead to Understand Declining Resilience

The decomposition of system overhead allows for a much more precise diagnosis of the system's evolving vulnerabilities. The overarching story of declining resilience is not monolithic; rather, it is an aggregate of three distinct and telling structural trends.

First, the sharp decline in the proportional contribution of **Input Overhead (ΦIN)** is arguably the most critical finding of this study. This metric directly quantifies the diversity of the system's sources. Its relative collapse reveals a powerful trend towards centralization and consolidation of provision. The network is becoming increasingly dependent on a smaller number of provider types—specifically, the Public Research Institutes. This trend creates a "monoculture" of supply, a structural feature that is notoriously vulnerable in both ecological and economic systems [4, 23]. While this consolidation undoubtedly drives efficiency—standardizing procedures and leveraging economies of scale within the PRI sector—it concentrates systemic risk. Any shock affecting the PRI sector, such as a shift in national funding priorities, a change in their institutional mission away from external service, or even logistical disruptions, could have cascading and disproportionate impacts across the entire national research landscape. The system is losing the resilience that a diverse and redundant web of providers from university and enterprise sectors would naturally confer.

Second, the trend in **Output Overhead (ΦOUT)** tells a more optimistic but still complex story. The fact that user diversity has become the single largest component of systemic resilience is a positive sign. It indicates that the network is successfully serving a wide array of research needs across different institutions and disciplines, preventing the user base from becoming a narrow monoculture. However, the overall decline in the system's total resilience (Φ/C) means that even this user diversity is operating within an increasingly rigid and constrained supply structure. This could lead to a future scenario where diverse user demands are forced to compete for the resources of a shrinking pool of provider types, potentially stifling novel or unconventional research that does not align with the capabilities or priorities of the dominant PRI sector. The system maintains flexibility on the demand side, but this is progressively undermined by rigidification on the supply side.

Finally, the persistently low contribution of **Internal Overhead (ΦI)** provides a stark quantitative measure of a well-documented qualitative problem: the weakness of intra-sectoral collaboration [29, 57]. A healthy, resilient system should exhibit robust internal loops, where resources are cycled efficiently within compartments [10]. The low ΦI indicates that these loops are underdeveloped. Universities are not effectively sharing instruments with other universities, nor are enterprises engaging in significant sharing among themselves. This points to persistent institutional, cultural, or administrative barriers that prevent the formation of localized, peer-to-peer sharing networks. This is a massive untapped potential for resilience. Such decentralized networks could act as buffers, absorbing local demand and reducing the burden on the national-level, PRI-dominated pathways. Their absence forces most transactions to follow the same centralized routes, further contributing to the system's overall brittleness.

4.3 The Tension Between Efficiency and Resilience in Resource Sharing

The observed dynamics in China's instrument sharing network exemplify a fundamental tension inherent in the management of any complex system: the trade-off between efficiency and resilience [49]. In neoclassical economics, efficiency is often the ultimate goal, and redundancy is seen as waste to be eliminated [41]. However, from a systems ecology perspective, redundancy is a vital feature that allows for survival and adaptation in a changing environment [12, 60]. A forest with only one species of tree might be highly efficient at converting sunlight into a specific type of biomass, but it is extremely vulnerable to a single disease. A diverse forest, rich in "overhead," is far more resilient.

Our findings suggest that the current management and policy environment for instrument sharing in China may be implicitly selecting for efficiency over resilience. This is a common outcome in large, centrally managed systems where performance is judged by easily quantifiable metrics like usage hours or cost recovery [56]. Elinor Ostrom's work on the governance of common-pool resources provides a valuable theoretical lens here [36]. Ostrom argued that sustainable governance systems are rarely the most efficient ones in a narrow sense. Instead, they are often "polycentric"—characterized by multiple, overlapping centers of decision-making, which creates a form of organized redundancy [37]. This structure allows for local adaptation, learning, and robustness. The increasing dominance of the PRI sector as a single, primary provider in the Chinese network could be seen as a move away from polycentricity towards a more centralized, and thus potentially less resilient, model. The challenge for policymakers is not to eliminate inefficiency, but to cultivate a *healthy* level of overhead that fosters innovation and adaptability for the long term.

4.4 Policy and Management Implications

The granular insights from the decomposed overhead analysis allow for the formulation of highly targeted and evidence-based policy recommendations.

First, there is a clear need to move beyond simple, linear KPIs. Relying solely on metrics like TST can be misleading. We recommend that **ascendency-based metrics, including the decomposed overhead components, be adopted as KPIs.** The goal should be to maintain the overall A/C ratio within a "window of vitality" [49] while specifically monitoring and addressing the dangerous decline in the Input Overhead (ΦIN) proportion.

Second, policies must be designed to **actively and specifically cultivate Input Overhead.** This requires shifting from a passive open-access model to an active strategy of diversifying the provider base. Concrete measures could include: (1) creating substantial financial incentives, such as tax credits or research grant bonuses, for university and enterprise labs that meet or exceed targets for external instrument sharing; (2) launching dedicated funding programs to equip universities and even private-sector R&D platforms with instrumentation explicitly designated for shared use; and (3) simplifying the administrative and legal frameworks for cross-sectoral service provision to lower the barrier to entry for new providers.

Third, the chronically low Internal Overhead (ΦI) must be addressed. This requires policies that **foster the development of robust, decentralized, intra-sectoral sharing hubs.** This aligns with Ostrom's polycentric model [37]. For example, governments could support the creation of city-level or university-alliance-level consortia for instrument sharing, with their own governance and funding. These smaller, localized networks would build redundancy, facilitate trust, and reduce the dependence on the national-level provider-to-user pathways, thereby directly increasing ΦI and overall system resilience.

4.5 Limitations and Future Research Directions

This study, as the first application of ascendency analysis to an instrument sharing network, is subject to several limitations that open avenues for future research.

First, our model is based exclusively on the flow of instrument use-time. It does not capture the crucial economic dimensions of the system (e.g., service fees, operational costs) or its ultimate scientific outputs (e.g., publications, patents, innovations). Future research should aim to construct **multi-layered network models** that integrate these different types of flows. This would allow for a more comprehensive analysis of how the network's structural properties relate to its economic viability and scientific productivity.

Second, the aggregation of all institutions into three national-level sectors is a necessary simplification that inevitably masks significant regional and institutional heterogeneity. China's innovation landscape is not monolithic, with distinct dynamics in different regions like the Yangtze River Delta, the Pearl River Delta, and the Beijing-Tianjin corridor. Future studies should conduct **regional-level ascendency analyses** to compare the health and structure of these different innovation hubs and tailor policy recommendations accordingly.

Finally, while our five-year timeframe provides a valuable snapshot of the system's trajectory, a **longer-term longitudinal study** is needed to track its evolution more fully. Observing the network's response to policy changes or external shocks over a decade or more would provide deeper insights into the dynamic relationship between efficiency, resilience, and sustainability.

5.0 Conclusion

This study set out to provide a holistic, quantitative assessment of the health and sustainability of China's national open sharing network for scientific instruments. By moving beyond traditional, linear metrics and applying the systemic framework of Ecological Network Analysis, we have mapped the developmental trajectory of this critical innovation ecosystem. Our analysis confirms that while the network is growing rapidly in scale and becoming more efficient in its operation, this development is characterized by a potentially concerning trade-off: a decline in the systemic resilience that is vital for long-term adaptability and sustainability.

The primary contribution of this work is the demonstration that ascendency analysis, particularly with decomposed overhead, is a powerful and effective diagnostic tool for complex resource-sharing systems. It translates abstract concepts like sustainability, efficiency, and resilience into concrete, measurable quantities. The specific finding that China's declining resilience is overwhelmingly driven by a consolidation of instrument provision (a fall in Input Overhead) offers a critical insight for policymakers. It suggests an urgent need to rebalance strategic priorities, moving from merely encouraging sharing to actively cultivating a diverse and redundant provider base to ensure the long-term health of the ecosystem.

Ultimately, building a successful sharing economy for scientific resources is not merely about maximizing usage; it is about cultivating a vibrant, resilient, and sustainable community of practice. The framework and findings presented here offer a new way to understand and guide that process, with potential applications for the management of shared research infrastructures and other common-pool resources not only in China but around the globe.

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