A Study of the Governance of Knowledge Sharing in Open-Source Communities

Abstract

Purpose: Open-source communities are platforms that promote knowledge sharing. The mitigation of open-source risks is crucial to these communities. Therefore, this article explores the governance mechanisms of knowledge sharing in open-source communities.

Design/methodology/approach: To answer the core research question – "What are the governance mechanisms of knowledge sharing in open-source communities?" – we conducted an in-depth case study analysis of two open-source communities based in China.

Findings: Two types of open-source communities were found: technology-driven communities and enterprise ecosystem-oriented communities. Hence, their governance mechanisms differed. For the former type, it was important to integrate social and commercial value to encourage knowledge exchange and enhance business scenarios through community-user experience. For the latter type, mutual collaboration and knowledge sharing could be fostered through differentiated layouts and the distributed collaboration of developers around data-driven innovation scenarios. This required the integration of individual and ecosystem value through value exchange.

Originality/value: This study advances our understanding of the coordinated development between founding firms and digital technology-based open-source communities. The findings offer important guidance to business practitioners seeking to manage knowledge-sharing activities during digital transformations.

Keywords: *knowledge sharing, open source, open-source community, community governance*

1. Introduction

In the digital era, the principle of open source has provided significant technical support to science and technology development, and it has advanced emerging fields such as big data, artificial intelligence (AI), the internet of things (IoT) and cloud computing (Tamburri *et al*., 2019). Open source enables knowledge sharing and collaboration (Iskoujina and Roberts, 2015; Torres and Fernandez, 2014); it also simplifies project implementation and mitigates the risk of failure (Butler *et al*., 2004). According to the *2023 China Open-Source Development Blue Book*, the number of open-source developers in China has surpassed eight million, ranking second globally. China also ranks second in annual additions, with numerous large homegrown enterprises, such as Huawei, emerging as global leaders in the field of open-source communities (OSCs).

OSCs are a competitive strategy adopted by many enterprises, and they are centred around open-source projects. These communities involve multiple innovation actors, including contributors, users, operators and service providers. They rely on infrastructure such as code-hosting platforms to achieve collaboration and value co-creation (Garrett *et al.*, 2017; Kilamo *et al.*, 2012;). OSCs can bring economic benefits to enterprises by reducing R&D costs and expanding business models (Germonprez *et al*., 2017); they can also produce social benefits, such as market legitimacy and peer reputation (Shaikh and Henfridsson, 2017). Technical benefits can be achieved by promoting technical standards and accelerating the R&D process (Manikas, 2016). However, OSCs also face risks related to security, technical operation and maintenance, and intellectual property (IP) (August *et al*., 2021).

In OSCs, the similarity among participants facilitates knowledge sharing and allows even competitors to use the relevant knowledge without incurring investment costs (Estrada *et al*., 2016). This can undermine the innovation capabilities of enterprises, especially when unshared core knowledge is disclosed. Furthermore, partners may breach contracts during the sharing process, leading to trust violations (Guo *et al*., 2020). Therefore, effective governance mechanisms are needed for OSCs to manage risks while promoting knowledge exchange.

Currently, there are two main governance mechanisms in OSCs: self-regulation and government supervision. The former primarily emphasises internal governance, with a focus on the formation and distribution of power and the protection of shared knowledge (O'Mahony and Ferraro, 2007). This approach encourages participants to actively share knowledge by satisfying their external and internal motivations, such as career development, reputation building and the improvement of personal knowledge, skills and abilities (Roberts *et al*., 2006). In contrast, government supervision emphasises regulations and incentives in the form of clear standards, documentation norms and management rules to guide participant behaviour in the communities (Tullio and Staples, 2013). In particular, government subsidies motivate enterprises to participate in OSCs, increase participants' risk tolerance in knowledge sharing, promote knowledge-sharing behaviours and supplement R&D resources (Jian and Wang, 2019).

Although there are studies of knowledge sharing (Chen and Zhou, 2022) and governance (O'Mahony and Ferraro, 2007), the factors influencing knowledge sharing in OSCs remain unclear. Also, little is known about the differences in knowledge-sharing governance mechanisms among various types of OSCs. Therefore, we ask the following question: What are the governance mechanisms of knowledge sharing in OSCs?

Based on the in-depth study of two cases, this article analyses the collaborative behaviours of OSC participants and identifies the factors that influence such behaviours. The findings show the presence of effective governance mechanisms in various OSC scenarios, and they contribute to our understanding of knowledge-sharing activities in the novel form of OSCs, which is still underexplored in the literature. Practically, the article can guide enterprises, participants and policymakers in knowledge management-related decision-making during digital transformations.

2. Literature review

2.1 Knowledge sharing in OSCs

2.1.1 Connotation and influencing factors

Knowledge sharing – the interaction and exchange of ideas and information – occurs through face-to-face communication or via various media, such as archives (Zarraga and Bonache, 2003). In OSCs, the source code serves as the medium of knowledge sharing, with ideas, comments and suggestions around a specific project constituting the knowledge. There is also knowledge sharing between OSCs to maintain long-term partnerships and achieve mutually beneficial symbiosis (Ritala *et al*., 2015).

Studies of the factors influencing knowledge sharing in OSCs cover individual psychological characteristics, community-value propositions and structures, organisational culture and social capital (Liu *et al*., 2022). Individuals are the initiators and executors of knowledge sharing, which makes their traits (e.g., psychological motivations) crucial for understanding, initiating and implementing knowledge-sharing behaviours (Nielsen *et al*., 2011). The cultural atmosphere and structural characteristics of communities also influence knowledge-sharing efficiency and effectiveness (Ajmal and Koskinen, 2008). According to Mele *et al.* (2024), knowledge exchange can be actively promoted by an atmosphere of trust, a communication-focused environment and the proper organisational structure. Moreover, the organisational culture can drive the exchange of knowledge, experiences and skills based on social interactions (Zahra *et al*., 2007). Globally, when operating OSCs, participants come from diverse cultural backgrounds and their behavioral patterns, communication practices, and motivations may result in different knowledge sharing approaches (Ardichvili *et al*., 2006). Social capital, including trust, reciprocity and shared values, facilitates the seamless transfer of information and experiences, thereby accelerating collective learning and innovation (Giglio *et al*., 2023). Additionally, OSCs emphasise openness, inclusivity and collaboration, which enhances participants' sense of belonging and responsibility, thus accelerating knowledge dissemination (Holste and Fields, 2010).

Furthermore, digital technology has become an important tool for knowledge sharing (Lin and Maruping, 2022). Digital platforms attract software developers to participate, thereby accelerating technological innovation (Andersen-Gott *et al.*, 2012). Also, AI can extract valuable information from vast datasets, which enables OSCs to quickly acquire new knowledge, enhance knowledge reserves, identify market trends and potential risks, and improve resource allocation efficiency (Rammer *et a*l., 2022).

2.1.2 OSC participants

In OSCs, developers and users are the primary participants. As the supply side of knowledge, developers have intrinsic and extrinsic motivations. The former include hobbies, interests, skill acquisition and a willingness to contribute to open-source projects (Osterloh and Rota, 2007), whereas the latter mainly comprise economic rewards, career promotions, prestige and honour (Shah, 2006). The stronger the developers' motivations, the more likely the exchange of knowledge. In OSCs, network relationships are formed among individuals, groups and organisations (Spender *et al*., 2017). The stronger the social networks among the developers, the stronger the facilitation of knowledge sharing (Germonprez *et al*., 2017). The culture of OSCs, which is often manifested as tacit, personally held values, can also potentially influence knowledge sharing (Grimaldi *et al*., 2017). Alongside OSC development, it is essential to introduce developers from diverse disciplinary backgrounds to foster interdisciplinary collaboration. By incorporating various knowledge types and perspectives, the OSC knowledge content can be enriched (Medappa and Srivastava, 2019).

Users are the demand side of knowledge sharing, and they primarily influence it in terms of user innovation. Users represent another key participant group besides that of the developers, and they can be divided into developer users and non-developer users. Specifically, developer users contribute directly to OSCs with their experiences of proprietary-technology development. User innovation and feedback on projects can influence knowledge acquisition and transfer (Corvello *et al*., 2023). User innovation comprises two parts: the willingness to innovate and the ability to innovate (Bin, 2013). The former pertains to the awareness level of user innovation, and it emphasises users' satisfaction with open-source software and their willingness to solve new problems (Jeppesen and Frederiksen, 2006). The latter refers to the behavioural level of user innovation (Bin, 2013), and it highlights the extent to which users realise their innovative ideas. The stronger users' willingness and ability to innovate, the stronger the promotion of knowledge sharing in OSCs (Baldwin and von Hippel, 2011).

The interaction between developers and users is not limited to technical exchanges but also encompasses aspects such as requirements feedback, feature design, and user support. This is seen as a cyclical process: users raise demands or identify issues; developers respond and implement improvements; users then test the outcomes and provide feedback. Throughout the process, community managers play a pivotal role in facilitating knowledge sharing by establishing a shared vision, allocating resources, resolving conflicts, and motivating participants (Anderson and Hardwick, 2005).

2.2 Governance in OSCs

Companies create OSCs to advance innovation as well as acquire external resources and knowledge (Germonprez *et al*., 2017). As enterprises deepen their understanding of open-source practices, they may evolve from being peripheral users to being key contributors to knowledge; eventually, they may create their own OSCs (Greenstein and Nagle, 2014). As OSCs are operated on digital platforms, their governance mechanisms are different from those of traditional communities (Schaarschmidt *et al*., 2015). Therefore, efficient management procedures and clear decision-making hierarchies are necessary to encourage stakeholders to promote knowledge sharing, coordinate development processes and achieve the projects' intended goals (Tullio and Staples, 2013). Some European OSCs rely on legal safeguards and common technical standards for knowledge sharing and emphasise value creation through cooperation and information transparency among participants (Blind *et al*., 2015). In contrast, OSCs knowledge sharing governance in the US tend to adopt bottom-up approach, meaning innovation are driven by collaboration among developers (Medappa and Srivastava, 2019). In Asia, OSCs knowledge sharing is influenced by collaborations between companies and universities, facilitated by IP sharing agreements and common technology platforms to avoid potential competitive conflicts (Chen and Zhou, 2022).

Studies of community governance cover two aspects: incentive governance and control. Incentive governance promotes the generation and contribution of internal knowledge, and it increases community innovation output (Von Krogh and Von Hippel, 2006). Since participants in OSCs are often freelancers and volunteers rather than traditional employees, and given the geographical dispersion and lack of face-to-face interactions among developers, a key governance challenge is how to motivate participants to share knowledge. Accordingly, scholars have emphasised the difference between extrinsic and intrinsic motivations, which can be linked to developers' motivations, participation processes and performance outcomes (Roberts *et al*., 2006). Meanwhile, leadership and management skills play a critical role in this process. Research by del Rocío Martinez-Torres (2014) indicates that leaders in OSCs can maintain high levels of user cohesion by aligning community strategies with project requirements, coordinating developers' work, resolving conflicts, and monitoring the progress of issue resolution. Regarding control, there are mechanisms encompassing self-monitoring and management, self-authorisation, and cultural control through shared goals and open-source values (Colombo *et al*., 2013). There is also behaviour-process control, which is implemented through rules, procedures and performance evaluations, and outcome control, which relies on open-source licences to manage the use and modification of software and its derivatives (Cavallo *et al*., 2019). On the one hand, excessive control may suppress participants' creativity and enthusiasm for engagement; on the other hand, overemphasis on autonomy may lead to difficulties in aligning project goals and even result in chaos (Lauritzen and Karafyllia, 2019). Successful governance of OSCs typically seeks to strike a balance between these two extremes (Lauritzen and Karafyllia, 2019).

2.3 Research framework

Scholars have highlighted the important factors in the knowledge sharing of OSCs, including individual characteristics (Nielsen *et al*., 2011), community-value propositions and structures (Adel *et al*., 2007), and organisational culture and social capital (Lin and Maruping, 2022; Zahra *et al*., 2007). Less is known about the interaction of these factors. Moreover, digital technologies have accelerated the acquisition, sharing and use of knowledge and information within OSCs (Shehzad *et al*., 2024; Nambisan *et al*., 2017). Nevertheless, it is not known whether existing governance mechanisms, including incentive governance (Roberts *et al*., 2006) and control (Caballo *et al*., 2019), are applicable to OSCs. Also, there is a lack of research on the governance mechanisms of knowledge sharing across various types of OSCs (Schaarschmidt *et al*., 2015).

Thus, this study explores the governance mechanisms of knowledge sharing in OSCs by asking the following questions: *How can participants be motivated to share knowledge? How can knowledge sharing be promoted during open-source collaboration? How can innovation performance be improved through OSCs'* *knowledge management?* Given the important role of knowledge in competitive advantage, knowledge sharing has significant implications for the innovation performance of OSCs (Fitzgerald, 2006). This can be interpreted as open-source project performance, market application, technical advantage and community-operation efficiency.

We draw on the above literature and the analytical framework proposed by Roberts *et al.* (2006) in their research on maintaining participation in open-source software communities. We develop a conceptual framework on factors, governance and performance (Figure 1) to understand the governance mechanisms of knowledge sharing in OSCs.

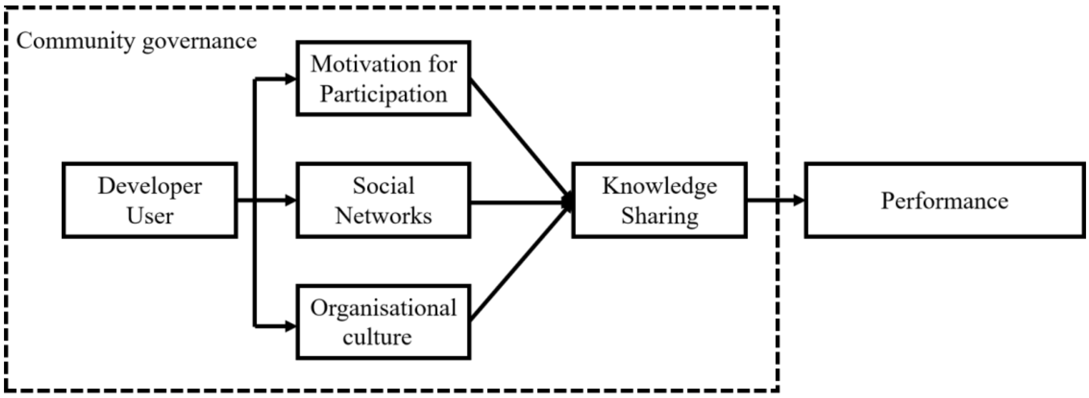

Figure 1. Research framework

3. Methodology

To answer the research questions outlined in Section 2, we used case study analysis. This is an appropriate qualitative research method to examine complex social phenomena, which typically addresses questions such as “What?” “Why?” and “How?” (Yin, 2014; Eisenhardt and Graebner, 2007). Knowledge sharing in OSCs is an emerging phenomenon. Case study analysis is suitable for extracting patterns from data, thereby advancing the understanding and recognition of new phenomena in OSC management practices. Also, by investigating studies comparatively, rigorous, generalisable and verifiable theoretical propositions can be developed. Therefore, our study adopted the case study method informed by Yin (2014), and it selected two OSCs as its sample.

3.1 Measurement of constructs

To ensure the reliability and validity of our research, we developed standards for measuring each construct (Table 1). The conceptual dimensions refer to the elements of each theoretical construct, while the measurement standards serve as the link between the constructs and the cases.

Table 1. Constructs and measurement

Module	Dimension	Measurement
Motivation for participation	Intrinsic motivation	The internal drive generated by individual needs (interests and hobbies, skill improvement, gratitude and reciprocity).
	Extrinsic motivation	The drive induced by the external environment or external stimuli (career advancement and recognition by others).
Social networks	Cognitive dimensions	Members' understanding and attitudes towards the project (shared background and common goals).
	Relational dimensions	Formal and informal networks formed through member interactions (network effects, rules and regulations).
	Structural dimensions	Interactions and relationships among members (the frequency of interactions and the strength of relationships).
Organisational culture	Freedom and openness	The openness of information sharing among members (transparency, openness and freedom).
	Cooperation and sharing	Perception of work division and collaborators; recognition of collaboration and sharing.
	Geek spirit	The challenge of new technologies (the pursuit of excellence).
Community governance	Building trust	Mutual trust among members (the establishment of open-source creeds).
	Collaboration	Collaboration and knowledge contribution between members and external participants (integrated collaboration and distributed collaboration).
	Value drivers	Realisation of individual and community values.
Project performance	Market success	The number of users and the usage of the project (market acceptability and application value).
	Technical success	Meeting technical requirements and solving practical problems (the technical level).
	Community success	The activity level of the project community, continuous dissemination, or the generation of new knowledge (community activity).

3.2 Case selection and overview

We adopted multiple-case studies, as the method allows for identifying patterns across cases and adhering to the principle of replication, in comparison with sing-case (Eisenhardt, 1989; Yin, 2014). The cases should be typical and enlightening, meeting requirements of theoretical sampling (Eisenhardt and Graebner, 2007). This can facilitate the exploration of the research phenomenon and its contextual linkages, ultimately serving the purpose of theory building (Eisenhardt, 2021). In addition, selected cases must also exhibit a degree of typicality to ensure alignment with the research questions. Furthermore, the availability of case data was considered to ensure comprehensive and sufficient data from various sources can enhance the rigor and depth of the study. Therefore, we engaged with two cases – the OSCs created by Company B and Company H – based in China for the following reasons.

First, the cases are globally recognised and have international influence. The open-source projects set up by Company B and Company H, such as new-generation operating systems and distributed databases, have become top-tier global initiatives. According to the 2023 China Open-Source Development Blue Book, Company B and Company H have created reputable OSCs, which are among the top 50 largest OSCs globally and the top 10 largest OSCs in China. Hence, a detailed investigation of the two cases can provide valuable theoretical and practical insights.

Second, we consider the comparability of the core digital technologies of the two cases. Both OSCs operate in core digital technology fields, such as operating systems, databases, AI and cloud-native technologies. They are comparable in terms of overall project activity, number of participating developers, project-merge frequency and number of branches. For example, in 2021, Company B's community for the deep learning framework PaddlePaddle, and Company H's communities for the open-source deep learning training-framework MindSpore and the open-source operating system OpenHarmony were among the five most active projects on the global code-hosting platforms GitHub and Gitee.

Third, the two cases exhibit differences in participant types and strategic positioning. Despite their similarities in the open-source field, the two OSCs differ in terms of participant type, project layout and strategic positioning. The Company B community primarily consists of developers seeking to pursue open-source ideals or technical opportunities; thus, it focuses on social value to enhance commercial value. In contrast, the open-source efforts of the Company H community are part of a strategic investment in open innovation, with the community being embedded in the firm's existing business to support and expand its product and service ecosystem. The participants in Company H's community are mainly corporate employees seeking performance incentives or personal growth; the community addresses individual value to enhance ecosystem value. The key features of the two OSCs are shown in Table 2.

Table 2 Features of the two OSCs

Similarities and differences	Dimension	OSC	
		Company B community	Company H community
Common characteristics	Open-source field	Primarily focuses on foundational software for digital technologies, such as deep learning, natural-language processing and computer vision.	Primarily focuses on foundational software for digital technologies, such as operating systems, databases and AI frameworks.
	Open-source effectiveness	The scale and activity level of the OSC are world leading. This is shown by PaddlePaddle, which has garnered 47,000 stars on GitHub.	The scale and activity level of the OSC are world leading. This is shown by OpenHarmony, which has garnered 32,000 stars on Gitee.
Distinct characteristics	Founding year	Open-sourced the main product code in 2017.	Open-sourced the main product code in 2019.
	Participant types	Community participants are mainly developers pursuing the open-source philosophy or technical opportunities.	The initial external participants were primarily employee developers from ecosystem companies seeking performance incentives or self-improvement.
	OSC project layout	Combines open-source technology with commercial applications; continuously optimises products and services through technological innovation and user-oriented concepts; promotes synergistic development between the company and the OSC.	Operates multiple OSCs independently, such as those for the multi-architecture operating system openEuler, the enterprise-level database openGauss, the data virtualisation engine openLooKeng, the all-scenario AI computing framework MindSpore, and the distributed operating system OpenHarmony.
	OSC strategic	Focuses on technological innovation and	Aims to support and expand the

	positioning	frontier exploration, thus building an OSC around core business areas.	product and service ecosystems by integrating various OSCs into the business.

Founded in 2000, Company B is a global provider of full-stack AI technologies, such as AI chips, software architectures and applications. It is recognised as one of the top four AI companies in the world. Company B made a significant move in 2009 by initiating the large-scale customisation of Hadoop based on open-source software. In 2013, it began constructing an open-source platform to encourage internal knowledge sharing. In 2016, PaddlePaddle was officially launched. In 2017, Company B's Apollo autonomous-driving platform was created with open-source technology. Then, Company B joined the Apache Software Foundation, the Cloud Native Computing Foundation and the Linux Foundation as a gold member of the foundations, and it has maintained this status since. To date, Company B has led over 1,000 open-source projects, with the contributions of more than 10,000 community members, and it has accumulated over 300,000 GitHub stars. Its open-source projects have been applied to the business, whereas the OSC has created a positive feedback loop for product development, research capabilities and engineering quality.

Founded in 1987, Company H is a global leader in information and communication technology solutions and one of the earliest enterprises in China to implement an open-source strategy. In 2008, it established the Open-Source Capability Centre to manage internal open-source projects and development. Over the years, Company H has become a core contributor to numerous domestic and international OSCs and foundations, including Linux, Apache, OpenStack, Eclipse and OpenAtom. In 2019, the company evolved from a user to a contributor and creator, initiating OSCs in foundational-software fields such as operating systems, databases and AI computing frameworks (e.g., openEuler, MindSpore, EdgeGallery and OpenHarmony). Each community operates independently, focusing on ecosystems related to computing, connectivity and mobile terminals. Since its establishment in 2019, the openEuler community has grown to include 5,000 code contributors and 10,000 community users. OpenHarmony has seen over 3.5 million lines of code contributed by its member organisations, and MindSpore has become the most popular AI OSC in China.

3.3 Data collection and analysis

We gathered data by conducting semi-structured interviews and field observations, as well as by consulting the official websites of the OSCs, the companies' archives and academic papers. The interviews were carried out online from 2020 to 2023; each interview lasted 60–120 minutes. Information on community organisational structures, user groups, contributors, mailing lists and interest groups was gathered from the code-hosting platforms GitHub and Gitee. In addition, we observed a series of structured interactions in the companies' Shenzhen and Beijing headquarters in 2022. These observations focused on several critical aspects of the history of community development, participants' contributions and motivations, knowledge input, project performance and so on. An overview of the dataset is presented in Table 3.

Table 3. Overview of the dataset

Case	Data sources	Interview subjects	Interview content
Company B community	Semi-structured interviews	Senior executives responsible for the open-source strategy	History of development, open-source strategic-development plan, product generation and marketing process, etc.
		Technical architects, R&D engineers, technical consultants, project managers, product managers and other technical staff	OSC technology architecture, big data ecological R&D process, product delivery and practice, OSC project management and organisational interaction management, etc.
		OSC leaders and operating staff	Overall operation of commercial versions, operation of the OSC, governance methods, open-source talent development programme, internationalisation level of the OSC, sales and servicing of core product solutions, etc.
		OSC developers and users	OSC activities and operation, community code of conduct, community technology learning and certification process, external-participant engagement process, product-application scenarios, etc.
	Archival data	Internal management system, technical documents, mailing lists, meeting lists, promotional PowerPoint presentations, news reports, research papers, monographs, open-source white papers, etc.	
Company H community	In-depth interviews	Senior executives responsible for the open-source strategy	History of development, open-source strategic-development plan, product-generation and marketing process, etc.
		Open-source software architects, OSC project manager	OSC project management and organisational interaction management, open-source cutting-edge technology planning, open-source software capability-building process, etc.
		OSC leaders and operating staff	Overall operation of commercial versions, operation of the OSC, governance methods, open-source talent development programme, internationalisation level of the OSC, sales and servicing of core product solutions, etc.
		OSC developers and users	OSC activities and operation, community code of conduct, community technology learning and certification process, external-participant engagement process, product-application scenarios, etc.
	Archival documents	Internal management system, technical documents, mailing lists, meeting lists, promotional PowerPoint presentations, news reports, research papers, monographs, open-source white papers, etc.	

As for data analysis, content analysis (Strauss and Corbin, 1998) was employed based on the conceptual framework established in Section 3.1. Additionally, the study utilised the “replication logic” and analysed cases according to the established constructs.

To achieve the validity and reality of the findings (Yin, 2014), the following approaches were adopted. Data were collected from various sources e.g. primary and secondary data to cross-verify the phenomenon and form evidence triangulation. This can enhance the validity of the findings. We built a clear and standardised database for each case to present data systematically and improve reliability. Data specified details such as time and venue of the events to ensure consistency. We also repeatedly compared findings with the literature and conceptual framework to ensure the consistency and robustness of the study.

By comparing similarities and differences across cases, we extracted insights into the knowledge sharing and governance mechanisms of OSCs, and identified the causes and effects from the aspects of 1) reasons for participating and knowledge sharing in OSCs, 2) social networks and knowledge sharing in OSCs, 3) organisational culture and knowledge sharing in OSCs, 4) knowledge sharing and performance in OSCs. This eventually led to the development of four propositions.

Proposition One: In technology-driven OSCs, where motivation rests on internal-value recognition and status, the focus is on developing cutting-edge core technologies and contributing high-quality technical content. In enterprise ecosystem-oriented OSCs, which are driven by self-improvement and explicit performance incentives, the focus is on establishing trust through clear boundaries and the attributes of foundational technologies.

Proposition Two: Technology-driven OSCs employ integrative collaboration, which entails layouts centred around core technological products and relies on integrated operations within the community to achieve efficient collaboration among developers. Enterprise ecosystem-oriented OSCs employ distributed collaboration; they adopt differentiated layouts focused on data-driven innovation scenarios, and they establish multiple independently distributed OSCs to coordinate developers.

Proposition Three: Organisational culture and trust play critical roles in knowledge sharing within OSCs. Trust and an open culture enhance belonging and the willingness to collaborate among community members, which facilitates the sustainable development of the communities.

Proposition Four: Technology-driven OSCs emphasise the construction of social value by integrating users' social experiences and enterprises' commercial value, which drives the iterative development of both. Enterprise ecosystem-oriented OSCs concentrate on individual value within ecosystems; they widen the margins of ecological value by clearly defining individual and ecological boundaries, thus promoting mutual gains in both areas.

4. Case analysis

4.1 Knowledge sharing and governance in the Company B community

In 2017, the Company B community officially released the source code of its core products. Building on the firm's technological achievements in AI and big data, this community is driven by technological innovation and cutting-edge exploration. It operates various projects, including the OpenEdge operating system, the PaddlePaddle deep learning framework, the BigData distributed database, the Cloud-Native AI intelligent cloud-native computing platform, and the Apollo autonomous-driving open platform. These initiatives provide developers with comprehensive development frameworks covering AI, cloud computing and autonomous driving. The community in question offers rich resources and support to developers, and it fosters close collaborations between Company B and external developers.

4.1.1 Knowledge sharing among participants in the Company B community

1) Motivation for Participation. The participants in the Company B community are driven by different motivations. Some are internally motivated by a fundamental agreement with open-source principles, which leads to a sense of intrinsic-value alignment. Others are externally motivated by the pursuit of industry reputation, and they engage in the community to experiment with or adopt new technologies. The development of OSC projects depends on attracting talent for collaboration (Medappa and Srivastava, 2019). Company B's annual Create AI developer conference garners global attention; it is now established as China's AI technology hub and acts as a barometer for emerging technologies. Unsurprisingly, the event attracts numerous industry professionals. The participants are motivated by Company B's reputation and open-source vision. They believe that AI represents the main direction of technological development, and they are committed to contributing the knowledge necessary to tackle relevant challenges. At the same time, impressed by Company B's open-source products, they engage in the writing, testing and debugging of newly developed open-source programmes. In this way, developers gain technical and knowledge benefits. This enables them to build professional reputations among peers and achieve industry recognition (West and Gallagher, 2006).

2) Social networks. Through open-source technology, the Company B community continuously attracts developers. This in return enhances the company's reputation. As a representative from a complementary enterprise in Company B's Apollo community pointed out, *"The extensive resources enable continuous updates and iterations. We believe that Apollo is the best and most robust platform; it is also the most widely participated one."* As the number of community developers grows, knowledge sharing and interactions within the community become more frequent, which results in knowledge accumulation through positive reinforcement. In addition, the community also provides direct training and learning opportunities. Since 2017, Company B has collaborated with educational platforms (e.g., Udacity) and the Universities of Peking and Beihang to offer training courses. These have effectively disseminated technical knowledge within the community, increased the platforms' visibility and fostered collaboration opportunities. Moreover, at the project level, the stability of collaboration depends on developers' consistent participation (Wareham *et al*., 2014). For this reason, the operational team of the Company B community strongly emphasises user experience in open-source projects. There is a bidirectional interaction and feedback mechanism between the community and its users. The latter can submit inquiries, report issues and propose improvements through online platforms. The community's operational team and project developers respond promptly and provide technical support and solutions. This real-time interaction helps users resolve technical problems, and it fosters a sustained relationship between the community and its users.

3) Organisational culture. When they participate in OSCs, developers seek external resources and knowledge, but they are also concerned about the potential devaluation of their resources by other participants. To enhance trust among members, the Company B community integrates its value propositions and its partners, aiming to create a more open and collaborative environment. According to a Company B community operator, *"In the community, we have established internal open-source-related groups to actively promote the open-source culture, organise open-source-related activities and advance open-source practices. The best practices are compiled and made available on the internal wiki platform."* The community has clear IP protection measures, alongside contribution and reward systems. These include review processes for code contributions, standardised protocols for knowledge sharing and mechanisms to protect developers' rights. By increasing the transparency and fairness of community operations, the Company B community enhances developers' trust and sense of belonging, which motivates user participation and enthusiasm. In the long run, this strengthens the community's cohesion and innovation capacity.

4.1.2 The governance of knowledge sharing in the Company B community

The technology-driven open source of the Company B community attracts participants for ongoing engagement. To upgrade the OSC and expand commercial markets, the community implements iterative interaction between commercial clients and community users. The following evidence demonstrates the company's continuous operation of the OSC through value-driven initiatives.

1) Strengthening the open-source principle. The Company B community reinforces its technology-driven open-source principle by continuously updating its core products and organising community-member activities. This approach creates sustainable motivation and network effects for community participation. By enhancing the technical features of its products, the community attracts developers' attention, thereby promoting its knowledge and image. A community operator emphasised the importance of user-value circulation and breaking down user silos with the following words: *"For community operators, the most critical task is to prevent silent users from utilising the platform deeply. Operators must establish connections between them and other users in the network."* The Company B community includes both developers and users. Therefore, it has created a developer centre and technical academy based on the degree of participants' involvement in projects. Community members can learn cutting-edge knowledge through online Q and A sessions, technical publications and offline technical salons, thus transmitting valuable content to the community.

2) Integrated collaboration. Regarding the layout of open-source projects, the Company B community relies on the OSC to carry out component-based expansions, thereby coordinating, integrating and operating interrelated open-source projects. In technical projects, the community divides different modules of open-source projects into specialised interest groups and working groups as units of community activity, which facilitates internal learning and collaboration among developers. In an open-innovation environment, the OSC can enhance its ability to utilise and absorb external knowledge through the contributions of different technical developers. As a community

operator reflected, *"Project contributors can participate in project development by solving technical problems, increasing project testing, improving technical documentation and writing example articles, thus becoming active contributors and qualifying for entry into specialised interest groups."* When guided by community technical leaders from diverse backgrounds, the professional capabilities of the members of specialised interest groups are significantly enhanced. Through periodic meetings and technical sharing, these groups autonomously discuss, plan, develop and maintain specific modules of open-source projects.

3) Social-value empowerment. The profits that Company B generates from commercialisation are reinvested into the operation of its OSCs. This strengthens the community's value proposition. To refine its core technology products, the Company B community has made the core code, development roadmap, and technical-discussion plans of its database products available on GitHub, the world's leading code-hosting platform. This allows global community users to access and contribute, thereby maximising community value. Through these initiatives, enterprise users from various industries and technology enthusiasts across the world collaborate with the Company B community. They voluntarily test products, provide feedback on practical-use cases and suggest product improvements, which creates a product-iteration loop. This process harnesses social value to underpin commercial-value creation.

4.1.3 Performance of the projects of the Company B community

The Company B community has achieved significant success in the open-source field. As a global leader, Company B has consistently promoted its technological innovation and open-source culture. Community members can share and discuss technical issues, collaboratively advancing projects and driving innovation. Projects such as Apollo and PaddlePaddle have become industry focal points, leading technological trends and promoting the commercialisation and widespread dissemination of these technologies. For instance, PaddlePaddle is China's first cloud-based, fully functional AI chip-development framework. It aims to lower the technical barriers to deep learning and accelerate the intelligent transformation of industries. The framework's functionality and performance are continually optimised, with new features (e.g., the PaddlePaddle dynamic graph API and the PaddlePaddle dynamic library) further enhancing the developer experience. PaddlePaddle also collaborates with numerous enterprises and research institutions to advance the application of deep learning technology across sectors. Furthermore, the Company B community supports various open-source hardware and software projects, such as those based on Arduino and ESP32. Through these efforts, the Company B community has strengthened its knowledge and technical capabilities, and it has made significant contributions to the global open-source ecosystem.

4.2 Knowledge sharing and governance in the Company H community

In 2019, the Company H community officially released the source code of its core products. This attracted developers and users from numerous ecosystem co-

construction enterprises. Through the operation of foundational-software OSCs, including those for the operating system openEuler, the enterprise-grade database openGauss, the data virtualisation engine openLooKeng, the all-scenario AI computing framework MindSpore, and the distributed operating system OpenHarmony, the Company H community provides its members with a comprehensive development framework covering end, edge and cloud scenarios. This framework enables members to develop their brands or products using the resources of the Company H community.

Company H views its OSC as a strategic investment, using it to support and extend its product and service ecosystem. Thus, the community revolves around the company's core business and is regarded as an enterprise ecosystem-oriented OSC.

4.2.1 Knowledge sharing among participants in the Company H community

1) Motivation for Participation. In the early stages of the Company H community, external participants primarily consisted of employees who worked as developers in ecosystem partner companies. These individuals were driven by two main motivations. On the one hand, they engaged in the community to fulfil their personal needs for self-improvement and self-directed learning as software developers. On the other hand, they were motivated by explicit performance incentives, such as financial compensation or career advancement opportunities provided by their employers. According to the head of the openEuler OSC, *"As a technical foundation, openEuler allows users to add differentiated content based on their own scenarios, markets and industries."* Thus, open-source participation has become an industry consensus for building a technology-innovation ecosystem. Leveraging its leading technology advantages, the Company H community provides developers with opportunities for self-guidance, creative expression and skill enhancement. To co-build technology, developers contribute knowledge to strengthen the technological foundation, and they enhance their technical capabilities through community knowledge feedback. Ecosystem partner companies aim to ensure long-term benefits by integrating open-source participation into employees' work responsibilities. These companies deploy staff to contribute to the community by offering payments or chances for career advancement. This approach allows them to gain access to and assimilate knowledge from open-source projects, thereby expanding their business models (Germonprez *et al*., 2017).

2) Social networks. The Company H community creates a space for technological development by placing technology within a community that is external to the enterprise. In this community, a complex social network is constructed through the connections among individuals, groups, organisations and the community itself. The Company H community uses various channels, such as social media and technical forums, to disseminate information about open-source projects among developers across the world. When developers join the community, they establish close collaborative relationships through discussions, code reviews, technical documentation and conferences. This interaction promotes the wider dissemination and sharing of knowledge, thus enhancing the community's cohesion and collaborative capabilities (Lauritzen, 2017). This accelerates problem-solving and project progress.

While contributing knowledge, developers are continually learning and improving their skills. The Company H community regularly organises online seminars, training courses, and live broadcasts and interactions, which promote knowledge dissemination. For instance, Company H's annual developer conference attracts millions of developers through live streaming and social network interactions. By consistently gathering feedback and making continuous improvements, the Company H community brings together global developer resources for project development and ecosystem building. It also empowers projects to achieve flexible and sustainable growth. Projects within the community are closely aligned with user needs, frequently receiving requests from users and project founders to conduct on-site technical training. This reflects a high level of user attention and active participation in the projects. Users with relevant technical skills also suggest areas for improvement. This bidirectional communication enhances users' technical proficiency and enables project teams to understand user needs promptly, which leads to optimisations and improvements.

3) Organisational culture. The Company H community stimulates participants' enthusiasm for innovation by sharing the latest technological achievements and research progress. For instance, Company H released an open-source project based on its operating system – HarmonyOS – in the community. This attracted significant attention and participation, as internal teams and external developers actively shared knowledge. In the community, participants are also involved in project discussions and decision-making processes. The community provides abundant learning resources, including technical documentation, tutorials and training courses, to help participants enhance their abilities. There are regular technical seminars, hackathons and programming competitions during which participants can express opinions, propose suggestions and develop improvement plans. To attract high-quality intellectual capital and skills, the community has further increased its openness and transparency. At present, it even shares open code with complementary product manufacturers and direct competitors to establish collaborations. This fosters an environment that encourages free exploration, high-quality standards, the free contribution of knowledge and open governance. As Company H's rotating CEO stated, *"We aim to create an open, vibrant, diverse and mutually prosperous environment. Regardless of the size of our partners, as long as they are capable and innovative, we will collaborate with them to solve business challenges and create value for our customers."*

4.2.2 The governance of knowledge sharing in the Company H community

To stimulate participation among external developers and users, who are primarily employees of ecosystem partner companies, the Company H community fosters a collaborative environment and mutual trust. As project scenarios diversify, the number of community users continues to grow. To upgrade the OSC, the Company H community has adopted an individual-value-driven governance approach. It promotes the development of complementary technologies within the ecosystem, and it ensures the sustained growth of the community. The governance mechanisms are presented in detail below.

1) Building trust. The Company H community emphasises building trust through ecosystem development. It has created a collaborative environment and mutual trust by clearly defining technological attributes. Also, it has established a unified industry-standard technical foundation. This encourages participants to optimise technical routes and achieve differentiated competition. The community also employs a multidimensional layout for interconnected ecosystem integration to facilitate knowledge exchange with employees from ecosystem partner companies. As the head of the HarmonyOS OSC stated, *"We aim to create commercial value for participants. Only by creating commercial value will participants be willing to join the ecosystem*

for co-construction.” Moreover, the Company H community has launched the Fertile Soil Programme, which supports partners, start-ups, developers and university researchers in learning and building technical capabilities through open-source projects.

2) Distributed collaboration. The Company H community has established multiple foundational-software open-source projects, and it has achieved independence through differentiated layouts. Its OSCs focus on innovation and collaboration across various scenarios, such as cloud, edge, device and AI. There is also cross-scenario innovation. For example, a community operator from the openEuler community said, *“Developers can choose to join existing special interest groups by reviewing the list available in the OSC or collaborate with two or three individuals who share common interests and goals to create new groups.”* Specifically, these operations are responsible for workflows, architectural designs, project maintenance and the identification of technological advancements in the community. The modular-environment design allows developers to concentrate their intellectual capital on specific work modules, thus reducing the cost of collaborative participation (Pil and Cohen, 2006).

3) Individual-value empowerment. The Company H community combines its value with the ecosystem, and it shares the technologies that complement the ecosystem partners’. This fosters the adoption and development of complementary technologies in the community, and it forms an interconnected societal ecosystem. It also encourages other ecosystem partners to innovate. As the complementary technologies are advanced in the community, the societal ecosystem becomes an interface for Company H’s products. The continuous participation of internal and external developers advances the technical standards. This collaboration gradually reduces the marginal cost of technology development, which enables more efficient coordination of information transmission and data sharing. Additionally, external knowledge is continuously absorbed, improved and supplemented by the Company H community.

4.2.3 Performance of the projects of the Company H community

The projects of the Company H community span various domains, including cloud computing, AI and operating systems. In recent years, the community has focused on areas such as cloud-native computing, automation and intelligence, and it has encouraged global developers to contribute to these areas. Through open forums and technical support, Company H has established a vibrant platform for knowledge exchange and collaboration. It has openly shared several platform-level foundational-software projects, including EdgeGallery, MindSpore, openEuler, openGauss and OpenHarmony, which have been widely welcomed by global developers. These initiatives have encouraged numerous manufacturers, developers, research institutions and universities to collaborate. For example, the openEuler community has has released commercial products to support broader industrial applications. The Ascend and Kunpeng communities motivate developer innovation and technological breakthroughs through developer programmes and competitions, such as the Ascend AI Innovation Competition and Kunpeng Application Innovation Competition. The OpenEuler and OpenHarmony projects have brought together innovators to advance digital transformation across the industry. The above open-source software projects have been downloaded by users in over 1,000 cities worldwide, which shows the global impact of the Company H community.

5. Discussion

This section further elaborates the findings and discusses the four propositions purposed in Section 3. Overall, in the digital age, enterprises develop digital resources, build digital capabilities and update digital infrastructures and platforms to maintain competitiveness (Wimelius *et al*., 2021). OSCs are created to develop foundational software, hardware and applications around emerging digital technologies, such as AI, big data, blockchain, cloud computing and IoT. Based on the case of Company B and Company H, this study investigated the knowledge sharing and governance mechanisms of OSCs, and it produced several results. For instance, the initial condition for knowledge-sharing governance in OSCs is to attract participants and implement motivation governance. This involves incentivising contributors to produce and freely share knowledge. Meanwhile, under the influence of open-source culture, participants construct social networks and explore collaborative solutions. This increases community contributions and forms a collaborative open-source project community, which is the core process of knowledge-sharing governance in OSCs. Also, from focal companies' perspective, the ultimate goal of their OSCs is to achieve innovation performance. This creates a virtuous cycle of commercial and social value, alongside individual and ecosystem value, which supports the continuous growth of the community. It also fosters technological innovation and, eventually, establishes a sustainable model.

5.1 Reasons for participating and knowledge sharing in OSCs ***(Proposition One)***

Participation motivation is a reflection of the focal enterprise's strategy behind the value propositions of its OSCs. Since business interests and community goals are not always aligned, a mismatch can create cognitive and behavioural barriers for participants wishing to enter the community. OSCs rely on shared values, knowledge sharing, mutual respect and human-centred traditional trust mechanisms to maintain consistency in participants' motivations (Stewart and Gosain, 2006). In the Linux community, participants are primarily motivated by their alignment with the philosophy of free software and the opportunity to enhance their technical skills. With digitalisation, traditional human-centred trust mechanisms are transitioning towards technology-centred digital trust mechanisms. Apart from concerning traditional trust elements (e.g., enhancing community identity), it is necessary to leverage the knowledge-sharing and dissemination characteristics of digital technologies (Mubarak and Petraite, 2020). This aims to enhance external participants' confidence in the operational capabilities, collaboration processes and technological development of OSCs. For example, the Steemit community leverages blockchain technology to enable participants to hold tokens with various rights and attributes. This motivates participants to engage in the OSCs and thereby promoting knowledge sharing behaviours (Liu *et al*., 2022). The Company B community has established a technological innovation ecosystem that attracts developers and users from all over the world thanks to a strategy of technological openness, resource sharing and developer empowerment. The primary motivations for participation stem from the recognition of AI and big data technologies and the pursuit of industry reputation. Developers participate due to the ecosystem's alignment with open-source culture or a desire to achieve personal value (Spaeth *et al*., 2015). The Company H community attracts employee developers from ecosystem partner enterprises through its clear foundational technology attributes and ecosystem trust building. Participants are primarily motivated by self-improvement and the material rewards offered by their employers. They contribute knowledge and engage with the community to enhance technical skills.

5.2 Social networks and knowledge sharing in OSCs ***(Proposition Two)***

To enhance collaboration efficiency, OSCs must address the diverse and evolving needs of participants. By uniting community forces to attract, improve and supplement technical knowledge, these communities accelerate R&D processes, expand application scenarios to form social networks and improve software quality. OSCs primarily enhance the division of labour and collaboration through the introduction of formal and informal norms, such as incentives and controls. By leveraging AI-driven collaborative tools, they facilitate more effective task allocation, thereby strengthening specialised division of labour and collaboration within the community (Sun *et al*., 2021).

Compared to the Apache community, which emphasises a self-management model for community participants, Company B community and Company H community promote knowledge sharing through robust social networks and collaborative mechanisms. Given the high complexity and uncertainty of digital technologies, the Company B community emphasises technological development and innovation during project collaboration. It needs to continuously develop to enhance its technological capabilities while integrating fragmented external market demands. The Company B community has established an open and inclusive knowledge-sharing environment through extensive technical exchanges and training activities. In contrast, the Company H community focuses on enterprise interests. It needs to guide project development through control mechanisms to align with its commercial objectives while maintaining community openness to ensure the projects' legitimacy.

5.3 Organisational culture and knowledge sharing in OSCs ***(Proposition Three)***

As leading technology firms, both Company B and Company H recognise the significance of organisational culture and actively support extensive technological innovation and ecosystem collaboration (Lauritzen and Karafyllia, 2019). Despite certain differences in their open-source strategies, both firms clearly foster positive organisational culture and establish relationships of trust to drive community development.

By opening the source code of core technology products, the Company B community also enhances community transparency and fairness. The community has established clear contribution rules and reward systems. These elements promote technology sharing and innovation, and they foster belonging and trust among participants. For instance, Company B's Apollo OSC ensures active communication and continuous technological advancement in the community through regular code reviews and technical-roadmap updates. This facilitates an open and inclusive environment. Company H emphasises the openness and transparency of its ecosystem in its OSCs. By creating a collaborative environment that respects diverse opinions and focuses on high-quality standards, the community attracts global partners and promotes cross-disciplinary innovation. Company H's OSCs, such as those for OpenHarmony and MindSpore, provide platforms and tools that enable partners to collaboratively explore and solve industry challenges under clear technical directions and project goals. This open attitude and win-win strategy strengthens Company H's brand image. Also, Company B community and Company H community leverage blockchain technology to provide a foundation of trust, facilitating collaboration across national and cultural boundaries.

5.4 Knowledge sharing and performance in OSCs ***(Proposition Four)***

Regarding performance, OSCs emphasise the integration of different values. To ensure the communities' sustainable development, it is essential to maintain self-growth, which is driven by a large and diverse pool of participants willing to create value. Generally, OSCs primarily aim for value creation in the form of cost reduction, knowledge absorption and distribution-channel expansion. As a result, community performance outputs often align with the strategic goals of the founding enterprises (Schaarschmidt *et al*., 2015). With digital technologies altering the nature and scope of traditional business dependence, digital ecosystems are becoming networks where enterprises are interdependent, which create and capture value through connectivity (Yun *et al*., 2020). The two communities examined here have achieved sustainable operation and commercialisation through value-driven initiatives. The Company B community has created a positive cycle of commercial and social value by opening product technologies and expanding into commercial markets. The Company H community fosters a virtuous cycle that encourages ecosystem partners to innovate.

6. Conclusion

This study explores the governance mechanisms that promote knowledge sharing in OSCs. The in-depth analysis of the OSCs established by Company B and Company H revealed two important mechanisms. First, technology-driven OSCs are dedicated to fostering technological innovation, particularly in cutting-edge areas such as AI and big data. These communities maintain a high level of openness by encouraging external contributors to participate. They promote third-party innovations through open-source projects. Furthermore, there is coherent and flexible participation around modular layouts, which facilitates knowledge exchange.

Second, enterprise ecosystem-oriented OSCs focus on advancing the company's product and technology ecosystem. Their goal is to enhance the market competitiveness and compatibility of the firm's technologies, which often rely heavily on the firm's own resources. These companies tend to foster eco-building-driven mutual collaboration and knowledge sharing. Individual and ecological value can be combined through value exchange. Our study conducted a comparative exploration of knowledge sharing and governance in OSCs. By investigating technology-driven and enterprise ecosystem-oriented OSCs, our research advances the understanding of the role and attributes of enterprises as community creators within OSCs. The study reveals the underlying reasons for the differences in knowledge sharing and governance between OSCs created by different types of enterprises. Meanwhile, the outputs of OSCs are mainly foundational software, hardware, and applications based on digital technologies e.g. AI, blockchain. These outputs inherently possess reprogrammability (Yoo *et al*., 2012). Therefore, OSCs across different fields face similar management challenges in system design, coordination, knowledge sharing, and governance. By designing knowledge sharing and governance mechanisms, OSCs can enhance public and commercial value. Our findings can also offer support for government agencies in designing inclusive policies and promoting social co-creation.

Due to geographical constraints, this study primarily conducts case analyses in China. Given the rapid development of OSCs and their significance in global technological innovation, future scholars could explore knowledge-sharing governance in cross-border OSCs. This would help us understand how OSCs adjust their governance strategies in different political, economic and cultural contexts. Furthermore, more research is needed on the impact of AI and other technologies on knowledge-sharing dynamics and the performance of open-source projects.

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