▪ Journal of Competitiveness

Impact of a Standard Cooperation Network on Technological Standardization Capability - Evidence from the Communication Equipment Manufacturing Industry

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Abstract

Drawing on social network analysis and resource theory, we analyze the influence of the location (centrality and structural holes) in and network density of the standard cooperation network on technological standardization capability. We use the negative binomial regression model to analyze data on communication equipment manufacturers in the standard cooperation network that participated in the standard development from 2008 to 2023. The results reveal that centrality and structural holes have significant positive effects on technological standardization capability. Meanwhile, the network density negatively affects technological standardization capability. High network density can help enterprises to leverage the advantages of their centrality, but simultaneously weaken the advantages of structural holes.

Keywords: *Standard cooperation network, Technological standardization capacity, Network density, Structural holes, Centrality*

JEL Classification: O32, L24, L63

Article history: Received: November 2024; Accepted: August 2025; Published: March 2026

1 INTRODUCTION

Technical standards, serving as the crucial drivers of industrial competition and lingua franca of international trade, have become pivotal elements in global technological innovation and industrial upgrading (Blind et al., 2020; Xu & Zheng, 2025). With increasing technological complexity and globalization, standard cooperation networks have emerged as a critical organizational form for standardization activities. By integrating complementary resources and reducing technological friction, such networks enable firms to overcome technical barriers and enhance international competitiveness. This mechanism holds particular significance for latecomer countries like China: through collaborative innovation within standard cooperation networks, firms in such countries can achieve technological catch-up and leapfrogging. For instance, in the telecommunications sector, Chinese firms accounted for 42% of global 5G standard-essential patents by 2025 (MIIT, 2026), supported by more than 200 international standard cooperation projects led by industry giants such as Huawei and ZTE. However, extant research predominantly focuses on standardization practices in developed economies, with limited attention to the linkage between standard cooperation networks and technological standardization capabilities in developing countries, particularly in China.

Addressing this gap, this study investigates how standard cooperation networks shape technological standardization capabilities in China's telecommunications industry. First, it provides empirical evidence from an emerging economy, demonstrating how latecomer countries leverage such networks to capitalize on their latecomer advantages. Thus, it offers actionable insights for other emerging economies in global standards competition.

https://doi.org/10.7441/joc.2026.01.04

Second, this study unravels the mechanisms of standard cooperation networks through a structural embeddedness perspective. Studies have extensively examined technology collaboration and innovation networks. However, standard cooperation networks fundamentally differ in their objectives (establishing technical rules rather than developing technologies), member heterogeneity (spanning firms, institutions, and governmental bodies), and collaboration modes (competitive-cooperative dynamics) (Farrell & Simcoe, 2012; Singh & Stout, 2018). Few studies adequately characterize the structural attributes of these networks, limiting the specificity and practical relevance of findings. To address this, we deconstruct network structure through dual dimensions: At the micro level, centrality (resource control) and structural holes (information brokerage advantages) capture firms' positional characteristics. At the macro level, network density (collaborative cohesion) reflects the collective network configuration. This analytical framework not only deepens the understanding of structural properties in standard cooperation networks but also uncovers the coordinated mechanisms between micro-level positioning (individual members' network roles) and macro-level network contexts (overall collaborative intensity). Thus, it provides theoretical and practical insights into how structural embeddedness shapes technological standardization capabilities.

The subsequent sections proceed as follows: Section 2 integrates network embeddedness theory and technological standardization literature to propose a conceptual model linking "individual positional attributes–network contextual features–standardization capabilities." Section 3 discusses the research methodology and data collection. Section 4 empirically tests hypotheses using social network analysis and negative binomial regression models based on standard cooperation data from China's telecommunications industry (2008–2023). Section 5 concludes with theoretical contributions, practical implications, and future research directions.

2 THEORETICAL BACKGROUND AND HYPOTHESES FORMULATION

2.1 Standard Cooperation Network

A standard cooperation network refers to the interconnected relationships formed among diverse actors (e.g., enterprises, universities, government agencies, and research institutions) during technical standardization. Its primary function is to enhance firms' technological standardization capabilities by integrating heterogeneous resources (Chen et al., 2012; Liu, 2024). Unlike technology collaboration or innovation networks, which focus on knowledge sharing or technology development, standard cooperation networks prioritize establishing and diffusing industry-wide technical rules (Wen et al., 2020). Drawing on the resource-based view (RBV), participation in such networks enables firms to transcend internal resource constraints, accessing complementary technical resources through direct collaborations and diverse knowledge via indirect network ties (Carnabuci & Operti, 2013). This mechanism is particularly critical in high-tech industries, where the complexity of technical standards necessitates cross-domain and cross-organizational coordination (Qian et al.,2010).

Standard cooperation networks exhibit three defining characteristics: multi-actor heterogeneity, structural complexity, and network effects (Ranganathan et al., 2018; Song et al., 2022). First, multi-actor heterogeneity reflects the diversity of participants, including technology contributors (firms), knowledge providers (universities), and policy coordinators (governments), whose complementary roles generate synergistic outcomes (Sun et al., 2006;

Wen et al., 2021). Second, structural complexity arises from the dynamic evolution of network configurations, where continuous adjustments in member relationships reflect the nonlinearity and uncertainty inherent in standardization activities (Burt, 1992). Third, network effects emphasize how an organization's position determines its resource access and technical influence. For instance, highly central actors can dominate standard-setting agendas by controlling critical resources(Goerzen, 2007). Meanwhile, those occupying structural holes optimize knowledge flow efficiency through information brokerage (Zaheer & Bell, 2005).

Extant studies analyze standard cooperation networks through two primary lenses: relational and structural embeddedness (Yan et al., 2020). Relational embeddedness emphasizes collaboration intensity and trust mechanisms. Meanwhile, structural embeddedness focuses on how network positions shape resource control and information flow (Wen et al., 2020). This study adopts the structural embeddedness perspective due to its alignment with the core objectives of standard cooperation networks: enhancing standardization capabilities through optimized network structures. Although attributes such as network clustering (subgroup formation) or tie strength (collaboration frequency) may influence standardization processes, their relevance is constrained by the rule-oriented nature of standard-setting (Qian et al.2010). Social capital theory further justifies this choice, as structural embeddedness effectively explains phenomena like knowledge redundancy and innovation suppression (Pomegbe et al., 2020). For example, strong ties in dense networks may entrench technological path dependence. Meanwhile, structural holes facilitate heterogeneous knowledge's infusion.

2.2 Standard Cooperation Networks and Standardization Capabilities

From the structural embeddedness perspective, standard cooperation networks can be deconstructed into individual positional attributes and network contextual features (Gonzalez-Brambila et al., 2013). Individual positional attributes reflect a firm's capacity to control resources and mediate information flows, measured by centrality and structural holes (Zhao et al., 2021). Centrality captures a firm's dominance over critical resources, enabling highly central actors to accelerate technical standard adoption through proposal leadership and resource integration (Borgatti & Everett, 2006) . Structural holes denote a firm's bridging role in information circulation, allowing actors occupying these positions to filter non-redundant knowledge and catalyze cross-domain technological convergence (Burt, 2004). Network contextual features are operationalized through network density, which reflects the overall cohesion among members (Gilsing et al., 2008). While dense networks enhance collaboration efficiency through reinforced trust mechanisms, they may also stifle breakthrough innovations due to knowledge homogenization (Rogers, 2003).

These dimensions collectively underpin the conceptual model of "individual positional attributes–network contextual features–standardization capabilities." The model posits that individual positional attributes (centrality and structural holes) directly shape standardization capabilities via resource control and information mediation. Meanwhile, network density moderates these effects by regulating knowledge redundancy and collaboration intensity. For instance, empirical studies demonstrate, that high network density amplifies the resource integration advantages of central firms but diminishes structural holes' information-filtering efficacy (van de Kaa, 2017). This framework provides a dynamic analytical lens for understanding how latecomer firms leverage standard cooperation networks to achieve technological catch-up.

2.3 Centrality and Technological Standardization Capacity

Centrality refers to the degree of connection between the focal enterprise and other nodes in the standard cooperation network. Enterprises with high centrality occupy an important strategic position in the standard cooperation network. They may find it is easier to obtain and integrate technological resources and information, thus improving the technological standardization capability of enterprises. On the one hand, focal enterprises with high centrality have more power in the network. Further, they have more opportunities to cooperate and exchange resources with enterprises, obtain more heterogeneous knowledge and complementary resources, and check and extract diversified information. This can help enhance the technological standardization capability of enterprises. Jiang et al. (2022) argue that enterprises with higher network centrality can have a stronger influence, attractiveness, and credibility. This can help attract more technological standard partners and improve their technological standard input, thus enhancing the enterprise technological standardization capability.

On the other hand, Sun and Liu (2018) believe that enterprises with high centrality have a stronger ability to integrate information and resources, and absorb them into new knowledge that is valuable for their own innovation. This can strengthen enterprise innovation capability. Di et al. (2024) believes that focal enterprises occupying a central position can have more channels to obtain heterogeneous resources and information. Further, the rich and diversified access to technological resources, and the reduction of information asymmetry is conducive for integrating resources, effectively transforming external resources into internal ones, and improving the efficiency of enterprise technological standard-setting. Together, these can improve the technological standardization capability of enterprises. Therefore, we hypothesize the following:

H1: The degree of network centrality positively affects the technological standardization capability of enterprises.

2.4 Structure Holes and Technological Standardization Capacity

Drawing on Burt’s (1992) definition of structural holes, we argue that the standard partners directly contacted by the focal firm do not have direct contact or intermittent relationship with each other. Further, the focal enterprises can be considered to occupy a structural hole from the network’s perspective as a whole. Its essence lies in the channel to obtain external resources and influence the behavior of other node enterprises through information asymmetry at both ends (Wen et al., 2020). Focal enterprises occupying structural holes can provide resource and control advantages.

From resource acquisition and integration perspectives, Xu et al. (2019) argue that focal enterprises occupying structural holes can screen and integrate resources due to non-redundant heterogeneous ties. Further, they can obtain effective information and technological resources from direct access. Finally, they can more clearly select partners with matching resources to reduce maintenance costs and improve technological standardization capability. Wiegmann et al. (2017) highlighted that occupying structural holes means having non-redundant information dissemination channels. This can help in obtaining more complete information, grasping industry dynamics, and promoting the formation of consensus on technical solutions to enhance the enterprise's technological standardization domination and following ability.

Finally, from a control advantage perspective, Burt’s structural holes theory notes that enterprises occupying structural holes have access to heterogeneous resources, and thus, become the information and resource control center in the cooperative network. Moreover, firms in a standard cooperative network may lead to redundancy of resources and information due to the similarity of their organizational structure and operation. However, Cai et al. (2021) argue that focal firms occupying structural holes can exert control advantages, such as controlling the direction of information flow and critical path of technological resource flow. This can aid in better identifying the risks and opportunities for focal firms, and positively influence focal firms' technological innovation and technological standardization capability. Therefore, we hypothesize:

H2: The location of structural holes in the standard cooperation network positively affects the technological standardization capability of enterprises.

2.5 Moderating Role of Network Density

Network density refers the extent of interconnectedness among actors in a network. It critically shapes how positional advantages translate into technological standardization capabilities. For centrally positioned firms, dense networks amplify resource mobilization and coordination efficiency. Centrally located actors leverage frequent interactions and shared trust in high-density environments (Zeng et al,. 2016), enabling them to consolidate heterogeneous knowledge (Li & Gao, 2023) and drive consensus through redundant communication channels (Wu, 2014). Such dynamics reduce transaction risks and stabilize collaborative processes, as evidenced in policy-driven standardization alliances where dominant players efficiently integrate cross-partner inputs (Vakili, 2016). This synergy between centrality and density enhances firms' capacity to codify technical standards, particularly in industries requiring rapid consensus-building. Thus, we hypothesize the following:

H3: Network density strengthens the positive relationship between centrality in standard cooperation networks and technological standardization capability.

Conversely, dense networks erode the advantages of structural hole positions. Firms bridging structural holes rely on brokering non-redundant information across disconnected clusters (Shi et al., 2020). Yet, heightened density fosters knowledge homogeneity and partner similarity, diminishing the uniqueness of bridged resources (Zou & Zeng, 2020). Two mechanisms explain why redundancy hampers standardization capability: First, overlapping information flows force firms to allocate excessive resources to filter repetitive inputs rather than integrating novel knowledge (Wen & Zeng, 2019). Second, homogenized knowledge pools constrain arbitrage opportunities critical for disruptive innovation. In technology-intensive sectors like communication equipment, where standardization success hinges on synthesizing novel technical trajectories, dense networks exacerbate redundancy. This is particularly true in policy-driven ecosystems where politically aligned partners replicate existing frameworks. These dynamics weaken structural hole occupants' control and negotiation power, as their bridging role becomes redundant in overconnected networks.

H4: Network density weakens the positive relationship between structural holes in standard cooperation networks and technological standardization capability.

Our conceptual model is summarized in Fig. 1.

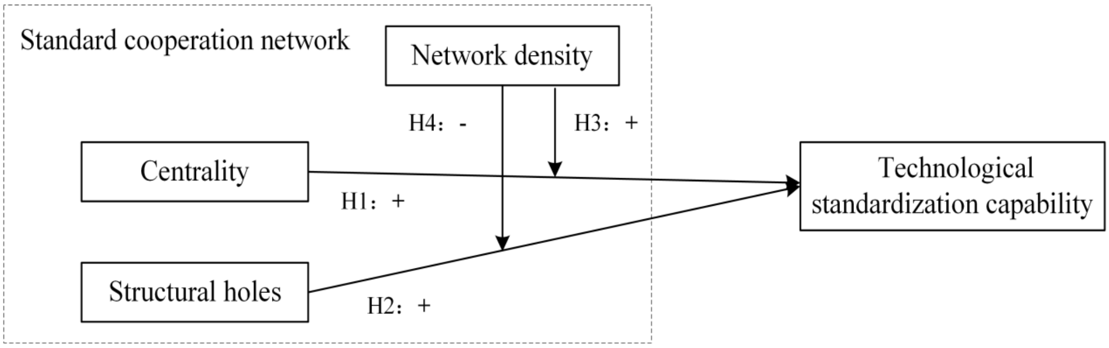

Fig. 1 – Conceptual model. Source: Author's own work

3 METHODOLOGY

3.1 Data Collection

This study focused on China's communication equipment manufacturing industry, constructing a comprehensive database of standard cooperation networks based on all firms participating in national standard-setting activities from 2008 to 2023. The data collection and processing procedures were as follows.

First, industry boundaries were defined using the "communication equipment" subclass (classification codes: M30–M39) under the "broadcasting and communication" category in the Chinese classification of standards. National standard data were retrieved from the Standard Information Service Platform administered by the Standardization Administration of China, encompassing fields such as standard codes, release dates, and drafting entities. To ensure data quality, three filters were applied: (1) retaining only standards co-drafted by two or more entities; (2) restricting the timeframe to January 2008–December 2023; and (3) cross-verifying relevance using keywords (e.g., "communication equipment," "base stations," and "optical transmission") and classification codes. This yielded 239 national standards involving 237 drafting entities, including 179 manufacturing firms, 21 research institutes, 12 universities, and 25 industry associations.

Second, drafting entities were rigorously identified and cleaned. Enterprise registration details were verified via the Qichacha platform to exclude non-manufacturing entities (e.g., trading companies and system integrators). Inconsistent entity names were standardized using official corporate websites and annual reports. Firm-level attributes, including founding year, listed status, ownership type (state-owned or private), and high-tech certification, were extracted from the China Stock Market & Accounting Research database, and Qichacha. Notably, recent policies in China have encouraged small and medium-sized enterprises (SMEs) to engage in standardization. Incomplete statistics indicate that 40% of SMEs in the communication sector participate in standard-setting activities. Preliminary tests revealed no significant correlation between firm size (SMEs versus large enterprises) and technological standardization capability ($p > 0.1$). Consequently, firm size was excluded as a control variable. Meanwhile, founding year, listed status, and ownership type show significant explanatory power ($p < 0.05$), and were retained.

Third, a standard cooperation network was constructed using joint drafting relationships among the 237 entities. A 239×237 bipartite matrix was generated and analyzed in UCINET 6.0 to calculate degree centrality, structural holes (Burt's constraint index), and network density. The cooperation matrix and a partial network visualization were presented in Table 1 and Figure 2.

These procedures ensure full coverage of all entities in China's national standard cooperation network for communication equipment, with transparent filtering rules and endogenous controls enhancing reproducibility and validity.

Tab. 1 – Standard Cooperation Network 0-1 Matrix Table (part). Source: Authors' own analysis

	Zhejiang Nandu	Haerbin Guangyu	ZhongXinTongXun	Hua Wei	Guangzhou Saijie	Xian Hangtian
Zhejiang Nandu	0	1	0	0	0	0
Haerbin Guangyu	1	0	0	0	0	0
ZhongXinTongXun	0	0	0	1	0	0
Hua Wei	0	0	1	0	0	0
Guangzhou Saijie	0	0	0	0	0	1
Xian Hangtian	0	0	0	0	1	0

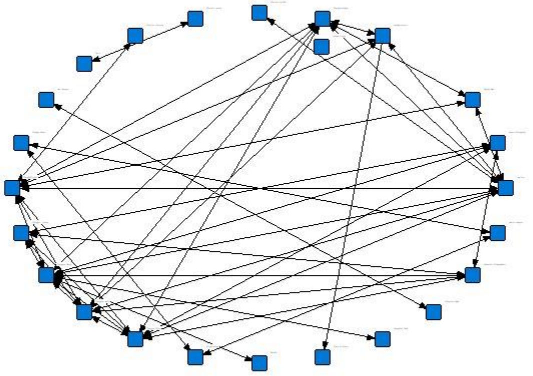

Fig. 2 – Standard Cooperation Network Diagram (part). Source: Authors' own analysis

3.2 Variable Measurement

Dependent variable: Technological standardization capability influences the enterprise's technological standard-setting. According to Zou et al. (2017), the ability to become a technological standard drafting unit indicates that the firm has substantial voice in formulating technological standards. Thus, the number of national standards formulated through the drafting unit's participation can be a good response to the enterprise's influence in formulating technological standards. We adopted the drafting unit's capability to formulate technological standards to measure its technological standardization capability. Therefore, drawing on Zuo & Lin (2022), we argued that the technological standardization capability of drafting units can be reflected by the number of national standards that drafting units participate in formulating.

Independent variables: We adopted two explanatory variables: centrality and structural holes.

Centrality: It refers to a measure of a node's importance in the network. Three commonly used metrics are degree, proximity, and intermediate centralities. Proximity centrality refers to a node's neighborliness. Intermediate centrality refers to a node's ability to act as a mediator. Degree centrality is the sum of the number of other nodes which are directly connected to a network node. However, not all members in the technological standards network have direct connections. Further, this study focuses on the differences in response to the position of different focal firms in the center of the network. Hence, we finally adopted the degree of centrality as the final measure.

Structural holes: It is generally measured by the limit system and effective size. The restriction regime is an indicator of the extent to which individuals are restricted by their direct contacts in the network. Effective size reflects the number of non-redundant contacts that an individual can reach through their direct contacts. In this study, structural holes refer to the non-redundant relationship between two nodes in a network. Therefore, effective size was used as its proxy variable as a measure of the focal firm's influence in the individual's network. A higher effective size indicates that the focal firm obtains effective resources from the periphery, thus gaining a certain resource advantage and control advantage. Regarding the measurement of effective size, we used the UCINET software to calculate the network structure holes.

Moderator variable: Network density referred to the closeness of the links between nodes in a network. The closer the cooperative links between network nodes, the greater the network density. This study focused on the egocentric network density of focal firms, which refers to the closeness of the connections between focal firms. The measure of network density is theoretically based on the comparison of the number of actual connections within the network and number of possible connections (Lovejoy & Sinha, 2010). In this study, network density was calculated with the help of UCINET software.

Control variables: The control variables were mainly incorporated at the enterprise level. First, to weaken the time difference in the enterprise’s establishment to affect the enterprise’s technological standardization capability, the logarithm of enterprise age was selected as the control variable. In addition, state-owned enterprises have advantages in resource sharing and information acquisition, which can positively impact enterprises’ participation in technological standardization. Therefore, dummy variables for state-ownership, listing status, and enterprise innovativeness were introduced. Each took a value of 1 if the enterprise was state-owned, listed, and innovative, respectively, and 0 otherwise.

Tab. 2 – Variable definitions. Source: Authors’ own work

Variables	Variable symbol	Variable measures
Technological standardization capacity	TSC	The number of national standards that the drafting unit participated in developing
Centrality	DC	The sum of the number of other nodes to which a network node is directly connected
Structural holes	SH	The focus enterprise lacks the quotient between the actual number of node pairs and the maximum possible number of node pairs that are directly linked
Network density	ND	A comparison of the number of actual contacts within the network and the number of contacts that could occur
Enterprise age	Ln(EA)	The number of years a business has been established is logarithmic
State-ownership	SO	For dummy variables, "1" means yes and "0" means no.
Innovation	I	For dummy variables, "1" means yes and "0" means no.
Listed	L	For dummy variables, "1" means yes and "0" means no.

https://doi.org/10.7441/joc.2026.01.04

4 RESULTS

4.1 Descriptive Statistics and Correlation Analysis Results

First, we perform descriptive statistics and preliminary diagnostics using STATA. As presented in Table 3, technological standardization capability exhibits a non-negative integer distribution. Given its substantial overdispersion (variance = 38.45 vs. mean = 11.66), a negative binomial regression model was selected over conventional linear regression or Poisson models to appropriately address count data characteristics.

Tab. 3 – Descriptive statistics. Source: Authors' own calculations

Stats	TSC	DC	SH	ND	Ln(EA)	SO	I	L
Mean	11.66	13.98	5.190	75.77	3.119	0.220	0.530	0.244
SD	38.45	11.79	8.404	26.19	0.361	0.415	0.501	0.431
Min	0	0	0	0	1.099	0	0	0
p50	2	9	2.083	89.31	3.135	0	1	0
Max	420	62	45.63	100	4.043	1	1	1

Correlation analysis results (Table 4) revealed moderate inter-variable relationships, with all coefficients below the 0.7 multicollinearity threshold. Initial findings suggested positive associations between centrality, structural holes, and standardization capability, while network density demonstrated a negative correlation. To further validate multicollinearity concerns, variance inflation factor (VIF) tests were conducted, yielding values ranging from 1.07 to 6.6. This is well below the critical threshold of 10 (O'brien, 2007). These diagnostics demonstrate the robustness of variable inclusion for subsequent regression modeling.

Tab. 4 – Correlation analysis results. Source: Authors' own calculations

Variable	1	2	3	4	5	6	7	8
TSC	1							
DC	0.512***	1						
SH	0.554***	0.846***	1					
ND	-0.210***	-0.377***	-0.634***	1				
Ln(EA)	0.165**	0.113	0.119	-0.0850	1			
SO	-0.0140	0.0200	0.00900	-0.0630	0.198**	1		
I	0.125	0.261***	0.126	-0.108	0.0490	0.204***	1	
L	0.0310	0.340***	0.246***	-0.166**	0.119	0.0760	0.364***	1

Tab. 5 – Variance inflation factor test results. Source: Authors' own calculations

Variable	VIF	1/VIF
DC	4.910	0.204
SH	6.540	0.153
ND	2.060	0.485
Ln(EA)	1.070	0.939
SO	1.080	0.929
I	1.240	0.807
L	1.230	0.810
TSC	-	-
MeanVIF	2.590	

4.2 Hypothesis Testing

4.2.1 Baseline Regression

A hierarchical regression approach was employed to systematically examine the effects of firm characteristics and network structural features. Model 1 incorporates control variables (firm age, public listing status, state-owned ownership, and innovative enterprise designation). It reveals that firm age ($\beta = 1.276$, $p < 0.01$) and innovative enterprise status ($\beta = 0.893$, $p < 0.01$) as significant predictors of technological standardization capability. This aligns with theoretical expectations that innovation-oriented firms leverage their R&D advantages to drive standardization outcomes.

Model 2 introduced degree centrality, revealing a statistically significant positive effect ($\beta = 0.064$, $p < 0.01$), thereby supporting H1. Including structural holes in Model 3 further strengthened these findings ($\beta = 0.059$, $p < 0.01$), supporting H2 that brokerage positions enhance standardization influence. Model 4 demonstrated that network density exerted a countervailing negative impact ($\beta = -0.015$, $p < 0.01$). Thus, sparser collaboration networks foster greater standardization capability. This finding is consistent with resource competition dynamics in densely connected systems.

Tab.6 – Negative binomial regression results. Source: Authors' own calculations

Variable	Model.1	Model.2	Model.3	Model.4
TSC				
Ln(EA)	1.276***	0.643***	0.785***	1.141***
	(0.256)	(0.246)	(0.259)	(0.265)
SO	-0.279	0.191	0.179	-0.055
	(0.262)	(0.223)	(0.242)	(0.262)
I	0.742***	0.398**	0.503**	0.635***
	(0.233)	(0.194)	(0.207)	(0.226)
L	0.036	-0.364*	-0.188	-0.105
	(0.254)	(0.218)	(0.230)	(0.249)
DC		0.064***		
		(0.008)		
SH			0.059***	
			(0.010)	
ND				-0.015***
				(0.004)
_cons	-2.081***	-1.200	-1.028	-0.579
	(0.801)	(0.762)	(0.807)	(0.916)

Standard errors in parentheses
$^{*}p<0.1$, $^{**}p<0.05$, $^{***}p<0.01$

4.2.2 Moderating Effects

Interactive models tested network density's contingent role in shaping positional advantages. Model 5 revealed a positive moderating effect of density on the centrality-standardization relationship ($\beta = 0.016$, $p < 0.01$), supporting H3. This implies centralized firms amplify their standardization impact in tightly-knit networks through enhanced resource control. Conversely, Model 6 identifies a weakly negative interaction between density and structural holes ($\beta = -0.002$, $p < 0.10$), corroborating H4. The diminishing returns to brokerage positions in dense networks likely stem from redundant information flows and reduced arbitrage opportunities.

Tab.7 – Results on the moderating effect of network density. Source: Authors' own calculations

Variable	Model.1	Model.5	Model.6
TSC	1.276^{***}	0.634^{***}	0.609^{**}
	(0.256)	(0.239)	(0.240)
Ln(EA)	-0.279	0.196	0.135
	(0.262)	(0.214)	(0.219)
SO	0.742^{***}	0.368^{*}	0.415^{**}
	(0.233)	(0.189)	(0.193)
I	0.036	-0.244	-0.411^{*}
	(0.254)	(0.218)	(0.215)
DC		-1.474^{***}	0.091^{***}
		(0.496)	(0.018)
SH		1.527^{***}	0.020
		(0.495)	(0.035)
ND		-0.017^{**}	-0.000
		(0.008)	(0.005)
ND*DC		0.016^{***}	
		(0.005)	
ND*SH			-0.002^{*}
			(0.001)
_cons	-2.081^{***}	-1.101	-0.984
	(0.801)	(0.824)	(0.855)

Standard errors in parentheses
$^{*}p<0.1$, $^{**}p<0.05$, $^{***}p<0.01$

4.3 Endogeneity Analysis

This study addresses potential endogeneity concerns by establishing the dominant causal direction of "network positions → technological standardization capability" through dual lenses of institutional sequencing and network structural dynamics.

First, the institutional sequencing of standardization activities necessitates prior network embeddedness. Technical standardization requires strict institutional access rules. Firms must secure membership in standardization bodies and build collaborative networks before proposing or negotiating technical specifications. This process typically spans 3–5 years (e.g., 4.2 years on average for 3GPP working groups to finalize initial standards), significantly exceeding the 1–2-year lifecycle of individual standard development (Leiponen, 2008). Consequently, network embeddedness temporally precedes the formation of standardization capabilities.

Second, path dependence in network structures mitigates reverse causality. Interfirm collaboration networks exhibit structural inertia (Moran, 2005), as centrality or structural hole acquisition depends on long-term resource accumulation and trust-building. For instance, Huawei's progression from a peripheral participant in the ITU-T working groups in the early 2000s to a leading role in 5G standardization by the 2010s exemplifies this structural rigidity. Such inertia implies that short-term improvements in technological capabilities rarely alter network positions.

Third, industry evidence reinforces the primacy of network positions. Powell et al. (2005) demonstrated that technologically advanced but network-isolated firms (e.g., early WiMAX proponents) were often excluded from mainstream standardization. Meanwhile, network-central firms with suboptimal technologies (e.g., certain 4G proposal leaders) dominated agenda-setting processes. Thus, network positions serve as a necessary but insufficient condition for standardization success, negating reverse causality.

While bidirectional relationships cannot be entirely ruled out, the combined effects of institutional sequencing and path dependence substantiate the “network-driven capability” causal logic, minimizing endogeneity threats to the conclusions.

4.4 Discussion

4.4.1 Network Centrality, Network Density, and Technological Standardization Capability

Network Centrality and Technological Standardization Capability

First, we find that network centrality positively influences firms’ technological standardization capabilities. This finding aligns with the RBV (Barney, 1991) and structural embeddedness theory (Burt, 2004). These posit that central network positions grant firms control over critical resources and information flows, enabling them to dominate the formulation and diffusion of technical standards. In developing economies, latecomer firms embedded in high-centrality nodes of standard cooperation networks can rapidly integrate external technological resources and policy support, compensating for their internal knowledge gaps. For instance, Chinese telecommunications firms participating in international standard-setting organizations (e.g., 3GPP) have successfully integrated self-developed 5G technical proposals into global standards, transitioning from technological followers to rule-makers (Wu & de Vries, 2022). These findings are consistent with studies on innovation networks (Ahuja, 2000) and technology collaboration networks (Powell et al., 1996). This demonstrates that network centrality serves as a universal driver of resource control and influence across diverse collaborative networks.

Moderating Role of Network Density

Next, we show that network density positively moderates the relationship between centrality and technological standardization capability. Drawing on social capital theory, high-density networks strengthen trust mechanisms and collaboration norms, reducing coordination costs for central firms and accelerating technical solution adoption (Freeman, 1978). For example, intensive interactions among members of the China Communications Standards Association have facilitated rapid consensus on technical specifications (Zhou et al., 2012). However, knowledge diffusion theory highlights that overly dense networks may induce knowledge redundancy, stifling breakthrough innovations (Najafi-Tavani, 2018). In such networks, frequent exchanges of homogeneous knowledge risk entrenching existing technical trajectories. Leveraging their resource control, central firms can mitigate redundancy by selectively integrating critical knowledge. This moderating effect aligns with findings in technology collaboration networks. Thus, network density’s amplifying role on centrality advantages transcends network types.

4.4.2 Structural Holes, Network Density, and Technological Standardization Capability

Structural Holes and Technological Standardization Capability

First, occupying structural holes significantly enhances firms’ technological standardization capabilities. This contrasts with studies on technology collaboration networks, where structural holes exhibit an inverted U-shaped relationship with innovation performance (Zaheer & Bell, 2020). The divergence stems from the distinct objectives of standard cooperation networks: While technology collaboration relies on deep trust to codify tacit knowledge (Sun, 2007), standardization prioritizes bridging discrete knowledge domains to establish compatible frameworks. In developing economies, firms in structural holes act as information brokers, aligning localized technological needs with global standardization systems. For example, Huawei's role in internet-of-things standardization, bridging industrial automation and cloud computing domains, has driven solutions tailored to emerging markets (Wang et al., 2016). This linear positive effect underscores how latecomer firms leverage structural holes to bypass technological path dependency and transform localized innovations into global standards.

Moderating Effect of Network Density

Next, network density weakens the positive relationship between structural holes and technological standardization capability. Social capital theory explains this phenomenon: high-density networks reinforce homogeneous interactions, eroding the informational heterogeneity inherent to structural holes (Liu et al., 2023). For instance, tightly knit subgroups in China's telecommunications alliances prioritize incremental improvements (e.g., 4G to 5G transitions). Meanwhile, cross-domain knowledge integration, critical for structural holes, relies on diversity in sparse networks (Singh & Stout, 2018). Additionally, normative pressures in dense networks may suppress non-mainstream technical proposals, constraining latecomer firms' capacity for disruptive innovation (Uzzi, 1997).

This conclusion diverges from innovation network studies, where density enhances structural holes' positive influence on technological innovation (Shukla et al., 2024). The contrasting moderating effects highlight fundamental differences between network types. In technology collaboration networks, density complements structural holes by facilitating tacit knowledge transfer (Lamb et al., 2016). However, in standard cooperation networks, density prioritizes rule harmonization over exploration, suppressing structural holes' diversity-driven value (Martínez-Noya & García-Canal, 2021). For latecomer firms, this implies a strategic trade-off between compliance with dominant technical norms and the pursuit of innovative autonomy in high-density standardization contexts.

5 CONCLUSION

5.1 Theoretical Contributions

This study advances the literature on interorganizational collaboration by elucidating the unique mechanisms of standard cooperation networks and their differentiated impacts on firms' technological standardization capabilities. The contributions are articulated in two interrelated dimensions.

First, this study expands the theoretical boundaries of collaboration network research. Studies predominantly focus on patent pools, technology alliances, and R&D collaboration networks, emphasizing knowledge sharing and innovation outcomes (Beaudry & Schiffauerova, 2011; Zhou et al., 2019). Meanwhile, this study shifts the analytical lens to standard cooperation networks. This is a distinct organizational form oriented toward rule-setting rather than technology development. These networks fundamentally differ in membership composition (e.g., firms, governments, and international bodies), collaboration dynamics (competitive-cooperative hybridity), and strategic objectives (market dominance through compatibility standards). By challenging the assumption that all collaboration networks operate under similar mechanisms, this research enriches the theoretical understanding of how institutional goals shape network structures and outcomes.

Second, we construct a structural embeddedness framework to explain standardization capabilities, validating both universal patterns and context-specific pathways through empirical analysis of China's telecommunications industry. The findings reveal cross-context consistency in the positive relationship between network centrality and standardization capabilities, and network density's amplifying role on centrality advantages. This pattern has been observed in U.S. semiconductor alliances (Meng & Wang, 2023) and European telecommunications standardization networks (Cantero Gamito, 2024). Meanwhile, we identify a linear positive effect of structural holes on standardization capabilities. This differs from research in developed economies, which find an inverted U-shaped relationship in U.S. biotechnology alliances (Zhang et al., 2007) and German industry 4.0 innovation networks (Sarbu., 2021). Furthermore, the weakening effect of network density on structural holes' benefits in standardization networks contrasts with findings from U.S. open innovation alliances (Reagans & McEvily, 2003). This underscores how network interactions depend on institutional objectives, whether on exploratory innovation or rule harmonization. These insights extend structural hole theory to latecomer contexts and refine network embeddedness' contingent logic.

Collectively, the findings provide a nuanced framework for understanding how latecomer firms leverage network positioning to transform from rule-takers to rule-makers, bridging the gap between Western-centric network theories and the realities of emerging economies.

5.2 Practical Implications

This study proposes a strategic framework for latecomer firms in developing economies to leverage standard cooperation networks for technological catch-up. This can help them leverage latecomer advantages and enhance global competitiveness.

Firm Level: Dynamic Positioning and Knowledge Integration

Latecomer firms should adopt dynamic network positioning strategies to balance resource control and knowledge diversity. During technological catch-up phases, firms should prioritize engaging structural holes to bridge cross-domain knowledge gaps, integrating heterogeneous resources from international standards systems to align localized needs with global frameworks. As technologies mature, firms must transition toward central network positions to lead standard revision processes and consolidate agenda-setting power. Concurrently, establishing institutional linkages between R&D and standardization activities (e.g., proactive participation in technical committees of international standards organizations) enables systematic translation of local innovations into global technical rules.

Government Level: Institutional Empowerment and Ecosystem Restructuring

Governments should reshape standardization ecosystems through targeted policies. Tiered incentive mechanisms can lower entry barriers, such as tax relief and R&D subsidies for firms leading international standards, and dedicated funding for SMEs in pre-standardization alliances. Constructing a multi-layered collaboration network, anchored by core firms as international standards conveners and supported by open innovation platforms, facilitates cross-organizational knowledge flows. South-south collaboration mechanisms should be promoted to amplify developing economies' collective bargaining power in global standards organizations, embedding shared priorities (e.g., cost-sensitive technology adaptation) into standardization agendas. Strengthening human capital through curriculum reforms and international internship programs is critical to cultivating interdisciplinary standardization experts.

Industry Association Level: Redundancy Governance and Collaborative Innovation

Industry associations must optimize knowledge flow efficiency through structural interventions. A phased "standards sandbox" mechanism, which encourages loose collaborations for exploratory innovation in early stages and consolidating core firm leadership in later stages, mitigates path dependency via cross-firm anonymized evaluations and dynamic team formation. Establishing shared pools of standard-essential patents with fair, reasonable, and non-discriminatory licensing rules reduces redundant R&D investments. Proactive monitoring of network health metrics, coupled with decentralized interventions (e.g., mandatory cross-licensing of critical interface technologies), prevents knowledge homogeneity from stifling disruptive innovation.

5.3 Limitations and Future Research Directions

First, the exclusive focus on China's communication equipment manufacturing industry may constrain the findings' generalizability due to context-specific factors such as technological intensity and policy dependence. The mechanisms through which network positions (centrality and structural holes) and density influence standardization capabilities may vary across industries with differing technological barriers or market structures. For instance, centrality's resource integration effect may diminish in industries characterized by slower technological cycles. Future research can extend the framework to heterogeneous sectors (e.g., biopharmaceuticals and renewable energy) or incorporate cross-national datasets to enhance external validity.

Second, the analysis of network density's moderating role insufficiently addresses its boundary conditions. Density's attenuating effect on structural holes may be more pronounced in heavily regulated or technology-monopolized industries. Meanwhile, its directionality can reverse in open-competition contexts. Subsequent studies should incorporate contextual variables (e.g., industry-specific technology diffusion rates and policy intensity levels) to systematically unpack the heterogeneity and dynamic evolution of these moderating mechanisms.

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