Postprint: Empirical Research on the Mechanism of Synergistic Effects of Multi-Stakeholder Information Chains in Smart Cities

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Abstract

[Purpose/Significance] Analyzing the mechanism of collaborative effects in the multi-stakeholder information chain of smart cities assists smart city managers in identifying the key factors for enhancing the collaborative effects of the multi-stakeholder information chain, thereby elevating the smart level of smart cities from the perspective of multi-stakeholder information chain collaborative services and providing citizens with higher-quality smart services. [Method/Process] Based on the identification and analysis of information stakeholders, information, and information environment in China' s smart city multi-stakeholder information chain, six research hypotheses concerning the mechanism of collaborative effects in the smart city multi-stakeholder information chain are proposed across three dimensions: stakeholder collaboration, information collaboration, and mechanism collaboration. A questionnaire survey was conducted to obtain 456 valid data sets, and structural equation modeling was utilized to test the proposed research hypotheses. [Results/Conclusion] The test results demonstrate that mechanism collaboration and information collaboration directly influence the collaborative effects of the smart city multi-stakeholder information chain; stakeholder collaboration indirectly influences the collaborative effects of the smart city multi-stakeholder information chain through mechanism collaboration and information collaboration. Based on these results, five targeted specific strategies for enhancing the collaborative effects of the smart city multi-stakeholder information chain are proposed, offering valuable references for research and practice on the mechanism of collaborative effects in smart city multi-stakeholder information chains.

Full Text

Preamble

An Empirical Study on the Synergistic Effect Mechanism of Multi-Subject Information Chain in Smart Cities

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Abstract

[**Purpose/Significance**] Exploring the synergistic effect mechanism of multi-subject information chains in smart cities helps administrators identify key factors for enhancing these synergistic effects, thereby improving the overall smart level of cities at the collaborative service level and providing citizens with higher-quality smart services. [**Method/Process**] Based on the identification and analysis of information subjects, information, and information environments within China' s smart city multi-subject information chains, this study proposes six research hypotheses regarding the synergistic effect mechanism from three dimensions: subject synergy, information synergy, and mechanism synergy. A total of 456 valid datasets were collected through questionnaire surveys, and structural equation modeling was employed to test these hypotheses. [**Result/Conclusion**] The results indicate that mechanism synergy and information synergy directly affect the synergistic effect of smart city multi-subject information chains, while subject synergy indirectly influences the synergistic effect through mechanism synergy and information synergy. Based on these findings, five targeted strategies are proposed to enhance the synergistic effect, providing valuable references for both theoretical research and practical implementation.

Keywords: smart city; information chain; multiple subjects; subject synergy; mechanism synergy; information synergy

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1. Research Review

The concept of smart cities originated from IBM' s "Smarter Planet" initiative in 2008. Regarding conceptual research, Zhu Kaiyue et al. employed content analysis to examine core journal literature on smart cities in CNKI over the past decade, using Nvivo software to extract eight core categories: innovation, management, intelligence, information technology, resources, services, life, and sustainability. They defined smart cities as integrating information technology with urban development to improve quality of life and promote sustainable development through innovative models, resource optimization, and enhanced operational efficiency. B. Mattioni et al. argue that smart cities represent a balance between hardware and software, technology and human resources, with the ultimate goal of ensuring residents' quality of life.

Regarding smart city development evaluation, G.C. Lazaroiu et al. constructed a fuzzy logic evaluation model to assess the smart levels of ten representative Italian cities. Li Xia et al., viewing smart cities as an advanced form of urban informatization, developed an evaluation index system comprising five indicators—innovation-driven development, smart industry level, intelligent infrastructure support, smart city information hub, and smart city information services—to examine regional differences in smart city informatization practices, using eight national central cities as case studies. Zhang Changliang et al. compared smart city construction between China and Singapore across three dimensions (smart government, smart transportation, and smart healthcare), concluding that China urgently needs to break down information synergy barriers between departments.

Recent research includes: (1) Studies on smart city information synergy mechanisms. Ma Jie et al. constructed a government smart service information synergy mechanism based on linked data, positing that "people" are the subjects of information synergy, "events" are the objects of smart services, and "information" is the fuel that drives government smart operations. (2) Research on smart city information service synergy systems. Wu Zhihong et al. applied matrix theory to integrate organization, technology, resources, personnel, services, and users into a regional cluster-based synergy system model to promote cluster integration and collaborative operation. (3) Studies on information synergy structure measurement and optimization. Chen Rui et al. developed a multi-subject information synergy difference measurement model using fuzzy clustering algorithms, providing optimization strategies from difference and relationship measurement perspectives.

As a complex giant system, smart cities can be better understood through information chain theory to grasp multi-subject information flow and synergy processes. Ma Jie et al. designed a smart city information ecological chain model based on multi-subject synergy to inform construction and management. Current research on China's smart city multi-subject information chain synergy effects primarily focuses on conceptual discussions, development evaluation, synergy mechanism and measurement index construction, and information ecological chain design. However, in-depth studies on the synergistic effect mechanism are scarce. Such research would help administrators identify key elements for enhancing synergy effects, thereby improving smart service levels. This paper adopts a hypothesis-testing approach through empirical research to uncover the synergistic effect mechanism of China's smart city multi-subject information chains.

2. Identification and Analysis of Smart City Multi-Subject Information Chains

An information chain constitutes a chain-like dependency relationship of information flow comprising information subjects, information, and information environments. In smart cities, information subjects include various government departments involved in smart city construction and development, as well as the citizens they serve. Information refers to data flowing among these subjects, while the information environment encompasses various supporting mechanisms such as economic and policy environments that ensure smooth information chain operation.

The "Guiding Opinions on Promoting the Healthy Development of Smart Cities" (hereinafter referred to as the "Opinions"), jointly issued by eight ministries including the National Development and Reform Commission, established fundamental principles for China's smart city construction. Using the Opinions' release date (August 27, 2014) as the starting point, this study collected 3,052 relevant documents—including ministerial orders, normative documents, and announcements—from the eight co-issuing ministries over the subsequent five years. Through thematic manual screening, these documents on smart government construction served as target texts.

Python programming was employed for named entity recognition of the target texts to identify government departments as information subjects within the smart city multi-subject information chain. Combined with analysis of information flow patterns and environmental support mechanisms, China's smart city multi-subject information chain was mapped [Figure 1: see original paper].

As shown in Figure 1, the information environment comprises economic, policy, technical, infrastructure, information security, and information openness environments. Within this environment, China's smart city multi-subject information chain includes 35 information subjects (represented by circles, with larger circles indicating greater information sending/receiving volumes) and 400 sub-information chains generated through inter-subject information flow. The interaction among information subjects, information, and information environments ensures the synergistic effect of the information chain.

3. Synergistic Effect of Smart City Multi-Subject Information Chains

Synergetics, established by German physicist Hermann Haken in the early 1970s, originated from systematic studies of synergistic effects. The synergistic effect of smart city multi-subject information chains is a complex, dynamic outcome produced through collaborative interaction among information subjects, information, and information environments. Through subject synergy, information synergy, and mechanism synergy, the information chain achieves safe, efficient, and intelligent operation, thereby enhancing its synergistic effect.

While similar to cross-organizational alliance synergistic mechanisms, the information chain' s unique characteristics require a specialized model. Based on cross-organizational alliance synergy models and incorporating smart city information chain features, this study constructs a synergistic effect mechanism model [Figure 2: see original paper].

As illustrated in Figure 2, the smart city multi-subject information chain comprises three elements: information subjects, information, and information environments. Information subjects correspond to subject synergy (encompassing strategic, organizational, and management synergy); information corresponds to information synergy (including information sharing, information flow, and interactive learning); and information environments correspond to mechanism synergy (comprising mutual trust, conflict resolution, and risk prevention mechanisms). Understanding this mechanism helps enhance synergistic effects and ensure safe, efficient, and intelligent operation.

3.1 Research Hypotheses

H1: Subject synergy positively correlates with the synergistic effect of smart city multi-subject information chains. As smart city construction rapidly develops, the number of information subjects (currently 35) will continue growing, potentially causing strategic misalignment and coordination challenges. This hypothesis examines whether and how these issues affect synergistic effects.

H2: Mechanism synergy positively correlates with the synergistic effect. As an indispensable element for realizing synergistic effects, mechanism synergy provides the institutional methods and means, offering motivation and support for subject synergy.

H3: Information synergy positively correlates with the synergistic effect. Information is the key resource in the synergy process, and information synergy is essential for maximizing information' s effect during collaboration.

Based on synergetics theory, the synergistic effect emerges not from individual components but from cross-interactions among subject synergy, information synergy, and mechanism synergy through information subjects, information, and information environments. Therefore:

H4: Mechanism synergy positively correlates with subject synergy.
H5: Mechanism synergy positively correlates with information synergy.
H6: Subject synergy positively correlates with information synergy.

3.2 Research Methods and Variables

Data were collected through questionnaire surveys to explore and verify the hypotheses. All questions (Table 1) used a seven-point Likert scale (1 = "completely disagree" to 7 = "completely agree").

Table 1: Indicator Variables and Descriptions

Latent Variable	Sub-dimension	Indicator	Description
Subject Synergy (A)	Strategic Synergy (A1)	a1	Consistent strategic goals among smart city government departments during cooperation
		a2	Holistic nature of strategic goal transformations during cooperation
	Organizational Synergy (A2)	a3	Tight inter-departmental coordination during cooperation
		a4	Optimized resource allocation through collaboration
	Management Synergy (A3)	a5	Personnel and division-of-labor collaboration among departments
Mechanism Synergy (B)	Mutual Trust Mechanism (B1)	b1	Trust-based relationships improving communication efficiency
	Conflict Resolution Mechanism (B2)	b2	Mechanisms enabling joint problem-solving
	Risk Prevention Mechanism (B3)	b3	Mechanisms reducing risk probability
		b4	Mechanisms enhancing cooperation stability

Latent Variable	Sub-dimension	Indicator	Description
Information Synergy (C)	Information Sharing Synergy (C1)	c1	Improved information sharing efficiency
	Information Flow Synergy (C2)	c2	Increased information flow frequency
	Interactive Learning (C3)	c3	Technology exchange among departments
Synergistic Effect (D)	Safety (D1)	d1	Enhanced information chain safety
	Efficiency (D2)	d2	Enhanced information chain efficiency
	Intelligence (D3)	d3	Enhanced information chain intelligence

Measurement Approach: - **Subject synergy** was measured using three second-order indicators (strategic, organizational, management synergy) with five observable items, drawing from supply chain and industrial cluster research. - **Mechanism synergy** employed three second-order indicators (trust, conflict resolution, risk prevention) with four observable items, adapted from inter-organizational alliance studies. - **Information synergy** used three second-order indicators (sharing, flow, interactive learning) with three observable items, synthesizing research on supply chain information synergy. - **Synergistic effect** was assessed through outcome-based measures of safety, efficiency, and intelligence.

3.3 Sample Selection and Data Sources

3.3.1 Sample Selection

Given that government departments constitute the primary collaborative subjects in smart city information chains, the survey targeted three groups: government officials (50% of questionnaires), university students (30%) as future civil servants, and citizens (20%) to reflect the human-centered smart city concept .

Table 2: Questionnaire Distribution and Recovery Statistics

Target Group	Distributed	Percentage	Valid Recovered	Percentage	Valid Recovery Rate
Government Officials	300	50%	242	53.07%	80.67%
Students	180	30%	138	30.26%	76.67%
Citizens	120	20%	76	16.67%	63.33%
Total	**600**	**100%**	**456**	**100%**	**76.00%**

3.3.2 Data Sources

Both paper and online questionnaires were distributed (600 total). After manual elimination of invalid responses, 456 valid questionnaires were retained, meeting the expected distribution proportions.

3.4 Empirical Analysis of the Synergistic Effect Mechanism

3.4.1 Reliability and Validity Analysis

Cronbach' s Alpha for the 15 variables was 0.946, indicating high internal consistency and reliability .

Table 3: Reliability Test Results

Cronbach' s Alpha	Standardized Cronbach' s Alpha	Number of Items
0.946	0.946	15

Exploratory factor analysis was conducted after KMO and Bartlett' s tests . The KMO value was 0.949, and Bartlett' s test was significant (^{2} = 4502.892, $p < 0.001$), confirming suitability for factor analysis.

Table 4: KMO and Bartlett' s Test

Kaiser-Meyer-Olkin Measure	0.949
Bartlett' s Test Approx. ^{2}	4502.892
df	105
Sig.	0.000

Principal component analysis extracted two factors with eigenvalues > 1, explaining 64.731% of total variance , confirming construct validity.

Table 5: Total Variance Explained

Component	Initial Eigenvalues	% of Variance	Cumulative %
1	8.656	57.705	57.705

Component	Initial Eigenvalues	% of Variance	Cumulative %
2	1.054	7.027	64.731

3.4.2 Structural Equation Model and Hypothesis Testing

AMOS software was used to analyze valid questionnaires and test the proposed model [Figure 3: see original paper]. Model fit indices showed acceptable fit: GFI = 0.911 (>0.90), PGFI = 0.638, RMSEA = 0.08 ($ $0.08), NFI = 0.931 (>0.90), IFI = 0.948 (>0.90), TLI = 0.935 (>0.90), CFI = 0.948 (>0.90).

Table 6: Model Fit Indices

Index	GFI	PGFI	RMSEA	NFI	IFI	TLI	CFI
Value	0.911	0.638	0.08	0.931	0.948	0.935	0.948

Parameter estimates revealed:

- **H3** (Information synergy → Synergistic effect): Standardized coefficient = 0.761, C.R. = 6.321, $p < 0.001$. **Supported**.
- **H2** (Mechanism synergy → Synergistic effect): Standardized coefficient = 0.342, C.R. = 2.493, $p < 0.05$. **Supported**.
- **H4** (Mechanism synergy → Subject synergy): Standardized coefficient = 0.893, C.R. = 14.268, $p < 0.001$. **Supported**.
- **H5** (Mechanism synergy → Information synergy): Standardized coefficient = 0.776, C.R. = 4.041, $p < 0.001$. **Supported**.
- **H6** (Subject synergy → Information synergy): Standardized coefficient = 0.434, C.R. = 4.363, $p < 0.001$. **Supported**.
- **H1** (Subject synergy → Synergistic effect): p = 0.086. **Not supported**.

Table 7: Parameter Estimates

Path	Unstd. Estimate	S.E.	C.R.	Std. Estimate	P
Subject Synergy ← Mechanism Synergy	1.118	0.086	14.268	0.893	***

Path	Unstd. Estimate	S.E.	C.R.	Std. Estimate	P
Information Synergy ← Mechanism Synergy	0.585	0.145	4.041	0.776	***
Synergistic Effect ← Subject Synergy	0.309	0.180	1.714	0.225	0.086
Information Synergy ← Subject Synergy	0.336	0.077	4.363	0.434	***
Synergistic Effect ← Mechanism Synergy	0.455	0.183	2.493	0.342	0.013
Synergistic Effect ← Information Synergy	0.951	0.150	6.321	0.761	***

Note: *** $p < 0.001$; C.R. > 1.96 ($p < 0.05$), C.R. > 2.58 ($p < 0.01$), C.R. > 3.29 ($p < 0.001$)

Figure 4 illustrates the final model: Mechanism synergy and information synergy directly affect synergistic effects, while subject synergy indirectly influences synergistic effects through the other two dimensions.

4. Optimization Strategies for Enhancing Synergistic Effects

Based on the structural equation model results, five targeted strategies are proposed:

4.1 Rationally Assess the Role of Subject Synergy
H1 was not supported, indicating subject synergy does not directly affect synergistic effects. Resources should not be over-allocated to subject coordination alone. Instead, a balanced approach focusing on mechanism and information synergy will better enhance overall synergistic effects.

4.2 Strengthen Subject Synergy Through Information and Mechanism Synergy
Since H4, H5, and H6 were supported, subject synergy indirectly influences synergistic effects via mechanism and information synergy. Therefore, enhancing information and environmental coordination will naturally strengthen subject synergy and improve overall synergistic effects.

4.3 Accelerate Improvement of Information Environment Coordination Systems
The information environment comprises economic, policy, technical, infrastructure, information security, and information openness dimensions. With H2 supported, improving coordination across these six environmental aspects will significantly enhance synergistic effects.

4.4 Focus on Strengthening Information Element Synergy
H3 was strongly supported, confirming that information synergy directly and positively affects synergistic effects. Prioritizing information sharing, flow, and interactive learning will substantially improve overall synergy.

4.5 Leverage the Mutual Promotion Between Mechanism and Information Synergy
H5' s support demonstrates that mechanism synergy and information synergy mutually reinforce each other. Flexibly utilizing this reciprocal relationship—where improvements in one area boost the other—will create a virtuous cycle enhancing overall synergistic effects.

Conclusion

This study constructed a synergistic effect mechanism model based on three elements (subjects, information, environment) and three synergy dimensions (subject, information, mechanism). Using 456 valid questionnaires and structural equation modeling, the research revealed that mechanism synergy and information synergy directly affect synergistic effects, while subject synergy operates indirectly. Five optimization strategies were proposed to provide practical guidance for smart city development. Future research should expand survey scope and employ more objective methods to further validate these findings.

References

[1] Goals & strategies of UN-Habitat [EB/OL]. [2019-01-16]. https://unhabitat.org/goals-and-strategies-of-un-habitat/. [2] Das R K, Misra H. Smart city and e-governance: exploring the connect in the context of local development in India [C]//2017 Fourth international conference on eDemocracy & eGovernment. Quito: IEEE, 2017: 232-233. [3] Paskaleva K. Enabling the smart city: the progress of city e-governance in Europe [J]. International journal of innovation and regional development, 2009, 1(4): 405-422. [4] Bakici T, Almirall E, Wareham J. A smart city initiative: the case of Barcelona [J]. Journal of the knowledge economy, 2013, 4(2): 135-148. [5] Sutanta H, Aditya T, Astrini R. Smart city and geospatial information availability, current status in Indonesian cities [J]. Procedia-social and behavioral sciences, 2016, 227(14): 265-274. [6] Komninos N, Pallot M, Schaffers H. Special issue on smart cities and the future internet in Europe [J]. Journal of the knowledge economy, 2013, 4(2): 119-134. [7] Njenja M, Braittstein P, Gallagher C. Innovations in urban agriculture and energy for climate-smart cities in Kenya [J]. Urban agriculture magazine, 2014(27): 24-27. [8] State Council' s Several Opinions on Promoting Information Consumption and Expanding Domestic Demand [EB/OL]. [2019-01-22]. http://www.gov.cn/zwgk/2013-08/14/content_{2466856}.htm. [9] Paroutis S, Bennett M, Heracleous L. A strategic view on smart city technology: the case of IBM smarter cities during a recession [J]. Technological forecasting & social change, 2014, 11(89): 262-272. [10] Zhu Kaiyue, Cui Qinghong, Zhao Jinxian, et al. Research on domestic smart city concept based on content analysis [J]. China management informationization, 2019, 22(1): 147-149. [11] Mattioni B, Guglielmetti F, Bisegna F. A multilevel method to assess and design the renovation and integration of smart cities [J]. Sustainable cities and society, 2015, 7(15): 105-119. [12] Lazaroiu G C, Roscia M. Definition methodology for the smart cities model [J]. Energy, 2012, 11(47): 326-332. [13] Li Xia, Fong P S W. Evaluation and countermeasure research on smart Wuhan informatization development based on wavelet neural network [J]. Information science, 2018, 36(2): 113-117. [14] Zhang Changliang, Han Xuewen, Li Jingtong. Comparative study on smart city construction between China and Singapore under big data background [J]. Modern intelligence, 2018, 38(10): 126-131, 141. [15] Ma Jie, Pu Hongyu, Zhang Yunkai, et al. Government smart service framework and information synergy mechanism based on linked data [J]. Information studies: theory & application, 2018, 41(11): 20-26. [16] Wu Zhihong, Zhao Yuanbin, Han Xiuzhen. Discussion on deep integration of regional cluster-based information service synergy system and smart city [J]. Library and information service, 2014, 58(13): 11-16. [17] Chen Rui, Jia Xiaofeng, Zhao Yu. Multi-source information synergy structure measurement and optimization for smart city based on fuzzy clustering [J]. Application research of computers, 2016, 33(7): 1945-1951. [18] Xiang Shang, Zou Kai, Zhang Zhongqingyang, et al. System dynamics simulation analysis of smart city information ecological chain [J]. Journal of intelligence, 2017, 36(3): 155-160, 154. [19] Ma Jie, Hu Mo, Lian Ming. Design of smart city information ecological

chain based on multi-subject synergy [J]. Information science, 2016, 34(12): 70-74, 81. [20] Li Meidi. Analysis of information ecosystem [J]. Journal of intelligence, 1998(4): 3-5. [21] Ma Jie, Zhang Yunkai, Pu Hongyu. Information synergy: connotation, concept and research progress [J]. Information studies: theory & application, 2018, 41(11): 12-19. [22] Li Li. Research on collaborative innovation mechanism of new industry technology standard alliance [D]. Harbin: Harbin University of Science and Technology, 2014. [23] Wang Peng. Research on synergy mechanism of food supply chain subjects based on evolutionary game [D]. Tianjin: Tianjin University of Science & Technology, 2016. [24] Zhang Fuping, Wang Xin, Wang Bo, et al. Research on synergy mechanism of interest subjects in urban modern agriculture—taking Beijing as an example [J]. Science and technology management research, 2014, 34(4): 1-5. [25] Si Linbo, Meng Weidong. Evaluation of synergy degree for equipment manufacturing industry technology collaborative innovation mechanism—empirical analysis based on SIM model [J]. 2017(2): 104-109. [26] Xie Xuemei, Xu Maoyuan. Collaborative innovation mechanism, collaborative innovation atmosphere and innovation performance—mediated by collaborative network [J]. Science research management, 2014, 35(12): 9-16. [27] Li Hui. Research on supply chain information synergy performance evaluation [D]. Dalian: Dalian University of Technology, 2013. [28] Liu Xing. Research on BIM-based project information synergy management [D]. Chongqing: Chongqing University, 2016.

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Hu Mo: Conceptualization, writing; Ma Jie: Framework design, revision; Li Lu: Literature collection and organization.

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