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Article

Research on the Pathways for the Digital Economy to Drive the Modernization of the Housing Industry Chain and Supply Chain

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Abstract: Under the impetus of the digital economy, the digital transformation of industrial chains and supply chains has become inevitable. Data assets effectively enhance the operational efficiency of industrial chains and supply chains, digital technologies can effectively enhance the competitiveness of enterprises in industrial chains and supply chains, and digital technologies effectively promote the transformation and upgrading of industrial chains and supply chains. This paper constructs an evaluation indicator system from four dimensions: research and design modernization, production and manufacturing modernization, logistics and transportation modernization, and sales and marketing modernization. Based on data from 30 provinces in China from 2015 to 2024, the paper uses the entropy method and spatial Moran index to analyze the digital economic development levels and spatial correlations of the 30 provinces, and examines the impact of the digital economy on the modernization level of the housing industrial chain and supply chain, as well as its underlying mechanisms. The research results show that the development of the digital economy exhibits a stable growth trend, while the modernization level of the housing industry chain and supply chain shows an overall fluctuating upward trend, with the overall modernization level of the housing industry chain and supply chain first declining and then rising. Additionally, the promotional effect of the digital economy exhibits significant spatial heterogeneity, with the development level of the digital economy generally showing a single threshold effect on the modernization level of the housing industry chain and supply chain, and a double threshold effect in western regions.

Keywords: digital economy; industrial chain and supply chain; modernization level; Moran index; entropy method

1. Introduction

The digital economy refers to a new economic model driven by digital technologies such as the internet, mobile internet, big data, and artificial intelligence. It is characterized by data-driven growth, internet-based infrastructure, innovation as a key feature, and a global scope [1-2]. Currently, the development of the digital economy is concentrated in areas such as artificial intelligence, 5G technology, and blockchain [3]. As global market competition, resource competition, and geopolitical competition intensify, the future of the commodity economy is increasingly moving toward high-tech, digitalization, and automation [4-6]. The digital economy has profoundly transformed the traditional economic landscape and has become a key driver of economic development [7]. After years of unregulated growth, the housing industry is undergoing a transformation from scattered development to refined management and precise development. The digital economy presents a crucial opportunity for the housing industry to undergo a rebirth [8].

The housing industry is a vital sector of the national economy, with a vast upstream and downstream industrial chain that impacts various aspects of people's lives. After years of rapid development, the housing industry has reshaped the urban landscape nationwide [9-10]. However, the housing market has shown signs of weakness post-pandemic, with a significant decline in transaction volumes. Many regions have introduced measures such as lifting purchase restrictions, recognizing housing ownership rather than loans, trade-in programs, and reducing down payment requirements to stimulate market recovery, but the effects have been limited [11-13]. Additionally, under the current tightening of financial and land policies, the housing industry chain and supply chain have entered a period of volatility, significantly increasing the challenges of market operations [14-15]. The traditional seller-dominated real estate development model no longer aligns with new market demands, highlighting the need for modernization of the housing supply chain [16]. In the digital economy era, advancing housing digital transformation to help real estate companies integrate resources, identify customers, enhance services, innovate products, upgrade the industrial chain, and optimize the supply chain has become a consensus in the housing industry.

Housing has distinct regional characteristics, long development cycles, complex transaction processes, significant capital requirements, and involves numerous upstream and downstream industries, including investment decisions, land supply, housing construction and development, sales and marketing, and housing use and maintenance. It also involves multiple stakeholders such as governments, developers, suppliers, brokers, financial institutions, and consumers, forming a complete housing supply chain [17-18]. By leveraging digital technologies to connect information across regions, departments, and processes, creating visible and usable data, and applying it through intelligent systems to a range of business activities such as investment and development, marketing, and service innovation, many real estate companies have made it a strategic choice to seize the benefits of the digital economy and modernize the housing industry chain and supply chain [19-21].

In the digital economy environment, the housing industry chain and supply chain involve Building Information Modeling (BIM), virtual reality technology, 5G technology, blockchain technology, and more, ensuring comprehensive support for housing from investment to housing service management. Literature [22] points out that emerging technologies such as artificial intelligence, blockchain, virtual reality, and 5G are transforming housing industry investment and financing management, driving industry transformation toward an open innovation model. Literature [23] analyzes that the use of BIM technology in housing construction helps optimize the management and control of housing construction projects, reduce construction costs, enhance coordination in the construction supply chain, and improve project accuracy. However, BIM technology remains relatively weak in project risk management, construction safety management, and engineering big data analysis. Literature [24] designed a virtual reality-supported pre-sales navigation system, where virtual reality enhances consumer understanding and increases their purchasing intent. Literature [25] confirms that blockchain technology can optimize real estate transaction processes, security, and cost-effectiveness, enabling efficient financial operations for traders. Literature [26] summarizes the application of artificial intelligence and machine learning in construction processes and housing services, primarily through intelligent construction planning, resource scheduling, and facility management to optimize construction processes, as well as through air quality and noise detection, and the establishment of waste management systems to optimize energy management and enhance housing experiences.

The modernization of the housing industry chain and supply chain can reshape the advantages of the modern industrial system, remove bottlenecks in economic development, and promote the high-quality development of the digital economy. The study constructs evaluation indicator systems for the digital economy and the modernization of the housing industry chain and supply chain, and uses the entropy method and Moran's I to measure their development levels and spatial evolution characteristics. Subsequently, the modernization level of the housing industry chain and supply chain is used as the core explanatory variable, with digital economic development as the dependent variable. Relevant control variables are selected based on previous literature, and a two-period DID and threshold regression model is constructed. Using panel data from 30 provinces in China (excluding Tibet and Hong Kong, Macao, and Taiwan) from 2015 to 2024, an empirical analysis of the driving pathways is conducted.

2. Measurement model for the modernization of the digital economy and the housing industry chain and supply chain

2.1. Construction of an evaluation indicator system

2.1.1. Digital Economy

The digital infrastructure is the foundation for the development of the digital economy, primarily encompassing two aspects: the information technology industry and digital infrastructure. Among these, internet penetration rates and broadband access points provide the enabling conditions for the development of the digital economy. Secondly, “digital industrialization” and “industrial digitalization” are the two main pillars of digital economic development. Digital industrialization constitutes the core of the digital economy, encompassing sectors such as the electronics manufacturing industry, the information and communications industry, the internet industry, and the software services industry. Industrial digitalization, on the other hand, refers to the process of integrating data as a key element with the primary, secondary, and tertiary industries under the support and guidance of next-generation digital technologies, driving comprehensive digital upgrades, transformations, and reinventions across the entire industrial chain. Finally, advancements in digital technology expand and extend the boundaries of innovation possibilities. Innovation-driven development relies on the positive interaction between technological progress and human capital. Therefore, the innovative development of the digital economy should be comprehensively examined from the perspectives of technological progress, human capital, and other dimensions.

2.1.2. Modernization of the housing industry chain and supply chain

Research and design, production and manufacturing, logistics and transportation, sales and marketing, and other links are crucial components of the housing industry chain and supply chain. These links play a significant role in promoting the application of research and development achievements in key industries and accelerating the modernization of the industry chain and supply chain. Among these, the research and design phase enhances the core competitiveness of entities within the chain by increasing investment in production factors to strengthen research and innovation. This approach extends technological innovation to the front end of the industry chain and supply chain, providing innovative pathways to support the modernization of the industry chain and supply chain. The production and manufacturing stage transitions from a traditional linear production model to a collaborative, open industrial ecosystem. Through interactive cooperation with upstream and downstream enterprises, high-end manufacturing enterprises, and strategic emerging enterprises, it expands the boundaries of the industrial chain and supply chain, providing a solid foundation for their modernization. The logistics and transportation stage builds a modern logistics system that matches supply and demand, enhancing efficiency across production, distribution, circulation, and consumption stages. It effectively improves the quality of logistics service supply, providing robust support for the modernization of the industrial chain and supply chain. The sales and marketing segment accelerates the modernization of the industrial chain and supply chain by developing new products, leveraging innovative platforms like e-commerce, and expanding sales channels. This enables personalized services and precise marketing for entities within the chain. An evaluation indicator system encompassing four dimensions—research and design modernization, production and manufacturing modernization, logistics and transportation modernization, and sales and marketing modernization—is proposed, as shown in Table 1, to assess the modernization level of the housing industrial chain and supply chain.

Table 1. Housing industry chain and supply chain modernization evaluation index system table

Reference layer	Standard layer
Modernization of the supply chain of housing industry	Research design modernization
	Production modernization
	Logistics modernization
	Marketing modernization

2.1.3. Data Sources

Based on data availability, this study defines the sample as the 30 provinces of China excluding Tibet and Hong Kong, Macao, and Taiwan. The data collection period spans from 2015 to 2024, with the sample data primarily sourced from the annual editions of the *China Statistical Yearbook*, *China Science and Technology Statistical Yearbook*, *China Information Yearbook*, and the official website of the National Bureau of Statistics. Since all indicators are based on panel data, there are instances of missing data for certain years. Therefore, this study employed Stata's linear interpolation method to impute some of the missing data.

2.2. Research Methods

2.2.1. Entropy Method

To calculate the comprehensive index for the modernization of the housing industry chain and supply chain, it is not only necessary to establish a relevant indicator system but also to assign weights to these indicators. Currently, the methods for determining the weight of indicator attributes can be broadly categorized into three types: subjective weighting methods, objective weighting methods, and combined weighting methods. This paper primarily employs the entropy method within the objective weighting method [27] to assign weights to the relevant indicators, ensuring that the calculation results are more scientifically sound and reasonable. The specific operational steps are as follows:

Step 1: Standardization. Since there are significant differences in the quantity, units, and attributes of various indicators, it is necessary to eliminate the influence of units of measurement to ensure comparability among indicators. Standardization processing is performed on the relevant data, as shown in Equations (1) and (2).

$$X'_{ij} = \frac{X_{ij} - \min(X_{ij})}{\max(X_{ij}) - \min(X_{ij})} \text{Positive indicators} \tag{1}$$

$$X'_{ij} = \frac{\max(X_{ij}) - X_{ij}}{\max(X_{ij}) - \min(X_{ij})} \text{Negative ndicators} \tag{2}$$

Among them, $\left(\max\left(X_{ij}\right)\right)$ is the maximum value of the selected year indicator, and $\min\left(X_{ij}\right)$ is the minimum value of the selected year indicator. X'_{ij} is the standardized result.

Step 2: Calculate the proportion of the i th sample data of the j th indicator, denoted by P_{ij}:

$$P_{ij} = \frac{X'_{ij}}{\sum_{i=1}^{m} X'_{ij}} \tag{3}$$

Step 3: Calculate the information entropy e_j:

$$e_j = -k\sum_{i=1}^{m} P_{ij} \ln P_{ij} \tag{4}$$

Step 4: Calculate the information redundancy d_j:

$$d_j = 1 - e_j \tag{5}$$

Step 5: Calculate weights:

$$W_j = \frac{d_j}{m - \sum_{j=1}^{m} e_j} \tag{6}$$

Step 6: Calculate the comprehensive score based on the weighting of each indicator:

$$S_i = \sum_{j=1}^{n} y_{ij} w_j \tag{7}$$

Among them, S_i represents the comprehensive index of the development of the digital economy of i province, usually the value range of S_i is between $(0, 1)$, the larger S_i is, the higher the comprehensive level of digital economy development in the province, and conversely, the smaller the S_i, the lower the comprehensive level of the province's digital economy development.

2.2.2. Moran Index Method

The Moran index is a correlation coefficient used to test spatial relationships, with values ranging from -1 to 1. When the value is greater than 0, it indicates that the data has a positive spatial correlation, and the larger the value, the more pronounced the spatial correlation. The Moran index includes the global Moran index and the local Moran index [28]. The global Moran's I index is primarily used to analyze whether there is a spatial correlation in the overall data. If the global Moran's I index shows significance, the local Moran's I index can be further analyzed to construct the following global Moran's I index:

$$\text{Global } Moran's\ I = \frac{n\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}\left(CSC_i - \overline{CSC}\right)\left(CSC_j - \overline{CSC}\right)}{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}\sum_{i=1}^{n}\left(CSC_i - \overline{CSC}\right)^2} \tag{8}$$

Furthermore, use the local $Moran's\ I$ -index expansion test:

$$\text{Local } Moran's\ I = \frac{n\left(NTI_i - \overline{NTI}\right)\sum_{j=1}^{n} w_{ij}\left(NTI_j - \overline{NTI}\right)}{\sum_{i=1}^{n}\left(NTI_i - \overline{NTI}\right)^2} \tag{9}$$

2.3. Analysis of measurement results

2.3.1. Spatio-temporal characteristics of digital economic development levels

Using the entropy weight method to calculate the comprehensive scores for the level of digital economic development in 30 provinces from 2017 to 2024, the results are shown in Table 2. China is divided into four regions: the eastern region, the western region, the central region, and the northeastern region.

It can be observed that the digital economy development levels of provinces exhibit a sustained growth trend, with Beijing, Guangdong, Jiangsu, Shandong, Shanghai, Zhejiang, Tianjin, Sichuan, and Hubei being the nine provinces with relatively high average digital economy development levels during the 2017–2024 period. During the study period, more than 50% of provinces had an annual average growth rate of the digital economy higher than the national average growth rate, with eight provinces—Shanxi, Shandong, Guizhou, Jiangxi, Guangxi, Hebei, Ningxia, and Chongqing—having an annual average growth rate of the digital economy approaching or exceeding 15%.

Table 2. Overall score of the digital economy development level of the provinces from 2016 to 2022

Region	**Province**	**Digital economic development level comprehensive score**							
		2017	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**
Eastern region	Beijing	0.3175	0.3503	0.3826	0.4103	0.4736	0.5258	0.5987	0.665
	Tianjin	0.0919	0.093	0.0923	0.1016	0.1124	0.1275	0.133	0.1458
	Hebei	0.0725	0.0813	0.0934	0.1075	0.1301	0.1481	0.133	0.1352
	Shanghai	0.1875	0.2138	0.2258	0.2492	0.2797	0.3177	0.3789	0.4407
	Jiangsu	0.2311	0.249	0.2693	0.3163	0.3602	0.4109	0.3942	0.434
	Zhejiang	0.1855	0.2117	0.2278	0.2682	0.3212	0.3775	0.3389	0.3682
	Fujian	0.1023	0.1309	0.1678	0.1724	0.1848	0.1666	0.1667	0.1746
	Shandong	0.1641	0.1877	0.2059	0.2451	0.2564	0.2961	0.3119	0.368
	Guangdong	0.3242	0.3731	0.4171	0.5212	0.6254	0.7112	0.6635	0.708
	Hainan	0.037	0.0398	0.041	0.0425	0.0487	0.0481	0.0434	0.0447
Central region	Shanxi	0.0441	0.0481	0.0517	0.0667	0.0716	0.0773	0.0704	0.0744
	Anhui	0.0787	0.0857	0.0945	0.112	0.1382	0.1592	0.1633	0.1824
	Jiangxi	0.0485	0.0517	0.0593	0.0756	0.0966	0.1093	0.099	0.1007
	Henan	0.0865	0.0954	0.1063	0.1353	0.1627	0.1846	0.156	0.1635
	Hubei	0.0999	0.1065	0.1163	0.1345	0.1684	0.1808	0.1791	0.2037
	Hunan	0.0683	0.0811	0.0882	0.1073	0.1351	0.154	0.1427	0.1625
Western region	Inner Mongolia	0.0479	0.0525	0.0566	0.061	0.0687	0.0747	0.0729	0.0735
	Guangxi	0.0413	0.047	0.0516	0.0663	0.0882	0.1004	0.0969	0.0942
	Chongqing	0.0583	0.0696	0.0753	0.0912	0.103	0.1178	0.1174	0.1404
	Sichuan	0.1127	0.1241	0.1414	0.172	0.2131	0.2443	0.2248	0.2273
	Guizhou	0.0373	0.0444	0.0484	0.0628	0.0809	0.0907	0.0854	0.0911
	Yunnan	0.0472	0.0527	0.057	0.0675	0.0851	0.0975	0.0775	0.078
	Shaanxi	0.0843	0.095	0.1016	0.1204	0.1452	0.1605	0.1583	0.1551
	Kansu	0.0363	0.0386	0.0429	0.05	0.0577	0.065	0.0587	0.0613
	Qinghai	0.0299	0.0328	0.0343	0.0378	0.0383	0.0415	0.0404	0.0423
	Ningxia	0.0267	0.0313	0.0326	0.037	0.0381	0.0409	0.0406	0.0416
	Xinjiang	0.0351	0.0349	0.0364	0.0432	0.0505	0.0574	0.0499	0.0557
Northeast	Liaoning	0.099	0.0942	0.0988	0.1097	0.1232	0.1338	0.1224	0.1313
	Jilin	0.0443	0.0482	0.0544	0.062	0.07	0.0749	0.0645	0.0651
	Heilongjiang	0.0537	0.0548	0.0592	0.0631	0.072	0.0815	0.0738	0.0775

2.3.2. Measuring the level of modernization of the housing industry chain and supply chain

To visually illustrate the evolution of the modernization level of the housing industry chain and supply chain from 2015 to 2024, the calculation results for the modernization level of the housing industry chain and supply chain in three regions and the national average are plotted as a line chart, as shown in Figure 1.

From a national perspective, the modernization level of the housing industry chain and supply chain has shown an overall fluctuating upward trend, increasing from 0.180 in 2015 to 0.208 in 2024. This evolution can be divided into three stages: the first stage from 2015 to 2016 saw the modernization level rise from 0.180 to 0.191, indicating an upward trend.

From a regional perspective, the modernization level of the housing industry chain and supply chain in the eastern region is significantly higher than the national average and notably higher than other regions. From 2015 to 2020, it grew rapidly from 0.261 to 0.342, and after 2022, it showed a slight downward trend.

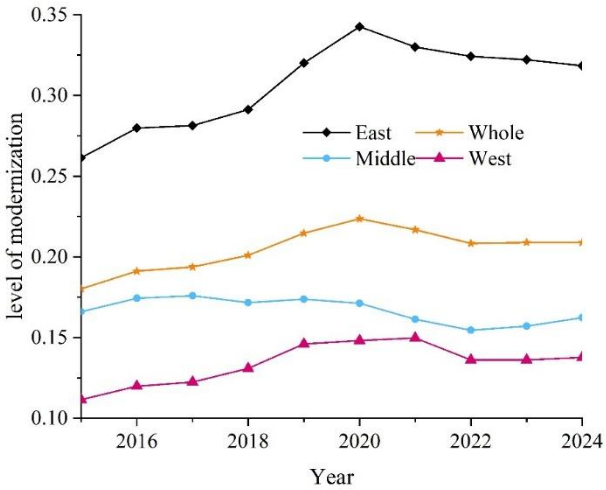


Figure 1. The evolution trend of modernization level of housing industry chain and supply chain

Considering the development trends and contributions of the indicators across various dimensions within the modernization index system of the housing industry chain and supply chain, this paper calculates the evaluation indices for the four dimensions of research and design modernization (A1), production and manufacturing modernization (A2), logistics and transportation modernization (A3), and sales and marketing modernization (A4) from 2015 to 2024 using the entropy method, and analyzes the annual averages. To more intuitively illustrate the trends in the evaluation indices of each dimension, the indices are plotted as line charts, as shown in Figure 2. The Research and Design Modernization Evaluation Index ranks first among all dimensions but shows an overall downward trend. Next, the Logistics and Transportation Modernization Evaluation Index exhibits a U-shaped trend. As the economy achieves high-quality development and economic scale increases, the economy's risk-resilience continues to grow.

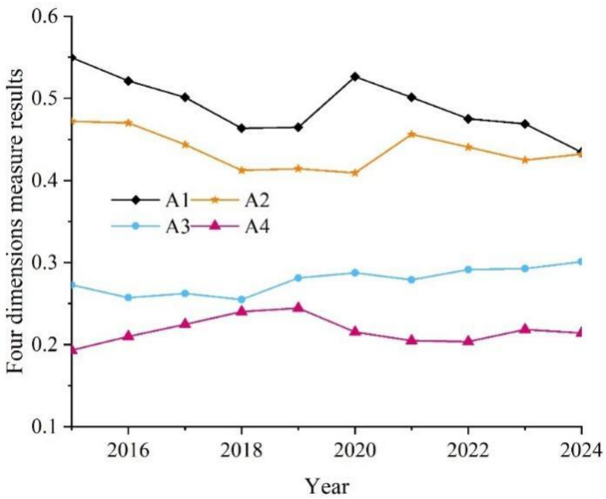


Figure 2. The trend of index change was evaluated in dimension

To further explore the evolving trends in the modernization levels of the housing industry chain and supply chain across provinces, the modernization levels of the housing industry chain and supply chain for 30 provinces are ranked from highest to lowest. Due to space constraints, only the rankings for the modernization levels of the housing industry chain and supply chain for each province from 2021 to 2024 are presented, as shown in Table 3. Province: PV, Housing Industry Chain and Supply Chain Modernization Level: MC, Ranking: RK.

As shown in the table, provinces such as Beijing, Zhejiang, Shanghai, Jiangsu, and Guangdong consistently rank at the top, while provinces such as Xinjiang, Gansu, Guizhou, and Yunnan rank toward the bottom. Additionally, there is a significant gap in the modernization levels of industrial chains and supply chains between provinces at the top and bottom of the rankings. Second, provinces at the bottom of the rankings are predominantly located in central and western regions, where they are significantly influenced by non-human factors such as natural environment and climate, leading to slower development of industrial chain and supply chain modernization and a substantial gap compared to developed provinces in eastern regions.

Table 3. The provinces are ranked in the modern horizontal ranking of industrial chain supply chain

2021			**2022**			**2023**			**2024**		
PV	MC	RK	PV	MC	RK	PV	MC	RK	PV	MC	RK
Heilongjiang	0.465	1	Beijing	0.574	1	Beijing	0.794	1	Beijing	0.773	1
Beijing	0.443	2	Heilongjiang	0.442	2	Shanghai	0.415	2	Shanghai	0.401	2
Zhejiang	0.354	3	Shanghai	0.436	3	Guangdong	0.403	3	Jiangsu	0.354	3
Shanghai	0.351	4	Zhejiang	0.341	4	Jiangsu	0.323	4	Guangdong	0.352	4
Jiangsu	0.33		Jiangsu	0.334		Zhejiang	0.32		Zhejiang	0.276	
Guangdong	0.32	5	Guangdong	0.309	5	Tianjin	0.251	5	Tianjin	0.253	5
Tianjin	0.221	6	Tianjin	0.231	6	Liaoning	0.23	6	Shandong	0.231	6
Shandong	0.205	7	Shandong	0.199	7	Shandong	0.228	7	Liaoning	0.222	7
Fujian	0.189	8	Fujian	0.184	8	Fujian	0.224	8	Fujian	0.21	8
Liaoning	0.182	9	Anhui	0.177	9	Hupei	0.216	9	Hupei	0.209	9
Hupei	0.167	10	Hupei	0.176	10	Chongqing	0.203	10	Chongqing	0.205	10
Anhui	0.158	11	Liaoning	0.173	11	Sichuan	0.202	11	Anhui	0.186	11
Chongqing	0.158	12	Chongqing	0.17	12	Anhui	0.195	12	Sichuan	0.184	12
Jilin	0.151	13	Sichuan	0.17	13	Shaanxi	0.171	13	Hebei	0.172	13
Sichuan	0.149	14	Shaanxi	0.166	14	Henan	0.164	14	Hunan	0.168	14
Shaanxi	0.149	15	Hainan	0.165	15	Jilin	0.162	15	Jiangxi	0.163	15
Hainan	0.145	16	Jilin	0.155	16	Hainan	0.162	16	Henan	0.157	16
Ningxia	0.137	17	Hunan	0.148	17	Hunan	0.158	17	Shaanxi	0.155	17
Hunan	0.135	18	Hebei	0.146	18	Ningxia	0.157	18	Jilin	0.153	18
Qinghai	0.134	19	Ningxia	0.138	19	Jiangxi	0.15	19	Hainan	0.147	19
Inner Mongolia	0.133	20	Henan	0.137	20	Heilongjiang	0.145	20	Shanxi	0.146	20
Shanxi	0.127	21	Shanxi	0.136	21	Hebei	0.142	21	Heilongjiang	0.145	21

Hebei	0.126	22	Inner Mongolia	0.133	22	Qinghai	0.135	22	Ningxia	0.138	22
Kansu	0.125	23	Guangxi	0.125	23	Yunnan	0.127	23	Guizhou	0.13	23
Henan	0.122	24	Jiangxi	0.125	24	Guangxi	0.127	24	Yunnan	0.127	24
Jiangxi	0.115	25	Yunnan	0.122	25	Shanxi	0.126	25	Guangxi	0.123	25
Yunnan	0.115	26	Qinghai	0.12	26	Xinjiang	0.125	26	Inner Mongolia	0.123	26
Guangxi	0.109	27	Kansu	0.113	27	Kansu	0.117	27	Qinghai	0.118	27
Xinjiang	0.107	28	Xinjiang	0.111	28	Guizhou	0.117	28	Kansu	0.111	28
Guizhou	0.09	29	Guizhou	0.101	29	Inner Mongolia	0.116	29	Xinjiang	0.107	29
Whole	0.190		Whole	0.201		Whole	0.214		Whole	0.208	

2.3.3. Spatial correlation analysis

(1) Digital Economy

A spatial weight matrix was constructed based on adjacency relationships, and the Moran's I index for the digital economy development levels of China's 30 provinces from 2017 to 2024 was calculated. As shown in Table 4, during the study period, the global Moran's I index was greater than 0 for all provinces, and all passed the significance test at $P < 0.01$. This indicates that the spatial distribution of digital economy development levels across China's provinces is not random but exhibits a significant positive correlation. This suggests that the spatial spillover effects of national digital economic development are gradually emerging, with notable regional spillover effects. This plays a crucial role in enhancing the overall development level and growth rate of the digital economy, as well as reducing disparities between provinces. From 2017 to 2024, the global Moran index scores showed a fluctuating upward trend, with spatial correlation increasing from 0.211 in 2017 to 0.234 in 2022, before declining to 0.220 in 2024. Overall, the trend of spatial aggregation is continuously strengthening.

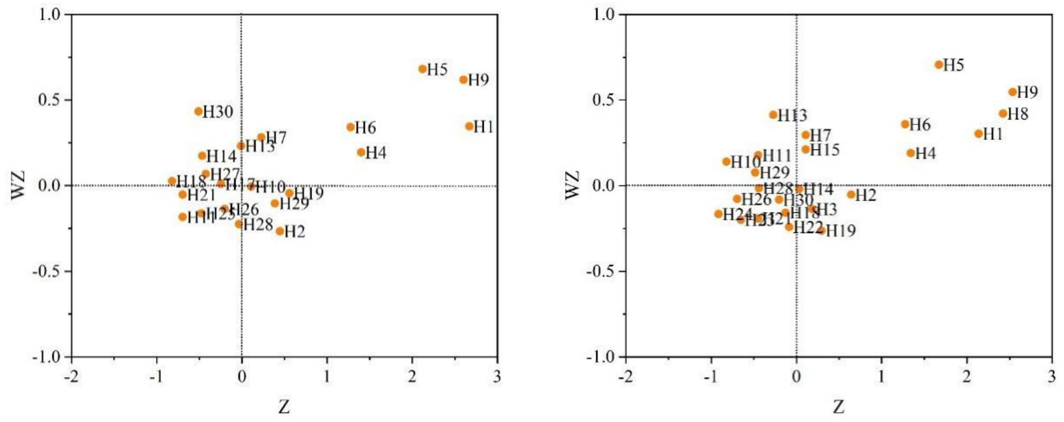
Table 4. The national digital economic development level of 2017 to 2024

Year	*I*	*Z*	*P*
2017	0.211	6.281	0.000
2018	0.213	6.338	0.000
2019	0.216	6.428	0.000
2020	0.217	6.385	0.000
2021	0.232	6.889	0.000
2022	0.234	7.012	0.000
2023	0.225	6.643	0.000
2024	0.220	6.491	0.000

In order to further study the local correlation of the digital economy, this paper uses the local Moran index to examine the correlation between some provinces and regions, and plots the Moran scatter plot as shown in Figure 3. The codes of each province are shown in Table 5.

Table 5. Chinese provinces

Province	**Code**	**Province**	**Code**
Beijing	H1	Inner Mongolia	H16
Tianjin	H2	Guangxi	H17
Hebei	H3	Chongqing	H18
Shanghai	H4	Sichuan	H19
Jiangsu	H5	Guizhou	H20
Zhejiang	H6	Yunnan	H21
Fujian	H7	Shaanxi	H22
Shandong	H8	Kansu	H23
Guangdong	H9	Qinghai	H24
Hainan	H10	Ningxia	H25
Shanxi	H11	Xinjiang	H26
Anhui	H12	Liaoning	H27
Jiangxi	H13	Jilin	H28
Henan	H14	Heilongjiang	H29
Hubei	H15	Inner Mongolia	H30



(a) 2023 (b) 2024

Figure 3. The local Morland index diagram for the year

(2) Modernization Level of the Housing Industry Chain and Supply Chain

Based on the aforementioned measurement and analysis of differences in the modernization level of the housing industry chain and supply chain, no obvious spatial correlation was found in the modernization level of the housing industry chain and supply chain. To enhance the rigor of the research, this paper introduces spatial correlation analysis to further explore whether there is a spatial effect in the modernization level of the housing industry chain and supply chain.

The Moran's I index is used to test for spatial effects. If the p-value is less than 0.1 and the Moran's I index is positive, it indicates that the modernization level of the housing industry chain and supply chain exhibits spatial correlation; if the p-value is greater than 0.1 or the Moran's I index is negative, it indicates that the modernization level of the housing industry chain and supply chain does not exhibit spatial correlation. Table 6 presents the results of the spatial correlation test, while Figures 4 and 5 illustrate the scatter plots of the Moran's I index for 2015 and 2024, respectively.

According to Table 6, the Moran index in 2015 was -0.004, which was not significant at the 10% level and was negative, indicating that there was no significant spatial correlation in the modernization level of the housing industry chain and supply chain across provinces in 2015. From 2016 to 2024, the Moran index was significant and positive, showing a trend of first declining and then increasing, with 2022 being an important turning point.

Additionally, as shown in Figure 4, when the modernization level of the housing industry chain and supply chain was low, the Moran index for the modernization level of the housing industry chain and supply chain in most provinces in 2015 was located in the “low-high” cluster zone and the “low-low” cluster zone, further confirming that there was no significant spatial correlation in the modernization level of the housing industry chain and supply chain in 2015; However, in Figure 5, the Moran's index for the modernization level of the housing industry chain and supply chain in most provinces is located in the “high-high” cluster and the “low-low” cluster, indicating that the modernization level of the housing industry chain and supply chain in more than half of the provinces in 2024 exhibits spatial correlation.

Table 6. Spatial correlation test results

Year	*Moran's I*	*Z*	*P*
2015	-0.004	0.792	0.316
2016	0.051***	2.513	0.006
2017	0.049***	2.502	0.007
2018	0.047***	2.451	0.016
2019	0.043**	2.384	0.018
2020	0.036**	2.371	0.019
2021	0.031**	2.359	0.019
2022	0.022**	1.973	0.052
2023	0.014*	1.791	0.067
2024	0.022**	2.207	0.031

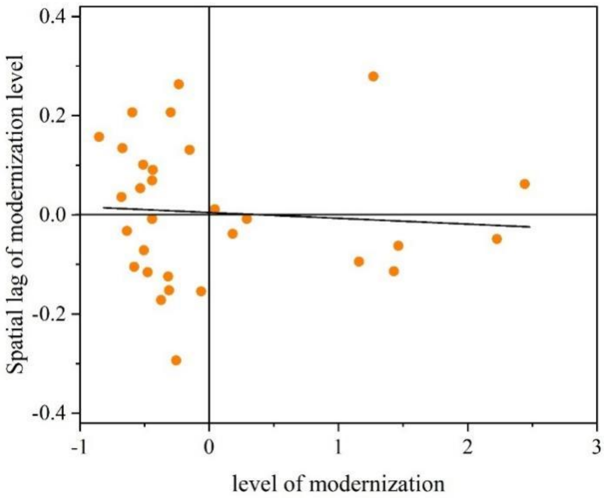


Figure 4. Scatter plot of Moran's index in 2011

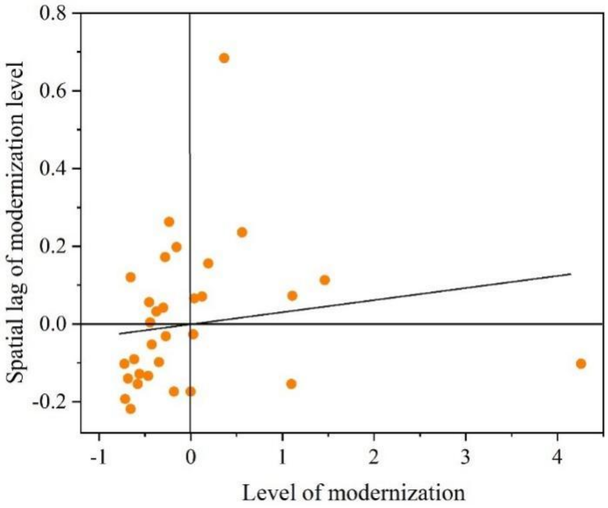


Figure 5. Scatter plot of Moran's index in 2011

3. Research on the Promotion of Modernization of the Housing Industry Chain and Supply Chain through the Digital Economy

3.1. Model Design

3.1.1. Dynamic Panel Model

Establishing a measurement model for the relationship between the digital economy and the modernization of the housing industry chain and supply chain:

$$\begin{aligned} MC_{it} &= \beta_0 + \beta_1 DIG_{it} + \beta_2 HUM_{it} \\ &+ \beta_3 FIN_{it} + \beta_4 INF_{it} + \beta_5 URB_{it} + \mu_i + \varepsilon_{it} \end{aligned} \tag{10}$$

In the above equation, i and t represent provinces and years, respectively; MC_{it} represents the modernization of industrial chains and supply chains; DIG_{it} represents the digital economy; HUM_{it} and FIN_{it} represent human capital, financial development, infrastructure construction, and urbanization, respectively; INF_{it} and URB_{it} represent control variables for human capital, financial development, infrastructure construction, and urbanization, respectively; β_0 represents the constant term; μ_i denotes the unobservable regional effect; and ε_{it} denotes the error term.

Additionally, considering the continuity of industrial chain and supply chain modernization, a lagged term of industrial chain and supply chain modernization is added to equation (10) for dynamic panel model estimation. This not only reveals the dynamic characteristics of industrial chain and supply chain modernization but also addresses the bias issues caused by endogeneity. The specific dynamic panel model is as follows:

$$\begin{aligned} MC_{it} &= \beta_0 + \beta_1 MC_{i,t-1} + \beta_2 DIG_{it} + \beta_3 HUM_{it} \\ &+ \beta_4 FIN_{it} + \beta_5 INF_{it} + \beta_6 URB_{it} + \mu_i + \varepsilon_{it} \end{aligned} \tag{11}$$

In the above equation, $MSC_{i,t-1}$ represents the lagged term of industrial chain and supply chain modernization, while the meanings of other variables are the same as in equation (10). The independent variables in the model include the lagged level of industrial chain and supply chain modernization. At the same time, there may be a bidirectional causal relationship between the digital economy and industrial chain and supply chain modernization, which may lead to endogeneity issues. Therefore, this paper uses a one-step system GMM estimation method for estimation.

3.1.2. Panel threshold model

Taking the "dual circulation" economic model and intellectual property protection as threshold variables, we further explore the nonlinear impact of the digital economy on the modernization of industrial chains and supply chains. The specific model settings are as follows:

$$\begin{aligned} MC_{it} &= \beta_1 DIG_{it} \times I\left(CDI_{it} \le \gamma_1\right) + \beta_2 DIG_{it} \times I\left(\gamma_1 < CDI_{it} \le \gamma_2\right) \\ &+ \cdots + \beta_n DIG_{it} \times I\left(\gamma_{n-1} < CDI_{it} \le \gamma_n\right) \\ &+ \beta_{n+1} DIG_{it} \times I\left(CDI_{it} > \gamma_n\right) + \theta Z_{it} + \mu_i + \varepsilon_{it} \end{aligned} \tag{12}$$

$$\begin{aligned} MC_{it} &= \beta_1 DIG_{it} \times I\left(IPP_{it} \le \gamma_1\right) + \beta_2 DIG_{it} \times I\left(\gamma_1 < IPP_{it} \le \gamma_2\right) \\ &+ \cdots + \beta_n DIG_{it} \times I\left(\gamma_{n-1} < IPP_{it} \le \gamma_n\right) + \theta Z_{it} + \mu_i + \varepsilon_{it} \end{aligned} \tag{13}$$

In the above equation, CDI_{it} and IPP_{it} represent the level of the "dual circulation" economy and the level of intellectual property protection, respectively; γ represents the threshold value; $I(\cdot)$ denotes an indicator function, taking the value 1 if the condition inside the brackets holds, and 0 otherwise; μ_i denotes the unobservable regional effect.

3.2. Variable Descriptions

3.2.1. Dependent variables

Modernization of the housing industry chain and supply chain (MC). An indicator system for the modernization level of the industry chain and supply chain is constructed from five aspects: digital, green, innovation, economy, and self-reliance. The entropy weight method-TOPSIS is used to measure the modernization level of the industry chain and supply chain in each province of China.

3.2.2. Explanatory variables

Digital Economy (DIG). The level of digital economic development is evaluated from two aspects: digital inclusive finance and internet development. Among these, digital inclusive finance is measured using the composite index from the Peking University Digital Inclusive Finance Index (PKU-DFIIC); internet development is reflected through a comprehensive assessment of four aspects: internet penetration rate, industry employment situation, mobile phone penetration rate, and output of related industries. Then, using the entropy method to process the data from the five indicators, including digital inclusive finance and internet development levels, the digital economy development index is derived.

3.2.3. Threshold Variables

Economic "dual circulation" level (CDI). The article establishes separate development systems for the domestic economic circulation and the external economic circulation, and uses the entropy-weighted comprehensive evaluation method to calculate the indices for both systems. The domestic economic circulation system is comprehensively reflected through six variables: production structure, domestic demand investment, domestic demand consumption, income distribution, consumption level, and factor circulation; while the external circulation system is objectively quantified using four variables: import and export trade, capital introduction, foreign investment, and advanced technology introduction. Based on this, the index of the internal circulation system is multiplied by the index of the external circulation system to obtain the level of the "dual circulation" economy.

Intellectual property protection (IPP). The level of intellectual property protection is reflected by the proportion of intellectual property cases in regional GDP, with the specific calculation method shown below:

$$IPP_{it} = \left(\frac{case_{it}}{\sum case_{it}} \right) \Big/ \left(\frac{GDP_{it}}{\sum GDP_{it}} \right) \tag{14}$$

In the above equation, $case_{it}$ and GDP_{it} represent the number of intellectual property cases and regional gross domestic product in region i during period t respectively.

3.2.4. Control variables

The article controls for the following variables: human capital (HUM), represented by the ratio of the number of students enrolled in higher education institutions in the region to the total population at the end of the year; financial development (FIN), measured by the sum of the balance of loans and deposits of financial institutions in the region at the end of the year, divided by GDP; infrastructure construction (INF), reflected by the per capita road area in the region; and urbanization (URB), represented by the proportion of the urban population in the total population of the region.

3.3. Analysis of empirical results

3.3.1. Benchmark regression analysis

The benchmark results of this paper are shown in Table 7. Specifically, Column (1) presents the regression results without controlling for city and year fixed effects, with the regression coefficient of DIG being 0.1195, which is significant at the 1% level, indicating that the digital economy significantly improves the supply chain security level of the housing industry in the region. Column (2) controls for city and year fixed effects, with the regression coefficient for DIG being 0.0127, also significant at the 1% level. Column (3) presents the regression results after controlling for variables, with the coefficient for DIG being 0.0151, still significant at the 1% level, indicating that smart city pilot programs significantly enhance the supply chain security level of the region.

Table 7. Baseline regression results

	(1)	(2)	(3)
	MC	**MC**	**MC**
DIG	0.1195*** (0.0049)	0.0127*** (0.0036)	0.0151 (0.0037)
HUM			0.0008* (0.0006)
FIN			0.0011*** (0.0003)
INF			0.0104***
URB			(0.0015)
Constant	0.5317*** (0.0017)	0.5537*** (0.0007)	0.5417*** (0.0664)
Urban year fixed effect	NO	YES	YES
N	5774	5774	5774
R^2	0.0853	0.7942	0.7993

Note: The values in parentheses are robust standard errors. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

3.3.2. Parallel trend test

The test results are shown in Figure 6. The results in the figure indicate that the coefficient estimates for each period before the policy implementation were not significant, indicating that there were no significant differences in the safety levels of the housing industry chain and supply chain in various regions before the policy implementation. The study passed the parallel trend test. However, the regression coefficients for multiple periods after the policy implementation were positive and significant at the 5% level, indicating that the implementation of the smart city pilot policy significantly promoted the improvement of the safety of the housing industry chain and supply chain in various regions.

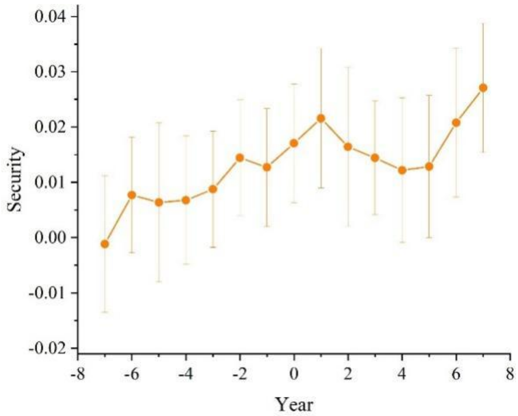


Figure 6. Parallel trend test results

3.3.3. Placebo testing

Using the new sample, the benchmark model was re-estimated, and the above operation was repeated 500 times. The estimation results are shown in Figure 7. The coefficient distribution chart shows that the randomly sampled coefficients have a mean of zero and are normally distributed. The estimated value of 0.0151 obtained from the baseline regression is not within the coefficient interval, indicating that the estimation results in this paper are robust.

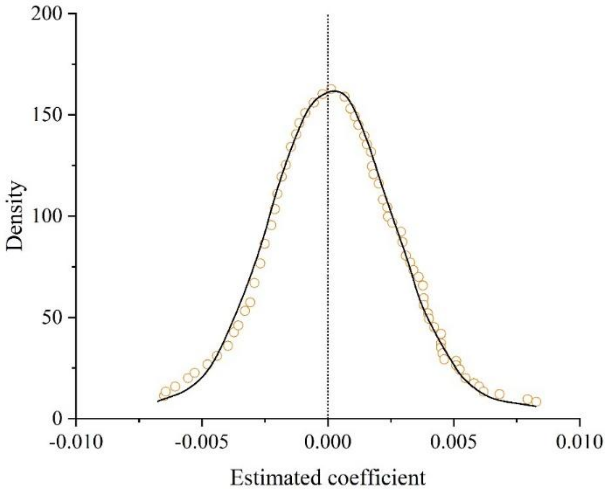


Figure 7. Placebo test results

3.3.4. Heterogeneity analysis

This paper will examine the impact of the digital economy on the modernization level of the housing industry chain and supply chain in the three major regions of eastern, central, and western China, with the results shown in Table 8. According to the regression results, the impact of the digital economy on the modernization level of the housing industry chain and supply chain in the eastern region is not significant. This may be because the eastern region has a relatively developed economy, more advanced digital infrastructure, and related industries are mostly located in higher-value-added segments of the housing industry chain, having already formed relatively complete supply chains, thereby rendering the impact of the digital economy less pronounced. However, for the central and western regions, the digital economy has significantly promoted the modernization of their housing industry chain and supply chain. According to the regression results, the digital economy has increased the supply chain security levels of the central and western regions by 0.0137 and 0.0131 units, respectively.

Table 8. Heterogeneity test results

	(1)	(2)	(3)	(4)	(5)
	East	**Central section**	**West**	**Not the Yangtze River Economic Belt**	**Yangtze River Economic Belt**
DIG	-0.0004 (0.0056)	0.0137** (0.0056)	0.0131** (0.0067)	0.0161*** (0.0047)	0.0121** (0.0053)
Controlled variable	YES	YES	YES	YES	YES
Urban/year fixed effects	YES	YES	YES	YES	YES
N	2064	2043	1655	3627	2218
R^2	0.8409	0.8463	0.8301	0.8217	0.8425

3.4. Threshold Effect Test

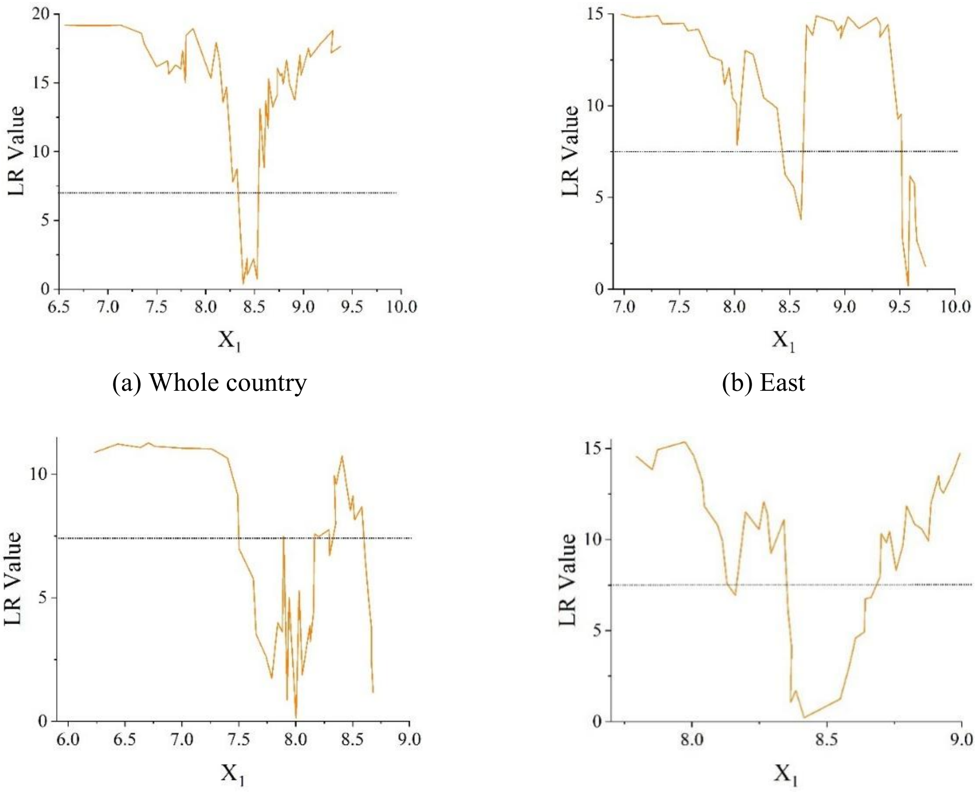
The results of the threshold value estimation are shown in Table 9. A panel regression model was used to test whether there was a linear relationship between the variables. When the level of the "dual circulation" economy (CDI) was used as the threshold variable and the digital economy (DIG) as the core explanatory variable, tests were conducted for the presence of a single threshold, double threshold, and triple threshold. Using Stata 17 statistical software, the "bootstrap method" was employed to repeatedly sample 100 times (due to data availability issues, the sample size was relatively small) to obtain the p-values for the tests, thereby determining whether a threshold effect exists.

The results show that when $x1 = In(CDI)$ is the threshold variable, the F-statistic is significant at least at the 5% level in the single-threshold model, indicating that a single-threshold effect exists for all regions. From the overall conclusion, the impact of digital economic development level on the modernization level of industrial chains and supply chains exhibits a "U"-shaped relationship with a two-stage effect. For the national level, the threshold value is 8.6134, with a threshold interval of 8.4153 to 8.4963.

Table 9. Threshold estimation results

Region	**Threshold value**	**RSS**	**Stage coefficients**	**The second stage coefficient**	**Sample number**	**The minimum threshold**	**The highest threshold**
Whole country	8.6134	4.2163	-0.0079372	0.0691157	223	8.4153	8.4963
East	9.5522	1.9538	0.1298753	0.2103451	87	9.5112	9.6123
West	8.0217	0.7613	-0.1968437	-0.0818175	61	7.9137	8.0726
Middle	8.4064	0.9823	-0.0811274	0.011473	67	8.3142	8.8214

By examining the likelihood ratio (LR) function plot shown in Figure 8, one can more intuitively grasp the process of constructing the threshold and confidence interval. In the figure, at a 5% significance level, the black dashed line represents the critical value, and the region below this line defines the 95% confidence interval. In Figure 8(c), the LR values are closely clustered around 0 and fall within the 95% asymptotic effective confidence interval [8.447, 8.522]. This result indicates that there is insufficient evidence to reject the null hypothesis that the threshold value is its consistent estimator, thereby suggesting that a single threshold effect exists in the model. Similarly, for the central region, the LR values are also close to 0 and fall within the 95% asymptotic effective confidence interval [8.347, 8.508]. The test cannot reject the null hypothesis that the threshold value is the consistent estimator of its true value, indicating that a single threshold effect also exists in the central region.



(a) Whole country (b) East

(c) West (d) Middle

Figure 8. Likelihood ratio function graph

During the process of establishing threshold models for the eastern and western regions, the likelihood ratio function plot also reveals a double threshold effect in the threshold models for both regions. As shown in Figures 8(b) and 8(c), there are two asymptotically finite confidence intervals at the red dashed line, suggesting that a dual threshold effect may exist between the two regions. After conducting a dual threshold test, the likelihood ratio function plot indicates that the eastern and western regions exhibit a dual threshold effect at the 5% significance level. Using the three-threshold model for testing, the F-value for the western region in the two-threshold model is 9.91, which is greater than 7.4583 at the 1% significance level. Therefore, for the western region, the role of digital economic development in promoting the modernization of the two chains exhibits a two-threshold effect. Additionally, since the P-value in the three-threshold test is >0.05 and does not pass the significance test, it indicates that only a two-threshold effect exists. For the eastern region, a possible double-threshold effect was identified in the likelihood ratio function plot. After the three-threshold test, the P-value was 0.07, and the F-value was 11.08, which is less than 11.6753. Therefore, at the 95% confidence level, it remains uncertain whether a double-threshold effect exists. Based on the above analysis, it is concluded that the promotional effect of the digital economy on the modernization level of the housing industry chain and supply chain exhibits regional heterogeneity across eastern, central, and western China.

4. Conclusion

The study employs the entropy weight method for indicator weighting to assess the digital economy development levels of 30 provinces from 2015 to 2024. Overall, the level of digital economic development in China showed a steady annual increase from 2015 to 2024. Nine provinces—Beijing, Guangdong, Jiangsu, Shandong, Shanghai, Zhejiang, Tianjin, Sichuan, and Hubei—exhibited relatively high average levels of digital economic development from 2017 to 2024. The modernization level of the housing industry chain and supply chain exhibited a long-term, slightly fluctuating trend in its spatial distribution. From a spatial distribution perspective, the Moran index scores for the period 2017–2024 showed a fluctuating upward trend, with most provinces exhibiting spatial correlation in the modernization level of their housing industry supply chains. The promotional effect of the digital economy on the modernization level of housing industry supply chains in central and western regions and non-Yangtze River Economic Belt cities is greater than that in eastern regions and Yangtze River Economic Belt cities.

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References

1. Lazebnyk, L. L., & Voitenko, V. O. (2020). The essence, features, and parameters of the digital economy. Economic Bulletin of the National Mining University scientific journal, 69(69), 22-29.
2. Zekos, G. I., & Zekos, G. I. (2021). E-Globalization and Digital Economy. Economics and Law of Artificial Intelligence: Finance, Economic Impacts, Risk Management and Governance, 13-66.
3. Limna, P., Kraiwanit, T., & Siripipatthanakul, S. (2022). The growing trend of digital economy: A review article. International Journal of Computing Sciences Research, 6, 1-11.
4. Shevchenko, I., Lysak, O., Shyshak, A. Z., Mazur, I., Korotun, M., & Nestor, V. (2023). Digital economy in a global context: world experience. International Journal of Professional Business Review: Int. J. Prof. Bus. Rev., 8(4), 11.
5. Katoka, B., & Dostal, J. M. (2022). Natural resources, international commodity prices and economic performance in sub-Saharan Africa (1990–2019). Journal of African Economies, 31(1), 53-74.
6. Ciuriak, D. (2022). Unfree Flow with No Trust: The Implications of Geoeconomics and Geopolitics for Data and Digital Trade. CIGI, February, 14.
7. Aniqoh, N. A. F. A. (2020). The role of digital economy to enhancing sustainable economic development. International Journal of Social Science and Business, 4(4), 519-527.
8. Li, D. (2024). Study on the Two-Way Promotion Path of Green Financing for SMEs and Green Transformation of Urban Housing Projects in Guangdong Province in the Era of Digital Economy. International Journal for Housing Science and Its Applications, 45, 48-63.
9. Fernandez, R., & Aalbers, M. B. (2017). Housing and capital in the twenty-first century: realigning housing studies and political economy. Housing, Theory and Society, 34(2), 151-158.
10. Glaeser, E., & Gyourko, J. (2018). The economic implications of housing supply. Journal of economic perspectives, 32(1), 3-30.
11. Uchehara, I., Hamma-Adama, M., Obiri, K. A., Jafarifar, N., & Moore, D. (2020). Impacts and risk management of COVID-19 pandemic on real estate supply chain. International journal of real estate studies, 14(S1), 41-53.
12. Igan, D., Kohlscheen, E., & Rungcharoenkitkul, P. (2022). Housing market risks in the wake of the pandemic. BIS Bulletin, (50).
13. Pollack, C. E., Leifheit, K. M., McGinty, E. E., Levine, A. S., Barry, C. L., & Linton, S. L. (2021). Public support for policies to increase housing stability during the COVID-19 pandemic. American journal of preventive medicine, 61(6), 919-922.
14. Chen, X., Zhou, L., Wang, L., & Zheng, Y. (2023). Risk spillover in China’s real estate industry chain: a DCC-EGARCH-ΔCoVaR model. Humanities and Social Sciences Communications, 10(1), 1-16.
15. Dong, X. (2017). Reform of China's housing and land systems: the development process and outlook of the real estate industry in China. Chinese Journal of Urban and Environmental Studies, 5(04), 1750027.
16. Cheng, Y., Clark, S. P., & Womack, K. S. (2021). A real options model of real estate development with entitlement risk. Real Estate Economics, 49(1), 106-151.

17. MacAskill, S., Mostafa, S., Stewart, R. A., Sahin, O., & Suprun, E. (2021). Offsite construction supply chain strategies for matching affordable rental housing demand: A system dynamics approach. Sustainable Cities and Society, 73, 103093.
18. Sarbabidya, S., & Nahar, J. (2018). Supply Chain Management System of the Real Estate Industry (REI): A Study from Bangladesh Perspectives. World, 8(3), 13-27.
19. Kaulwar, P. K., Pamisetty, A., Mashetty, S., Adusupalli, B., & Pandiri, L. (2023). Harnessing Intelligent Systems and Secure Digital Infrastructure for Optimizing Housing Finance, Risk Mitigation, and Enterprise Supply Networks. International Journal of Finance (IJFIN)-ABDC Journal Quality List, 36(6), 372-402.
20. Kwok, T. W., & Chang, S. (2024). Comprehensive evaluation of digital technology's effects on the supply chain of prefabricated construction. Engineering, Construction and Architectural Management.
21. Alotaibi, B. S., Shema, A. I., Ibrahim, A. U., Abuhussain, M. A., Abdulmalik, H., Dodo, Y. A., & Atakara, C. (2024). Assimilation of 3D printing, Artificial Intelligence (AI) and Internet of Things (IoT) for the construction of eco-friendly intelligent homes: An explorative review. Heliyon.
22. Souza, L. A., Koroleva, O., Worzala, E., Martin, C., Becker, A., & Derrick, N. (2021). The technological impact on real estate investing: robots vs humans: new applications for organisational and portfolio strategies. Journal of Property Investment & Finance, 39(2), 170-177.
23. Gottmann, W., Djakona, V., & Stankevics, A. (2024). Investment in Housing Construction: Current Trends and Digital Technologies. International Journal of Sustainable Development & Planning, 19(6).
24. Juan, Y. K., Chen, H. H., & Chi, H. Y. (2018). Developing and evaluating a virtual reality-based navigation system for pre-sale housing sales. Applied Sciences, 8(6), 952.
25. Pankratov, E., Grigoryev, V., & Pankratov, O. (2020, June). The blockchain technology in real estate sector: Experience and prospects. In IOP Conference Series: Materials Science and Engineering (Vol. 869, No. 6, p. 062010). IOP Publishing.
26. Kazeem, K. O., Olawumi, T. O., & Osunsanmi, T. (2023). Roles of artificial intelligence and machine learning in enhancing construction processes and sustainable communities. Buildings, 13(8), 2061.
27. Srinjoy Chatterjee & Shankar Chakraborty. (2024). A study on the effects of objective weighting methods on TOPSIS-based parametric optimization of non-traditional machining processes. Decision Analytics Journal,11,100451-.
28. Oliver Mendoza Cano,Rogelio Danis Lozano,Xóchitl Trujillo,Miguel Huerta,Mónica Ríos Silva,Agustin Lugo Radillo... & Efrén Murillo Zamora. (2025). Spatial patterns and clustering of dengue incidence in Mexico: Analysis of Moran's index across 2,471 municipalities from 2022 to 2024. . PloS one,20(5),e0324754.