A novel Spatial Econometric Model Approach to Analyze the Association Between Digital Economy and Consumption Upgrading

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Abstract. This paper examines the association between the digital economy and consumption upgrading in five coastal cities in China from 2016 to 2020, using a spatial econometric model. The results indicate that consumption upgrading exhibits significant spatial agglomeration. The development of the digital economy can facilitate the level of consumption upgrading and has a positive spilling over effect on the level of consumption upgrading in neighboring regions, thereby narrowing the spatial differences in consumption upgrading between regions. The mediation effect suggests that the digital economy can promote industrial upgrading, which in turn promotes consumption upgrading. To promote sustainable consumption, China should continue to develop the digital economy, upgrade traditional industries, and coordinate digital economy development across all regions.

Keywords: digital economy; consumption upgrading; spatial measurement; industrial upgrading; regional economy.

1. Introduction

Consumption has always been an important driving force for economic and social development, and the enhancement of consumption plays a fundamental role in economic development. Nowadays, the key to enhancing consumption lies in consumption upgrading, and the digital economy platform is a key platform for promoting consumption upgrading. The digital economy can promote the digital transformation and upgrading of the traditional industrial chain, giving rise to new consumption patterns, further releasing consumption potential and driving people's consumption upgrading. Therefore, the degree of influence of the digital economy on consumption upgrading is of practical significance. The digital economy has a significant effect on promoting consumption upgrading, and topics such as the digital economy boosting consumption upgrading are hot issues in current academic research.

This paper takes the assumption that the development of digital economy can promote consumption upgrading and the influence of digital economy on consumption upgrading has spatial effect as the hypothesis, and confirms it by using the form of data analysis, model design and calculation to get the correlation relationship between the level of development of digital economy and people's standards of consumption.

In the study of economics, consumption levels are influenced by a variety of factors, including income levels, consumer confidence, interest rates, employment rates, technological advances, consumer culture, and changes in market prices. With the accelerated transformation of digitalization, the digital economy has become a very new and important dimension of these factors. The digital economy is an economic activity that relies on digital technologies and Internet platforms to develop, including business models such as mobile payments, Internet travel, local Internet life service platforms, e-commerce, and takeaways. The core technologies of the digital economy platform include big data, cloud computing, blockchain, artificial intelligence and so on. It has not only boosted the traditional industrial chain to undergo digital transformation, but also given rise to brand new consumption patterns. For example, the onlineization of brick-and-mortar stores, real-time analysis of online consumption data, and personalized consumption recommendations have made consumption smarter and more convenient. In addition, the digital economy has unleashed a large

amount of consumption potential, bringing consumers more and higher-quality choices and further promoting the upgrading of consumption.

In research on the digital economy and consumer spending, the article uses spatial econometric modeling to perform statistics and calculations to provide richer and more accurate information for the study. In economics, geography, urban planning and other fields, many data are related to geospatial locations, and there is a correlation between these geospatial locations. Therefore, it would be more accurate to calculate the impact of digital economy on consumption based on spatial econometric modeling, which has the advantage of being able to effectively capture spatial effects, and to be able to predictively reveal the interactions and dependencies between different spatial units. At the same time, for data with spatial heterogeneity, spatial econometric models can provide more accurate estimates. In analyzing the impact of the digital economy on consumption upgrading needs to take into account the differences between different regions, cities and countries. The spatial econometric model can take these spatial effects into account, making the analysis more comprehensive and accurate. For example, the development of digital economy in one region may affect the consumption behavior of its neighboring regions. Traditional regression analysis, on the other hand, may ignore this spatial dependence and correlation, leading to biased results. Spatial econometric models, on the other hand, can take into account the impact of such factors.

The impact of digital economy on consumption upgrading is obvious, and it is reshaping people's consumption habits and patterns as a new driver of economic growth. And spatial econometric model, as an effective tool, can help researchers analyze and explain this impact more accurately. Therefore, the use of spatial econometric modeling has greater advantages than traditional analytical methods when investigating and surveying the issue of digital economy boosting consumption upgrading.

The transformation of the consumption pattern of the population by the digital economy is not only an significant driving force for contemporary economic development, but also predicts the reshaping of the social and economic structure in the future. As digital technology continues to be integrated into various industries, it not only promotes rapid changes in the behavioral habits of consumer groups, but also further affects the structure of the industrial chain and the way of value transfer. This should mean that under the wave of digital economy, not only the economic model and industrial pattern will undergo profound changes, but also people's lifestyles, values and socialization modes will be transformed, and the digital era will shape a new era that is very different from the traditional one.

2. Related Work

From the perspective of relevant literature, there are relatively few studies on digital economy and consumption upgrading, mainly focusing on the consumption effect of the Internet economy. In terms of theoretical mechanism research, Du Danqing (2017) believes that the Internet economy can promote the innovation and upgrading of consumer products, promote changes in the mode of consumer services, and improve the quality of residents' consumption [1]. Wang Xi (2016) found that "Internet+" can promote the upgrading of supply and demand, reshape the consumption structure and realize consumption upgrading [2]. In terms of empirical research, Cheng Mingwang (2019) argue that Internet penetration can significantly narrow the gap between urban and rural residents, and its reduction effect can be realized by narrowing the gap between subsistence, enjoyment, and developmental consumption [3]. Lan Leqin et al. (2021), by studying China's interprovincial panel data in 2013-2020, find that digital inclusive finance can effectively raise people's consumption level, and it has spatial spillover effects [4].

Chen Dongjing and Guo Xiaotong (2023) proposed a document that examines the influence of the digital economy and financial development on consumption upgrading, indicating it is an essential element of high-quality economic growth, using panel data from 30 provinces in China from 2006 onwards [5]. He Yuan et al. (2022) did a study available on *ScienceDirect* discusses the significance of digital economic development in the consumption upgrade of older individuals, which can inform communication strategies, education, and publicity campaigns [6]. Ye Jian et al.'s study (2023) from

Frontiers in Environmental *Science* investigates the relationship between digital inclusive finance and consumption structure upgrading, emphasizing its significant role in reducing carbon emissions and examining the impact of the digital economy on urban agglomerations' carbon emission intensity [7].

Another MDPI article by Su Jinqi et al. (2021) discusses how the development of the digital economy has been a driving force in the developing of the industrial structure of China, with multitudinous technological innovation playing an intermediary role in this promotion [8]. Easwaramoorthy Rangaswamy (2022) discussed the acceleration of digitalization trends due to the pandemic highlights the necessity for businesses to apply digital technologies strategically [9]. This is particularly important in Singapore, where the government supports digital adoption in most business sectors. It evaluates buyer preferences for an omnichannel approach, combining online and offline advantages.

Synthesize the above studies, this paper takes five provinces in China's coastal region as the research object in 2016-2020, explores the possible spatial correlation between the digital economy and consumption upgrading, empirically analyzes the impact and mechanism of the digital economy on consumption upgrading using spatial econometrics, and expects to put forward rationalized suggestions for consumption upgrading.

3. Methodology

3.1. Mechanisms of the digital economy's direct effect on consumption upgrading

As an emerging new economic form, the digital economy has had a profound impact on people's consumption level and habits. Specifically, the digital economy has, on the one hand, greatly stimulated people's consumption potential and raised the level of consumption. Through advanced digital technologies such as the Internet server, the Internet of Things, big data, and artificial intelligence, the circulation links and spatial restrictions of consumption have been significantly reduced. This makes the supply side and demand side of commodities more fluid, and consumers can more easily access a variety of commodity information, thus stimulating more consumption behaviors, fully tapping the consumption potential and raising the level of consumption. Big data analysis and algorithmic recommendations have further facilitated the provision of personalized goods and services to meet diversified consumer needs. On the other hand, the consumption structure continues to change and service consumption is developing rapidly. The digital economy has led residents' consumption towards a more personalized development, such as F2C private customization (factory to consumer), and a consumption structure dominated by service consumption is gradually taking shape, with residents' demand for service consumption increasing, lowering the marginal cost of service enterprises' operations, and facilitating the diversified development of service consumption supply, which in turn more conveniently meets residents' differentiated needs. At the same time, the digital economy promotes the efficiency of the supply chain, reduces inventory costs, optimizes logistics and distribution, and provides consumers with a more efficient shopping experience. In addition, the rise of cross-border e-commerce has expanded the range of consumer choices and promoted consumption upgrading. In summary, the first hypothesis of this paper is proposed:
Hypothesis 1: The upgrading of the digital economy can contribute to the upgrading of consumption levels.

3.2. Spatial mechanisms of the digital economy for consumption upgrading

The digital economy has developed unevenly and with significant differences between regions in China, and the differences in regional development will lead to the flow of factors of production; factor resources in developed regions will be transferred to less-developed regions with higher returns on opportunities, and the digital technology in developed regions will be popularized to less-developed regions, boosting the promoting of the digital economy and thus leading to the upgrading of consumption. In this process, developed regions promote the transformation of consumption

patterns through innovation promotion, industrial upgrading and market expansion, and drive less developed regions to promote the transformation of consumption patterns through technological learning, capital input and talent attraction. The digital economy can not only affect the consumption upgrading of people in the region, but also have an impact on the upgrading of other regions. This spatial effect may be manifested through a variety of ways, such as inter-regional cooperation on e-commerce platforms, the sharing of digital payment systems, and the co-construction of e-commerce logistics networks. Therefore, the second hypothesis of this paper is proposed:
Hypothesis 2: The effect of the digital economy on consumption upgrading has a spatial effect.

3.3. Transmission mechanisms of the digital economy affecting consumption upgrading

The development of digital economy not only promotes the digital transformation and upgrading of traditional industries, but also gives chances to many new industries. On the one hand, the digital economy continues to promote the transformation of traditional industries to intelligence and digitalization, and enterprises need to accurately grasp the new demand dynamics in the market, produce more personalized and differentiated products, and improve the fitness of supply and demand, thus promoting the upgrading of consumption; this supply-side innovation improves the match between products and services, accelerates the upgrading of consumer goods, and thus promotes the improvement of the overall quality of consumption. On the other hand, the growth of the digital economy has also helped the emergence and development of many new industries such as remote medical care, live streaming with goods, online teaching, etc., creating more diversified and convenient consumption experiences for people, breaking the spatial limitations, reducing the transaction costs, and becoming an important engine for promoting consumption upgrading. Therefore, the third hypothesis of this paper is proposed.

Hypothesis 3: Industry upgrading has a mediating effect between the digital economy and consumption upgrading, and the digital economy can boost industry upgrading and then promote consumption upgrading.

Table 1. Indicator System for Consumption Upgrading (C)

First Level Indicators	Second Level Indicators	Third Level Indicators	Indicators' Attribute
Consumption level	Per capita consumption expenditure	Per capita consumption expenditure (¥)	+
	Total retail sales of consumer goods per capita	Total retail sales of consumer goods per capita (¥)	+
	Consumption rate	Per capita consumption expenditure/GDP Per Capita	+
Consumption structure	High level consumption expenditure	High level consumption expenditure per capita (¥)	-
	Proportion of high level consumption expenditure	High level consumption expenditure per capita/Per capita consumption expenditure	-
	Engel coefficient	Per capita food consumption expenditure/Per capita consumption expenditure	-

Table 2. Comprehensive system of indicators for the digital economy

First Level Indicators	Second Level Indicators	Third Level Indicators	Indicators' Attribute
Digital economy Comprehensive Development Index	Internet penetration rate	Internet users per 100 population	+
	Number of Internet-related workers	Percentage of employees in computer services and software	+
	Internet-related outputs	Total telecommunication services per capita	+
	Number of mobile Internet users	Cell phone subscribers per 100 population	+
	Digital finance for inclusive development	China digital inclusive finance index	+

Table 3. Global Moran Index for Consumption Upgrading and the Digital Economy

Year	C		D	
	Moran's I	P value	Moran's I	P value
2016	0.321	0.001	0.222	0.008
2017	0.353	0.002	0.215	0.017
2018	0.375	0.000	0.208	0.022
2019	0.371	0.001	0.212	0.027
2020	0.362	0.000	0.210	0.030

4. Study Design

4.1. Selection of variables

1. Explained variable (dependent variable): consumption upgrading (C). Indicator construction is carried out from two aspects of consumption level enhancement and consumption structure optimization, and all indicators use entropy value method to measure people's comprehensive index of consumption upgrading, and the specific measurement indexes are shown in Table 1.

2. Explanatory variable (independent variable): level of digital economy development (D). As shown in Table 2, this paper adopts five indicators, which are "Internet penetration rate, Internet employees, Internet-related output, cell phone penetration rate, and China's digital financial inclusion index", and processes the data of the above five aspects through the entropy method to finally obtain a comprehensive development index for digital economy.

3. Control variables. Industrial upgrading (X_1), industrial upgrading can deal with the contradiction of excess supply at the low-end and insufficient supply at the high-end, and is a key way to promote consumption upgrading, which is expressed by the added value of the tertiary industry as a percentage of the added value of the secondary industry; residents' disposable income (X_2), according to the theory of consumption, income is the key factor influencing the consumption behavior of the residents, and generally speaking, consumption is positively correlated with income; human capital (X_3), residents with higher education have more opportunities to obtain higher incomes and thus have higher consumption expenditures, and participate in high-level consumption, which is measured by the number of years of education per capita; market segmentation (X_4). Human capital (X_3), more educated residents have more chances to get higher income, and thus have higher consumption expenditure and participate in high-level consumption, which is measured by the number of years of education per capita; market segmentation (X_4), market segmentation is not conducive to the upgrading of consumption, and this paper adopts the price index method to measure the degree of market segmentation; foreign direct investment (X_5), foreign direct investment can promote the upgrading of consumption structure, and this paper adopts the annual foreign direct investment in each province to measure the degree of foreign direct investment. The level of foreign direct investment (X_5), foreign direct investment can promote the upgrading of consumption structure, this paper adopts the ratio of foreign direct investment in each province to the GDP of each province every year.

4.2. Data sources

The data in this paper come from the provincial-level panel data of five provinces in the coastal region of China in 2016-2020. The data of the variables involved in the study come from the China Statistical Yearbook, provincial statistical yearbooks, and the China Science and Technology Statistical Yearbook. In order to reduce the effect of heteroskedasticity caused by the non-uniformity of units between the data, the data of all variables in this paper are logarithmic.

4.3. Modeling

1. Research methodology. There are spatial differences in the development of consumption structure and consumption level among regions in China. Although the development of digital

economy has alleviated the inter-regional gap to a certain extent, differences in consumption upgrading among regions still exist. Although the development of digital economy has alleviated the gap between regions to a certain extent, differences in consumption upgrading still exist in different regions. Consumption upgrading in a region is not only limited by its own degree of development of digital economy, but also by the development level of digital economy in other regions. Therefore, considering the existence of spatial effects, this paper constructs a spatial measurement model for research.

2. Spatial econometric modeling. This paper adopts the spatial Durbin model (SDM) to test the influence of the digital economy on consumption upgrading. Where C_{pn} and D_{pn} are the level of consumption upgrading and the level of digital economy development in the n_{th} year of province p, respectively; X_{pn} stands for a series of control variables X_1, X_2, X_3, X_4, and X_5; W_{pn} is the geographic distance matrix; ε_{pn} is the random disturbance term; μ_p and ν_p are the province fixed effect and time fixed effect, in that order.

3. Mediating effect test. This paper adopts the three-step test method to test the mediation effect, the specific model is as follows:

$$C_{pn} = \partial_1 \sum_{i=1}^{n} W_{pn} C_{pn} + \gamma D_{pn} + \partial_2 \sum_{i=1}^{n} W_{pn} D_{pn} + \iota X'_{pn} + \partial_3 \sum_{i=1}^{n} W_{pn} X'_{pn} + \mu_p + \upsilon_p + \varepsilon_{pn} \quad (1)$$

$$X_{1pn} = \Psi_1 \sum_{i=1}^{n} W_{pn} X_{1pn} + \varphi D_{pn} + \Psi_2 \sum_{i=1}^{n} W_{pn} D_{pn} + \nu X'_{pn} + \Psi_3 \sum_{i=1}^{n} W_{pn} X'_{pn} + \mu_p + \nu_p + \varepsilon_{pn} \quad (2)$$

$$C_{pn} = \pi_1 \sum_{i=1}^{n} W_{pn} C_{pn} + \lambda D_{pn} + \pi_2 \sum_{i=1}^{n} W_{pn} D_{pn} + \theta X_{1pn} + \pi_3 \sum_{i=1}^{n} W_{pn} X_{1pn} + \sigma X'_{pn} + \pi_4 \sum_{i=1}^{n} W_{pn} X'_{pn} + \mu_p + \upsilon_p + \varepsilon_{pn} \quad (3)$$

Where X_1 is the mediating variable and X'_{pn} is the other control variables except industrial upgrading (X_1)

5. Experimental results

5.1. Spatial correlation tests

1. Global Moran index analysis. In order to gain a deeper understanding of the spatial correlation between consumption upgrading and the degree of digital economy development, this study figures the global Moran index of consumption upgrading and the level of digital economy development for five coastal provinces in China during the period from 2016 to 2020. Table 3 demonstrates the relevant results. It is obvious from Table 3 that the Moran index is positive and all significant at the 1% significance level, which means that there is a significant global spatial positive correlation between the degree of consumption upgrading and the level of digital economy development, showing a strong spatial dependence. Overall, the two show a tendency to cluster geographically and have obvious positive spatial spillover effects.

2. Local Moran index analysis. This study demonstrates the spatial correlation between provinces by plotting localized Moran diagrams of consumption upgrading and digital economy development levels in 2016 and 2020. It is observed that the data points of most provinces are concentrated in the first and third quadrants of the Moran diagram of consumption and digital economy development level, which indicates that there is a strong spatial facilitation effect among provinces at the local spatial level. In addition, the number of provinces in the first and third quadrants has increased significantly during this five-year period, showing that the correlation between consumption upgrading and the level of digital economy development is getting stronger in the local area, and the positive spatial correlation characteristics are more obvious. Combined with the findings of the global Moran index, this paper believes that the spatial factor plays an important role, and therefore a more in-depth analysis is carried out using a spatial econometric model.

5.2. Spatial econometric modeling analysis

In this paper, we refer to Elhorst's spatial test theory, and carry out LM test and LR test in turn, and the results are shown in Table 4. According to Table 4, the LM test rejects the original hypothesis, which indicates that the two effects of spatial lag and spatial error autocorrelation exist, and the spatial

Durbin model considers these two effects at the same time, so it is initially judged that the spatial Durbin model is reasonable. According to the results of Hausmann's test, this paper adopts the spatial Durbin fixed effect model, and the LR test shows that the spatial Durbin model will not degenerate into the spatial error model or the spatial autoregressive model, and that the fixed effect should consider the individual and time effects at the same time, and the spatial Durbin model with bidirectional fixed effect is finally chosen as the benchmark model.

Table 4. LM, LR test results

Methods	Statistical Magnitude	Probability
LM-spatial error	6.411	0.021
Robust LM-spatial error	12.389	0.000
LM-spatial lag	4.223	0.028
Robust LM-spatial lag	10.370	0.002
LR-spatial lag	16.320	0.015
LR-spatial error	16.590	0.009

The baseline regression results shown in Table 5 indicate that the regression coefficient of digital economy is 0.161, which is significant at the 5% significance level, which points out that the development of digital economy in a province can significantly increase the level of consumption upgrading of local residents. Meanwhile, the coefficient of the spatial lag term of the digital economy is 1.091, significant at the 10% significance level, which points out that the spatial effect of the digital economy is significant, i.e., the development of the digital economy in one region also has a significant role in promoting the consumption upgrade in other regions. Although the spatial Durbin model elucidates the spatial correlation between regions, its parameter estimation cannot fully reveal the direct effect and spatial spillover effect. Therefore, this paper adopts the partial differentiation method to decompose the effects of explanatory variables into spatial direct effects, spatial indirect effects and total effects, and the results are displayed in Table 6. The spatial direct, indirect and total effects of the level of digital economy development are all significantly positive, implying that the development of the digital economy in the region not only promotes local consumption upgrading, but also produces a significant positive spilling over effect on neighboring regions. Among the control variables, the direct effect of industrial upgrading is positive and significant, indicating that the optimization of industrial structure and the balance of supply and demand in each province provide the necessary products and services for consumption upgrading.

Table 5. Spatial Durbin model regression results

VARIABLES	X	WX
D	0.161** (2.189)	1.091* (1.872)
X1	0.032*** (2.711)	0.038 (0.502)
X2	0.012 (0.219)	0.169 (0.523)
X3	-0.001 (-0.064)	0.012 (1.397)
X4	0.000 (0.049)	-0.075 (-1.239)
X5	1.488 (0.135)	67.833 (0.971)

Note: *** indicates significant at the 1% level, ** indicates significant at the 5% level, * indicates significant at the 10% level, and the same below.

Table 6. Direct, indirect and total effects

VARIABLES	Direct Effect	Indirect Effect	Total Effect
D	0.188** (2.451)	1.755* (1.736)	1.939* (1.881)
X1	0.032** (2.533)	0.066 (0.591)	0.099 (0.812)
X2	0.028 (0.413)	0.273 (0.542)	0.291 (0.573)
X3	0.000 (-0.103)	0.020 (1.323)	0.015 (1.263)
X4	-0.001 (-0.173)	-0.118 (-1.181)	-0.116 (-1.133)
X5	3.938 (0.333)	114.742 (0.901)	118.682 (0.891)

5.3. Mediation effects test

In this study, industrial upgrading was taken as a mediating variable and analyzed by using the mediating effect model. In model (1), the overall impact of the digital economy on consumption upgrading is 0.205 and passes the test at 1% significance level; in model (2), the coefficient of the digital economy's impact on industrial upgrading is 1.541; while in model (3), the coefficient of the industry structure's impact on consumption upgrading is 0.032, and both coefficients pass the test at 1% significance level. In model (3), the coefficient of the impact of digital economy on consumption upgrading is 0.161, which passes the test at the 5% significance level. Compared with model (1), the absolute value of this coefficient is slightly lower, indicating that industrial upgrading does play a mediating role between digital economy and consumption upgrading, i.e., the digital economy promotes industrial upgrading by promoting industrial upgrading, which in turn enhances the level of consumption upgrading.

5.4. Robustness tests

To assure the robustness of the measurement results, this paper replaced the geographic distance matrix for the economic distance matrix in the spatial Durbin model to carry out the regression test again. The analysis finds that although the effect of the digital economy on consumption upgrading is slightly different in the size of the estimated coefficients, it is basically consistent in terms of the direction of influence and significance. Therefore, the effect of digital economy on consumption upgrading can be considered robust and reliable. This finding further confirms the validity of the findings.

6. Conclusion

First, promote the high quality development of the digital economy. We need to accelerate the construction of a consumer-centered digital platform system, actively cultivate digital consumption patterns, and improve the digital product supply system. The digital economy plays an significant role in promoting consumption upgrading, so we should unswervingly push forward the construction of digital information facilities, continuously improve the application of digital technology, fully tap the consumption potential of residents, and promote the promoting of the consumption structure.

Second, we should strengthen the collaboration and connection of the digital economy among regions. It is necessary to realize the positive spatial spillover effect of the digital economy for promoting consumption upgrading, and making full use of the characteristics of digital elements, such as flexibility and mobility, to exert this spillover effect under the spatial interaction between different regions, thus assisting the consumption upgrading of each region.

Third, actively promote industrial upgrading and give full play to its intermediary role. It will accelerate the integration and development of digital information technology with the real economy, raise new business forms and new industries, use digital means to carry out industrial transformation, lead the digital development and intelligent transformation of the consumer service industry, innovate the mode of consumer supply, and promote the personalized and refined development of people's consumption.

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