

Article

The Impact of Digital Technology Penetration on Sustainable Household Consumption: Evidence from China's Sinking Market

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Abstract

Sinking markets have become a consumption blue ocean, as the digital economy enters its second phase. Based on data from 231 prefecture-level cities from 2011 to 2023, various econometric methods, including the fixed effects model, threshold effect model, and mediation effect model, are used to explore the impact and mechanism of digital technology penetration on sustainable household consumption in the sinking market. The findings suggest that the penetration of digital technology has a substantial impact on sustainability of household consumption in this market. This conclusion remains robust after addressing endogeneity and conducting a series of robustness checks. The threshold value for human capital is 0.0068, and only when human capital accumulation reaches this level can the synergy between human capital and sustainable household consumption be enhanced. The mechanism analysis indicates that the effect of digital technology on consumption is partially mediated by household income and financial development. A heterogeneity analysis reveals that the effect of digital technology penetration on sustainable household consumption is universally beneficial, with a more significant impact in central and western regions. This study provides reference ideas for enhancing the sustainability of household consumption in the sinking market in the context of digital transformation.

Keywords: digital technology penetration; sinking market; sustainable household consumption; human capital threshold; financial development



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1. Introduction

The extensive implementation of digital technologies is imperative for the advancement of China's economy, which is characterized by its substantial development. A substantial body of research on international consumption patterns indicates that consumption levels tend to exhibit a "U"-shaped change over time [1]. As illustrated in Figure 1, there has been a discernible upward trend in final consumption in China since 2010. This phenomenon signifies China's pivotal transition from a "production-oriented society" to a "consumption-oriented society" [2]. In the absence of novel economic catalysts, the Chinese economy is poised to transition into a phase of medium-to-low-speed growth. In the context of a contemporary technological revolution, digital technology has emerged as a pivotal catalyst for promoting high-quality economic growth and stimulating consumption. This phenomenon can be attributed to the efficiency, extensive penetration, and comprehensive coverage characteristics of digital technology. The following text is intended to provide a

comprehensive overview of the subject matter. The process of consumption represents both the objective and the outcome of social reproduction. The advent of novel technologies has precipitated two major shifts: firstly, in the domain of production, and secondly, in the domain of consumption. As early as the 1970s, Agnar Sandmo et al. [3] introduced technology into the consumption model, thereby constructing a new consumer utility function. Tero Pikkarainen et al. [4] used the Technology Acceptance Model (TAM) to study how technology can influence consumer behavior, leading to greater acceptance of new products and services and increased purchasing intent [5]. Specifically, on the one hand, the impact of technological progress on consumption manifests through a ratchet effect and a demonstration effect. Technological advancements suppress the ratchet effect on consumption while reinforcing the demonstration effect by altering consumer habits. The role of technological progress in consumption is determined by the combined strength of these two effects [6]. On the other hand, technological progress enables more sustainable business models, transforms production methods, and reshapes household consumption habits, structures, and behaviors through digital reconstruction, ultimately promoting sustainable household consumption [7]. These processes' combined effects enhance the matching of supply and demand, thereby unlocking the consumption market's potential.

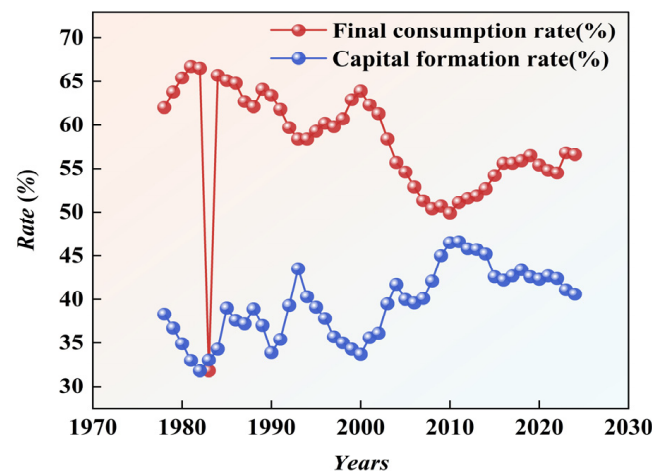


Figure 1. Trends in China's Final Consumption Expenditure and Gross Capital Formation as a Share of GDP. Note: Data are sourced from the National Bureau of Statistics of China [8].

The sinking market in the digital economy era is not entirely the Chinese-style rural society described by Fei Xiaotong, but has entered the stage of “urban-rural China” [9]. On the one hand, for consumers in the sinking market, one is the public consumers who are very sensitive to the price. The open quotation on the Internet platform alleviates the information gap in the consumer market to a certain extent and stimulates the consumption desire of residents in the sinking market. The other type is the mid to high-end consumers who pay more attention to product personalization and are willing to pay for product added value. The penetration of digital technology in the sinking market has brought them opportunities for diversified choices, which also stimulates consumption. On the other hand, comparing the consumption changes before and after COVID-19 in first- and second-tier cities versus the sinking markets reveals a gradual decline in consumption in the former. The growth rates of total retail sales of consumer goods in Beijing, Shanghai, Guangzhou, and Shenzhen during the first half of 2024 were -0.3% , -2.8% , -0.3% , and 1.2% , respectively, significantly below the national average growth rate of 3.5% . In contrast, the growth rate of consumption in the sinking market far exceeds the national average, which has, in turn, helped elevate the consumption growth rates of first-tier, second-tier, and new first-tier cities. This has positioned the sinking market as a “ballast stone” for the

consumption of Chinese households [10]. A report by Tsinghua University on county-level consumer markets shows that county households have a property ownership rate of 70% and a car ownership rate of approximately 58.5%, suggesting that compared to consumers in first- and second-tier cities, those in the sinking market enjoy higher discretionary income and substantial consumption potential [11]. This demographic has thus become a key consumer blue ocean market for the second phase of China's digital economy.

There is limited academic research on the impact of digital technology on consumption in the sinking market. Current academic research on the impact of digital technology on consumption in the sinking market remains relatively scarce. Existing studies are predominantly centered on the effects of digital technology-enabled traffic on consumption behaviors in this market, along with the subsequent influence of e-commerce and related digital channels. Internet platforms play a crucial role in stimulating demand in this market. Wang et al. [12] categorized the original market as sinking, high-end, or mixed. From the perspective of traffic competition, the researchers examined how different types of traffic and traffic pricing affect market performance. They found that public domain traffic fosters competition, lowers prices, increases business profits, and stimulates consumer enthusiasm. However, when monopoly power is introduced, public domain traffic weakens consumption activation in sinking markets. E-commerce formats, such as online retail, have reduced the cost of living in underdeveloped areas [13]. However, there is no conclusion regarding the impact of online retailing on sinking market consumption. On the one hand, online retailing increases consumers' exposure to goods, which increases the sinking market consumption [14]. On the other hand, online retail increases consumer exposure to goods, thereby boosting consumption in the sinking market. Conversely, research by Bai et al. [15] suggests that online retailing has no significant impact on consumption in sinking markets.

The present study focuses on the phenomenon of the sinking market, utilizing the penetration of digital technology within this market as the independent variable. The study employs a sample of 231 prefecture-level cities from 2011 to 2023 to examine the impact of digital technology penetration on sustainable consumption in the sinking market. Among them, due to various objective reasons, the agency scope of the sinking market is limited to prefecture-level cities, and sustainable consumption is represented by household consumption expenditure. The specific selection criteria are shown in Section 3.1. The marginal contributions are as follows: Firstly, the research sample focuses on the sinking market, a rapidly expanding consumption frontier, thereby addressing a significant gap in research concerning the sinking market in the context of building a unified national market. This study offers insights into the pivotal role of digital technology penetration and provides an essential theoretical foundation and policy recommendations for unlocking the consumption potential of households in the sinking market amid digital transformation. Secondly, the study explores the relationship between digital technology penetration and market consumption, with human capital serving as the threshold variable. This analysis is consistent with China's stated objective of enhancing science, technology, and education. Thirdly, it demonstrates that the penetration of digital technology has an inclusive effect on promoting sustainable consumption among households in the sinking market, contributing to development strategies for China's regional coordinated growth. The structure of the paper is as follows: Section 2 presents a theoretical analysis and research hypotheses; Section 3 outlines the research design; Section 4 discusses the empirical results; Section 5 analyzes the transmission mechanisms; and Section 6 offers research conclusions and policy recommendations.

2. Theoretical Analysis and Research Hypothesis

In the digital economy era, consumers' ability to access goods and the types of goods available to them are largely determined by algorithmic recommendations and platform displays [16]. Within the context of sinking market, this phenomenon can be interpreted as the degree of penetration of digital technology, which in turn exerts a significant influence on the consumption behavior of households. Based on the definition provided by Yang and Kuang, the AI penetration rate refers to the extent to which enterprises integrate and utilize AI technologies [17]. The digital technology penetration rate is a proxy for the extent to which economic agents adopt and use digital technologies in economic activity. The repercussions of such penetration on economic behavior are economy-wide and diffuse. Consequently, a conceptual framework is developed to explain how digital technology penetration and its transmission mechanisms shape sustainable household consumption in the sinking market. This framework is illustrated in Figure 2.

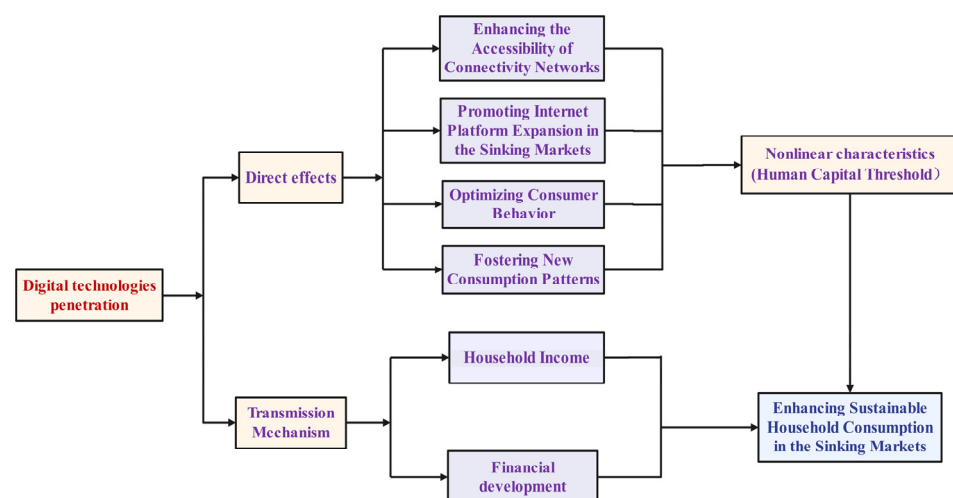


Figure 2. Analysis framework of the effect of digital technology penetration on sustainable household consumption in the sinking market.

2.1. The Impact of Digital Technology Penetration on Consumer Behavior in the Sinking Market

Digital technology is a key support for the development of the digital economy. In comparison to first-tier and second-tier city markets, the sinking market faces a digital divide. The existence of this digital divide leads to social exclusion, with its positive effects failing to benefit certain vulnerable groups [18]. Such a divide forces society into a prolonged, low-inclusion state, akin to the “middle-income trap” [19], thereby impeding the equitable sharing of digital dividends across different social groups. Promoting the penetration of digital technology in the sinking market is a critical means of bridging this divide [20]. Digital technology has the capacity to unlock consumption potential, elevate consumption levels, and optimize consumption structures by broadening information channels, influencing consumption concepts, changing consumption habits, and reducing transaction costs [21]. Firstly, the integration of digital technologies, particularly the Internet, has enabled households in declining markets to access online networks. The proliferation of the Internet has led to an augmentation of the consumer base, with Internet access catalyzing the stimulation of consumer desire [22]. Secondly, leveraging the Internet platform developed by digital technology, on the one hand, consumers’ ‘footsteps’ (search history, browsing records, order history) are tracked to create accurate consumer profiles using big data, allowing for the promotion of goods that align with expectations and consumption trends, thereby increasing transaction success rates. On the other hand, the penetration of digital technology and the application of big data models have strengthened the governance

of Internet platforms, further enhancing sustainable household consumption [23]. Thirdly, the proliferation of digital technology has been shown to have a significant impact on consumer behavior, prompting alterations in consumer attitudes. The pervasive adoption of digital payment systems (e.g., WeChat Pay, Alipay, mobile banking) has not only led to a reduction in “shoe-leather cost” but also resulted in the conservation of transaction time and the enhancement of payment convenience. Moreover, these systems have facilitated the digitization of currency. Digital payments have been shown to have a significant impact on consumers’ propensity to engage in e-commerce, thereby influencing household consumption patterns. In comparison with tangible banknote payments, digital payments have been found to enhance consumers’ inclination to make purchases, thus impacting their household consumption behavior [24]. The advent of credit services derived from digital payments (e.g., Huabei, Jiebei, JD Baitiao, Weipinhua) has been shown to mitigate income constraints on consumption. Furthermore, the penetration of digital technology has enhanced the level of digital consumption in the sinking market [25]. New consumption models and formats enabled by digital technology, such as smart tourism and online healthcare, have made consumption methods more convenient and diversified [26], thereby improving consumers’ experience and satisfaction [27]. Moreover, by increasing consumers’ awareness of low-carbon living, a low-carbon consumption model can be established, fostering sustainable consumption [28]. Based on the above, Hypothesis 1 is proposed.

H1: *Penetration of digital technology is conducive to promoting sustainable consumption among households in the sinking market.*

Studying and applying digital technology requires a certain level of knowledge. The degree to which digital technology is adopted not only determines the likelihood that consumers in the sinking market will access goods, but also dictates the size of the audience. In other words, the impact of digital technology penetration on consumption in the sinking market is subject to a human capital threshold. According to the permanent income hypothesis, temporary income has a limited effect on consumption; however, permanent income is the key determinant of consumption [29]. Permanent income depends on the enhancement of human capital. The widespread adoption of digital technology has given households in the sinking market a window to understand changes in the era. This new era requires a specific type of worker, and unskilled laborers will inevitably be replaced by intelligent machines. To achieve a persistent income, individuals must enhance their abilities to meet the demands of the labor market [30]. Therefore, the synergistic effect between human capital and the consumption patterns of households in the sinking market can only be fully realized when human capital accumulation reaches a certain threshold. Based on this reasoning, Hypothesis 2 is proposed.

H2: *Digital technology penetration has a human capital threshold that influences sustainable consumption in the sinking market.*

2.2. The Transmission Mechanism of Digital Technology Penetration on Sustainable Consumption in the Sinking Market

2.2.1. The Income Effects of Digital Technology Penetration

The penetration of digital technology has been shown to stimulate consumption through the income channel. Firstly, it has been demonstrated that penetration improves employment outcomes and raises earnings. Digital platforms have the potential to facilitate remote and hybrid work models, cloud-based collaboration, and platform-mediated gig arrangements by relaxing temporal rigidity (the “9-to-5” schedule), decoupling jobs from place (co-location requirements), and shifting the matching technology from one-to-one to

multi-client contracting. The implementation of these non-standard work arrangements has been demonstrated to enhance labor market access in the sinking market, which encompasses lower-tier cities and rural areas. This expansion has been observed to result in an augmentation of earnings, particularly among flexible and gig economy workers [31], thereby fostering consumer spending. Secondly, the penetration process enhances income through skill enhancement and improved alignment. Internet-enabled vocational initiatives (e.g., “Internet+” vocational skills programs) have been shown to enhance human capital, while big-data talent-service cloud platforms have been demonstrated to thicken markets and improve match quality for sinking market workers, thereby expanding employment opportunities, raising household income, and, consequently, increasing consumption [32]. Based on the theoretical framework discussed above, Hypothesis 3 is proposed.

H3: *Digital technology penetration promotes sustainable consumption growth by increasing household income.*

2.2.2. The Financial Inclusion Effects of Digital Technology Penetration

According to the principles of traditional consumption theory, the process of intertemporal consumption smoothing is of paramount importance. In practice, however, consumption is not fully smoothed because households face liquidity (cash) constraints [33], preference constraints [34], credit rationing [35], and broader financial frictions [36]. Among these, financial frictions have been identified as a significant impediment to consumption, and financial markets have been shown to facilitate intertemporal smoothing [37]. In the digital economy, a substantial body of literature characterizes digital finance as inclusive, with augmented consumption gains observed among low-income households and regions with inferior levels of development [38,39]. These effects, however, diminish as income and development escalate [40]. Some scholars posit that the positive impact of digital finance on household consumption is stronger in more developed areas. Specifically, its effect in central/eastern China and top-tier cities significantly outweighs that in western regions and less developed, third-tier cities and below [41]. The dissemination of digital technology has led to an increased utilization of BNPL-style and small-credit products, such as Huabei, Jiebei, Meituan Monthly Pay, and JD Baitiao, in the sinking market. These products have effectively extended quasi-credit lines to households of third-tier cities and rural areas, thereby facilitating economic opportunities and enhancing financial inclusion. The reduced barriers to entry for these products have the effect of relaxing liquidity constraints and supporting consumption. In accordance with the principles of supply and demand, survey results indicate that consumers residing in third-tier cities and the urban Generation Z demographic are among the most optimistic (>80%) [42]. In light of these observations, Hypothesis 4 is proposed.

H4: *Digital technology penetration stimulates sustainable consumption by enhancing financial development and inclusion—specifically, by easing financial constraints and expanding access to consumer credit and payments.*

3. Research Design

3.1. Data Sources, Sample Construction, and Preprocessing

3.1.1. Sample Selection and Processing

The sinking market refers to China’s third-tier and lower cities, counties, towns, and rural areas, encompassing approximately 300 prefecture-level cities, 2800 counties, 40,000 townships, and 660,000 villages. These areas account for about 70% of the total population and 48% of total consumption (with first-tier cities contributing 12%, new

first-tier cities 22%, and second-tier cities 18%) [43]. This study uses balanced panel data from 231 prefecture level cities in China from 2011 to 2023. The specific selection criteria are as follows: Firstly, considering the information on the first financial and economic city commercial charm ranking list from 2011 to 2023, it was found that second-tier and above cities are relatively fixed. Four first-tier cities (Shanghai, Beijing, Shenzhen, Guangzhou), 15 new first-tier cities (Chengdu, Hangzhou, Chongqing, Xi'an, Suzhou, Wuhan, Nanjing, Tianjin, Zhengzhou, Changsha, Dongguan, Foshan, Ningbo, Qingdao, and Shenyang), and 30 s-tier cities (Hefei, Kunming, Wuxi, Xiamen, Fuzhou, Wenzhou, Dalian, Harbin, Changchun, Quanzhou, Shijiazhuang, Baoding, Nanning, Jinhua, Guiyang, Nanchang, Changzhou, Yangzhou, Jiaxing, Zhuhai, Nantong, Huizhou, Taiyuan, Zhongshan, Xuzhou, Shaoxing, Taizhou, Jinan, Yantai, and Lanzhou) were deleted. The city that has abolished its prefecture-level city system (Laiwu City) is the initial sample. Secondly, considering the weak availability of county-level data and the deep exploration of rural areas in existing research, this study focuses on exploring the sinking market at the prefecture level city level, and these areas occupy an important position in the sinking market. At the same time, considering the continuity and comparability of data in the time dimension, samples with a high number of missing values (missing 30% or more in annual data) were deleted, including Suihua City, Yiyang City, Zhaotong City, Lincang City, Tongchuan City, Yan'an City, Haidong City, Sanya City, Sansha City, Danzhou City, and minority autonomous prefectures in China. Ultimately, 231 prefecture-level city samples with complete data (excluding Hong Kong, Macao, and Taiwan) were retained for empirical analysis. Moreover, these cities are well represented in terms of geographical distribution and economic development level: 231 prefecture-level cities cover all provinces in the Chinese Mainland except Xizang, covering not only the eastern, central, and western regions, but also cities with different economic development levels. Therefore, although the sample size is not all, it still ensures that the research conclusions have a certain degree of validity. Finally, the reason for choosing 2011 as the starting point of the study is that this year marks that China's mobile Internet has entered the stage of large-scale popularization, and digital technology has begun to systematically reshape household consumption behavior. At the same time, by examining authoritative statistical data, relevant statistical data at the urban level have been improving and stabilizing since 2011, providing a reliable data foundation for empirical analysis.

3.1.2. Variable Definitions

- (1) Dependent variable: sustainable household consumption (Cons). This study draws on Zhang et al. [44], who examined the macro-level impact of inclusive finance on household welfare. Total expenditure was adopted as an effective indicator to assess consumption levels and economic resilience, providing a foundation for understanding sustainable consumption patterns. The per capita consumption expenditure of households in the sinking market was used as a proxy indicator for sustainable household consumption. Specifically, Up , Uc , Rp , Rc , and Tp are used to denote urban population, urban per capita consumption, rural population, rural per capita consumption, and total population, respectively, with the results transformed into logarithmic form.

$$Cons = (Up \times Uc + Rp \times Rc) / Tp \quad (1)$$

- (2) Key independent variable: digital technology penetration (score). Digital technologies exhibit two core attributes—data factorization and digital enablement [45]. Although invention patent applications are widely employed as supply-side proxies of digital development [46], and some studies synthesize digital industry and application di-

mensions [47], the analysis centers on application-side penetration. Referring to the measurement of the impact of digital finance on consumption by Zhang et al. [21] and Guo et al. [48] pointing out that the digital inclusive finance index is mainly compiled based on consumer data, a composite penetration index is constructed from three subdimensions of the Digital Inclusive Finance Index—account coverage, payment activity, and digital support services—augmented with internet penetration. Indicators are directionally aligned and standardized; Compared with the Analytic Hierarchy Process and Principal Component Analysis, the entropy method is more objective in assigning values, weights are assigned via the entropy method. The specific calculation process is as follows:

Step 1: Standardize the variables:

$$z_{ij} = \frac{x_{ij} - \min(x_j)}{\max(x_j) - \min(x_j)} \quad (2)$$

The selected indicators in this article are all positive indicators, so there is no need for normalization processing, and standardization processing is directly carried out. Among them, z_{ij} represents the normalized value of the i -th sample on the j -th indicator, x_{ij} is the j -th indicator value of the i -th sample, and $\min(x_j)$, $\max(x_j)$ are the minimum and maximum values of the j -th indicator, respectively.

Step 2: Calculate the proportion of indicators. Calculate the relative proportion of each indicator in each sample:

$$p_{ij} = \frac{z_{ij}}{\sum_{i=1}^{231} z_{ij}} \quad (3)$$

Among them, p_{ij} represents the proportion of the i -th sample under the j -th indicator.

Step 3: calculate information entropy. Calculate the information entropy of each indicator based on its proportion:

$$e_j = -\frac{1}{\ln(231)} \sum_{i=1}^{231} p_{ij} \ln(p_{ij}) \quad (4)$$

The entropy value e_j reflects the uncertainty of the indicator. The smaller the entropy value, the greater the dispersion of the indicator, and the richer the information content.

Calculate the redundancy for each indicator:

$$d_j = 1 - e_j \quad (5)$$

where d_j is referred to as the information utility value of the j -th indicator.

Step 4: Calculate the weights of each indicator:

$$w_j = \frac{d_j}{\sum_{j=1}^4 d_j} \quad (6)$$

where w_j is the weight of the j -th indicator.

Step 5: Calculate the comprehensive score:

$$score_i = \sum_{j=1}^4 w_j p_{ij} \quad (7)$$

where $score_i$ is represents the comprehensive score of the i -th evaluation object.

Table 1 shows the calculation results of the entropy method. The entropy method calculates weights based on the degree of variation of indicators: the greater the degree

of variation, the smaller the entropy value, and the greater the weight, indicating that the indicator has a higher importance in comprehensive evaluation. All indicator attributes are “+”, indicating that these indicators are positive, meaning that the larger the value, the higher the penetration rate of digital technology. Specifically, the Internet penetration rate has the highest weight of 0.4248, accounting for 42.48% of the overall weight, which means that when evaluating the penetration rate of digital technology, the Internet penetration rate is the most important indicator, reflecting the coverage of infrastructure, and is the cornerstone of digital technology applications. The weight of payment business is 0.2126, accounting for 21.26% of the overall weight, second only to the Internet penetration rate, reflecting the depth of use of digital technology. The weight of account coverage is 0.2008, accounting for 20.08% of the overall weight, which is the basis for user participation in digital finance and reflects the breadth of digital technology usage. The lowest weight of digitalization level is 0.1618, accounting for 16.18% of the overall weight, but it involves multiple sub-indicators, indicating that although these indicators are important, their degree of variation is relatively small and their contribution to the overall evaluation is low. For robustness, the score is replaced with two alternatives: (i) a PCA-based penetration index and (ii) the Digital Inclusive Finance Index.

Table 1. Calculation of Digital Technology Penetration Rate.

Key Metric	Secondary Indicator	Indicator Description	Indicator Weight	Indicator Attribute
digital technology penetration	Account coverage rate	Number of Alipay accounts per 10,000 people	0.2008	+
		Proportion of Alipay card binding users		
		Average number of bank cards bound to each Alipay account		
		Per capita number of payments		
	payment business	Per capita payment amount	0.2126	+
		High frequency (active 50 times or more per year) ratio of active users to active 1 time or more per year		
		Proportion of mobile payment transactions		
		Proportion of mobile payment amount		
	Digitization level	Average loan interest rate for small and micro operators	0.1618	+
		Personal average loan interest rate		
		Proportion of Huabei payment transactions		
		Proportion of Sesame Credit Free Deposit Transactions (More than all cases requiring a deposit)		
	Internet penetration	Proportion of Sesame Credit Free Deposit Amount (More than all situations requiring a deposit)	0.4248	+
		Proportion of user QR code payments made		
		Proportion of user QR code payment amount		
		The ratio of Internet broadband access users to registered residence population		

Note: The Internet penetration rate comes from the National Bureau of Statistics of China [49], and the other data are selected from the digital inclusive financial indicator system of Peking University [48].

- (3) Instrumental Variable: Great Circle Distance to Hangzhou (dis_s). Referring to Fan et al. [50] selection of instrumental variables, this article selects the spherical distance

from prefecture level cities to Hangzhou as the instrumental variable, which is calculated using a geographic information system (GIS). The robustness test uses the 2000 mobile phone penetration rate as an instrumental variable, where the mobile phone penetration rate (ppl) is calculated as the number of mobile phone users at the end of the year (pp) divided by the total population (tp).

$$ppl = \frac{pp}{tp} \quad (8)$$

- (4) Mediators: Household Income (Inc) and Financial Development (Fin). Both theoretical and empirical evidence confirm that household income is the most crucial determinant of consumption. Digital technology penetration promotes consumption by raising household income. Urban and rural per capita income, denoted as Ui and Ri , are employed respectively, with household income calculated as:

$$Inc = (Up \times Ui + Rp \times Ri) / tp \quad (9)$$

And transformed by the natural logarithm. Digital technology penetration may also stimulate consumption through financial development. Here, Fd , Fl , and GDP denote the deposit balance of financial institutions, the loan balance of financial institutions, and regional GDP , respectively, with financial development measured as:

$$Fin = (Fd + Fl) / GDP \quad (10)$$

- (5) Threshold variable: human capital (Hca). The extent of digital technology penetration in the sinking market is correlated with the knowledge base of its households. Ep represents the number of students enrolled in regular higher education institutions. The calculation formula is as follows:

$$Hca = Ep / Tp \quad (11)$$

- (6) Other variables. Drawing on existing studies of the digital economy, digitalization, and household consumption, economic development level ($lngdp$), urbanization (Urb), government intervention (Gov), and openness ($open$) are included as additional explanatory variables. Lf and $Te-x$ denote local government general budget expenditure and total imports and exports, respectively. The calculation formula is as follows:

$$lngdp = \ln(GDP) \quad (12)$$

$$Urba = Up / Tp \quad (13)$$

$$Gov = Lf / GDP \quad (14)$$

$$open = Te-x / GDP \quad (15)$$

Descriptive statistics are reported in Table 2.

Table 2. Descriptive statistics.

Variable	Observations	Mean	Sd	Min	Max
Cons	3003	9.473	0.345	8.296	12.824
score	3003	0.335	0.137	0.031	0.812
index	3003	1.957	0.769	0.170	3.457
lngdp	3003	10.613	0.569	8.730	12.764
Hca	3003	0.0051	0.014	0.0001	0.0101
Urb	3003	0.538	0.128	0.182	0.988
Gov	3003	0.219	0.104	0.044	0.916
open	3003	0.002	0.002	0	0.029
Inc	3003	9.860	0.341	8.446	10.953
Fin	3003	2.386735	1.064346	0.5878793	21.30146
dis_s	3003	1072.568	533.2651	101.3577	3185.424
ppl	3003	0.070	0.072	0.009	0.742

3.1.3. Data Processing

In light of the National Bureau of Statistics' (NBS) revision of the statistical system of economic indicators in 2013, this study utilizes the consumption indicators outlined by Zhu et al. [51] to assess the consumption levels within the sinking market. Specifically, the analysis employs urban and rural per capita consumption as key metrics. Consequently, urban per capita disposable income and rural per capita net income are adopted as metrics to gauge the income of households in the sinking market. It is imperative to note that all monetary indicators undergo deflation using the 2011 Consumer Price Index (CPI) as the base period. In consideration of China's ongoing household registration system reform, the urbanization rate of the resident population is employed as the metric for urbanization. The primary data source is the municipal database of the EPS China Regional Research Data Support Platform. In instances where data is incomplete, researchers may consult the relevant prefecture-level city yearbooks or the Statistical Bulletins of National Economic and Social Development. In instances where indicators exhibit missing values, accounting for less than one-third of the observation period, linear interpolation is employed. Conversely, if the proportion of missing values exceeds this threshold, the corresponding prefecture-level city sample is excluded. The rationale behind the selection of NBS data is articulated as follows. First, NBS statistics are more comprehensive than household survey data. They reduce sampling errors, recall bias, underreporting, misreporting, and underestimation to some extent. Secondly, the studies conducted by Sala-i-Martin [52] and Maxim et al. [53] demonstrate that, in the context of examining equilibrium issues in rapidly developing economies, national accounts data are more reliable than household survey data. All data processing and econometric analyses were conducted using Stata 18.

3.2. Econometric Model Selection

3.2.1. The Relationship Between Digital Technology Penetration and Sustainable Household Consumption in the Sinking Market

The degree of digital technology penetration positively correlates with sustainable household consumption in the sinking market, and the promotional effect is significant (1.9404). As illustrated in Figure 3a, digital technology penetration is represented by the digital inclusive finance index. As illustrated in Figure 3b, digital inclusive finance is positively correlated with consumption in the sinking market, which is consistent with expectations. Among them, colored dots represent the degree of dispersion. However, according to previous theoretical analyses, the impact of digital technology penetration on sustainable consumption in the sinking market is not entirely linear. The popularization and application of digital technology are subject to the impact of the level of human capital

to a certain extent. To reduce estimation error, a nonlinear threshold model was used for further estimation.

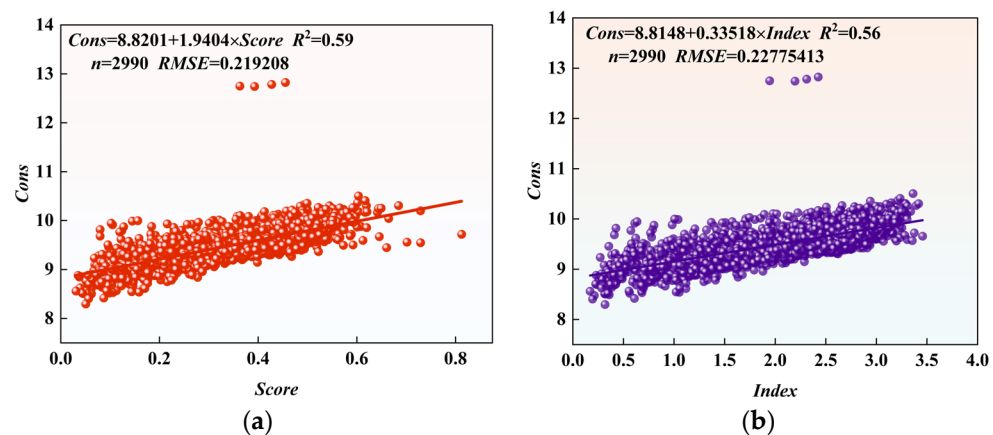


Figure 3. Relationships between digital technology and sustainable household consumption in the sinking market: (a) Digital technology penetration and sustainable household consumption; (b) Digital inclusive finance index and sustainable household consumption. The red and purple dots represent the degree of dispersion.

3.2.2. Econometric Model Specification: The Effect of Digital Technology Penetration on Sustainable Household Consumption in the Sinking Market

(1) Baseline model specification

In light of the foregoing discussion, the baseline empirical specification is hereby established as follows:

$$Cons_{it} = \partial_1 + \beta_1 \times score_{it} + \theta_{it}X_{it} + u_i + \gamma_t + \varepsilon_{it} \quad (16)$$

where i represents the prefecture-level city, t represents the year, $Cons$ represents the consumption of sinking market households, $score$ represents the penetration rate of digital technology in the sinking market, X represents a series of control variables, u_i the fixed effect of prefecture-level city, γ_t is the annual fixed effect, ε_{it} is a random error item. In Equation (16), the coefficient β_1 represents the impact of digital technology penetration on the consumption growth of the sinking market, and θ is the control variable coefficient.

The baseline specification may suffer from potential endogeneity concerns. On the one hand, it is difficult to fully exclude the possibility of reverse causality between digital technology penetration and sustainable household consumption in the sinking market. On the other hand, there may also be missing features that change over time. To test and address the endogeneity issue in Equation (16), the following instrumental variable model is specified for analysis:

$$score_{it} = \partial_{21} + \partial_{iv}IV_{it} + \sum \theta_{it}X_{it} + u_i + \gamma_t + \varepsilon_{it} \quad (17)$$

$$Cons_{it} = \partial_{22} + \partial_{score}score_{it} + \sum \theta_{it}X_{it} + u_i + \gamma_t + \varepsilon_{it} \quad (18)$$

where ∂_{21} , ∂_{22} are intercept terms, IV_{it} is the instrumental variable, ∂_{iv} is the coefficient of the instrumental variable, and the remaining variables are the same as in Equation (16).

3.2.3. Threshold Model Specification

The utilization of digital technology is contingent upon a certain threshold related to human capital, whereby consumers must possess a minimum level of education or literacy. For instance, illiterate individuals are more likely to be excluded from effective

participation in digital technologies. Therefore, the present study investigates the impact of digital technology penetration on sustainable household consumption in the sinking market further by treating human capital as a threshold variable. The threshold model is introduced to extend the baseline model, building on the framework of Hansen [54]. The model specification is as follows:

$$Cons_{it} = \partial_{20} + \beta_{20}score_{it} * I(\bullet)(Hca_{it} < \rho) + \beta_{21}score_{it} * I(\bullet)(Hca_{it} > \rho) + \theta_{it}X_{it} + u_i + \gamma_t + \varepsilon_{it} \quad (19)$$

In this specification, human capital Hca_{it} serves as the threshold variable, while ρ denotes the threshold parameter, and $I(\bullet)$ represents the indicator function. The function takes the value of 1 when the condition in parentheses holds, and 0 otherwise. The interpretation of the remaining symbols is consistent with that in the benchmark Equation (16).

3.2.4. Specification of the Sobel Mediation Effect Model

The preceding theoretical analysis has elucidated the mechanism through which digital technology penetration shapes sustainable household consumption in sinking markets, primarily via two transmission channels: enhancing household income and fostering financial development. Given the relatively large sample size, the Sobel test is employed to examine the significance of the mediation effects. The present study proposes a three-stage mediation model, as outlined by Wen and Ye [55]. Furthermore, in order to mitigate the potential bias and overlapping influences inherent in serial mediation analysis, a parallel mediation framework is adopted, drawing on the methodological insights of Ji et al. [56]. The corresponding specifications are presented in Equations (20)–(22).

$$Cons_{it} = c \times score_{it} + \sum \theta_{it}X_{it} + \delta_i + \mu_t + \varepsilon_{it} \quad (20)$$

$$M_{it} = a \times score_{it} + \sum \theta_{it}X_{it} + \delta_i + \mu_t + \varepsilon_{it} \quad (21)$$

$$Cons_{it} = c \times score_{it} + bM_{it} + \sum \theta_{it}X_{it} + \delta_i + \mu_t + \varepsilon_{it} \quad (22)$$

In the present specification, M_{it} denotes the mediating variable; household income and the degree of financial development are employed as mediators. The parameter c represents the total effect of digital technology penetration on sustainable consumption in the sinking market. a is the influence coefficient of digital technology penetration on intermediary variables. b is the influence coefficient of intermediary variables on sinking market consumption after adding digital technology penetration variables. The remaining variables are consistent with Equation (16).

4. Empirical Analysis of Digital Technology Penetration and Its Effects on Sustainable Household Consumption in the Sinking Market

4.1. Effects of Digital-Technology Penetration on Sustainable Household Consumption in the Sinking Market

The variance inflation factor (VIF) test reports a value of 2.02, well below the conventional threshold of 5, suggesting the absence of severe multicollinearity among explanatory variables. The Hausman test rejects the null hypothesis at the 1% significance level, thereby supporting the adoption of a fixed-effects specification. To mitigate potential omitted-variable bias and enhance the robustness of the estimates, a stepwise benchmark regression is conducted by progressively incorporating control variables, as summarized in Table 3. Specifically, column ① reports the univariate regression of digital technology penetration on sustainable household consumption in the sinking market, while columns ② through ⑥ sequentially introduce controls for economic development, human capital, urbanization, government intervention, and trade openness. This process yields the final benchmark

specification. As additional controls are incorporated, the R^2 values progressively increase, reinforcing the robustness of the results within the empirical context of sinking market households over the study period.

Table 3. Empirical results of digital technology penetration affecting sinking market consumption.

	①	②	③	④	⑤	⑥	⑦
score	1.767 *** (48.54)	1.389 *** (23.28)	1.418 *** (22.67)	1.149 *** (17.12)	1.015 *** (12.59)	1.039 *** (12.74)	
lngdp		0.224 *** (8.13)	0.231 *** (8.18)	0.192 *** (7.98)	0.251 *** (8.09)	0.242 *** (7.77)	0.229 *** (10.90)
Hca			−2.454 * (−2.23)	−2.606 * (−2.52)	−2.454 * (−2.39)	−2.440 * (−2.39)	
Urb				0.953 *** (7.25)	0.949 *** (7.15)	0.954 *** (7.21)	0.971 *** (12.57)
Gov					0.383 ** (3.32)	0.370 ** (3.23)	0.316 *** (3.82)
open						4.584 * (2.22)	4.520 * (2.25)
$score \times I (Hca < 0.0068)$							1.158 *** (20.94)
$score \times I (Hca > 0.0068)$							0.998 *** (20.16)
Region FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
_cons	8.880 *** (727.68)	6.626 *** (23.97)	6.578 *** (23.34)	6.576 *** (26.91)	5.908 *** (17.75)	5.981 *** (17.94)	6.088 *** (27.98)
N	3003	3003	3003	3003	3003	3003	3003
r2_a	0.744	0.760	0.761	0.773	0.775	0.776	0.759

Note: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Column ⑥ of Table 3 reports the fixed-effects regression results for the effect of digital technology penetration on sustainable household consumption in the sinking market. A one-percentage-point increase in digital technology penetration is associated with a 1.039 increase in consumption, significant at the 1% level, thereby lending strong support to Hypothesis 1. Regarding the control variables, economic development, urbanization, government intervention, and trade openness all show positive associations with sustainable household consumption, consistent with theoretical expectations. Notably, human capital exerts a negative effect on consumption growth, significant at the 10% level, with an estimated coefficient of −2.44. This unexpected result merits further exploration. In theory, it is possible that when human capital is low, its negative effects mainly stem from the strengthening of the “precautionary savings” motivation. According to the precautionary savings theory, when households have a high awareness of future income uncertainty, they tend to increase savings and reduce current consumption to resist risks. In the early stages of human capital accumulation (such as low education level and low skill level), family members usually engage in jobs with unstable income and poor risk resistance. At this point, the increased human capital (such as participating in short-term training) does

not immediately translate into substantial income growth. Instead, it may exacerbate the financial pressure and uncertainty of families towards the future due to the direct and opportunity costs of paying for education/training, leading them to be more inclined to restrain consumption and increase savings. When human capital crosses a certain threshold, its classic mechanism of promoting consumption begins to dominate [57]. A plausible interpretation is the presence of a threshold effect in the impact of human capital accumulation on consumption. The findings of Nan et al. [58] corroborate this view, demonstrating that the synergistic enhancement of consumption and human capital materializes only when human capital accumulation surpasses a critical threshold. In light of this reasoning, human capital is subsequently introduced as a threshold variable in the empirical analysis.

To rigorously assess the potential nonlinear nexus between digital technology penetration and sustainable household consumption, a threshold effect test is implemented with human capital specified as the threshold variable. The Bootstrap procedure with 500 replications of the simulated likelihood-ratio statistic is employed, and the resulting threshold estimates are reported in Table 4 and depicted in Figure 4. The analysis reveals the presence of a single threshold effect, with the estimated threshold value of human capital equal to 0.0068. The corresponding threshold regression results are presented in Column ⑦ of Table 3. When human capital falls below the threshold (0.0068), a one percentage-point increase in digital technology penetration is associated with a 1.158-unit rise in household consumption, significant at the 1% level. Once human capital surpasses the threshold, the marginal effect of digital technology penetration diminishes to 0.998 units, though it remains statistically significant at the 1% level. These findings suggest that the growth-enhancing effect of digital technology penetration on consumption in the sinking market is contingent upon the stock of consumer knowledge, implying the existence of a human capital threshold. From a practical perspective, this threshold value is much higher than the sample mean (0.0051), which means that only some regions with leading human capital levels can cross this development threshold, and most of them are concentrated in the eastern region. Only by continuously improving human capital accumulation and striving to break through the threshold value of 0.0068 can sustainable consumption in the sinking market be guaranteed in the digital economy era. Collectively, the empirical evidence lends strong support to Hypothesis 2.

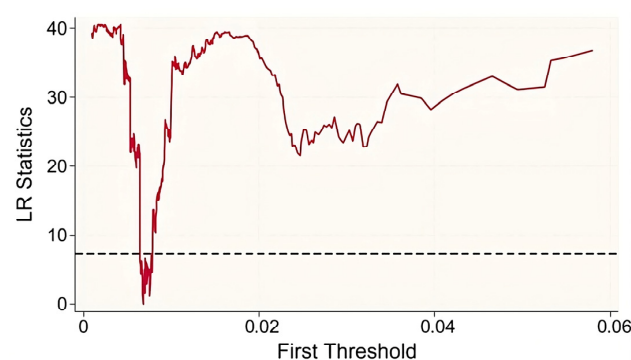


Figure 4. Threshold test of digital technology penetration affecting sustainable consumption in the sinking market. The red curve depicts the Likelihood Ratio (LR) statistic, which evaluates the significance of the threshold effect across a range of candidate values. A lower LR statistic indicates a better model fit at the corresponding candidate threshold. The dashed line represents the critical value at a specified significance level, providing a benchmark for testing the statistical significance of the estimated threshold. A threshold effect is confirmed if the minimum point of the LR curve falls below this dashed line.

Table 4. Threshold effect test of digital technology penetration as a threshold.

Explained Variable	Threshold Variable	Threshold Number	F-Statistic	10%	5%	1%	Threshold	95% Confidence Interval
Cons	Hca	Single	40.57	30.5845	37.7327	62.2610	0.0068	[0.0066, 0.0068]

4.2. Empirical Test for Endogeneity

To mitigate potential endogeneity between digital technology penetration and household consumption in the sinking market, an instrumental variable (IV) approach is adopted. The Hausman test rejects the null hypothesis of exogeneity of all explanatory variables at the 1% significance level, thereby motivating IV estimation. The great-circle distance from each prefecture-level city to Hangzhou is employed as the instrument, with estimation carried out using two-stage least squares (2SLS). The instrument satisfies both relevance and exclusion conditions: it is strongly correlated with digital technology penetration yet plausibly unrelated to local household consumption. The specific analysis is as follows: First of all, digital technology represented by Alipay originated in Hangzhou. As China's "digital innovation center" and e-commerce capital, Hangzhou is the source of digital technology, business models and consumer culture. Geographic distance directly affects the cost and speed of technology spillovers, knowledge diffusion and business model imitation from Hangzhou. That is, the closer the region is to Hangzhou, the more access to the latest digital applications and consumption concepts at a lower cost, and vice versa.

Weak-instrument diagnostics, reported in Table 5, confirm instrument strength. The first-stage F statistic equals 273.473, far above the Stock–Yogo critical value of 10, decisively rejecting the weak-instrument hypothesis. Likewise, the minimum eigenvalue statistic (317.93) exceeds the strictest Stock–Yogo threshold (16.38) by an order of magnitude, providing strong assurance that the instrument is not weak. These findings establish that the distance to Hangzhou has a robust and statistically significant association with digital technology penetration.

Table 5. Weak instrumental variable test.

Variable	R ²	Adjusted R ²	Partial R ²	Robust	Prob > F
score (IV dis_s)	0.4690	0.4680	0.0959	F(1,2996) 273.473	0.0000

Column ① of Table 6 shows the OLS regression results, which are consistent with the previous text. Column ② of Table 6 then presents the first-stage regression results. Consistent with theoretical expectations, the great-circle distance from prefecture-level cities to Hangzhou is negatively associated with digital technology penetration, with the coefficient significant at the 1% level. The negative relationship is consistent with the historical fact that major digital technologies, most notably Alipay, have their origins in Hangzhou. Furthermore, it is expected that penetration will decline with increasing distance. Regarding exogeneity, the distance from Hangzhou is unlikely to exert a direct effect on local household consumption, rendering the exclusion restriction plausible [59]. Taking infrastructure and income levels as an example, although China's infrastructure construction is related to the level of economic development, the construction of China's digital infrastructure is a systematic project at the national level (such as broadband networks, 4G/5G base stations), and its planning and coverage (such as the "Broadband China" strategy) are not centered around Hangzhou and radiate outward. On the contrary, cities like Guiyang (in western China) have become national-level data hubs. Therefore, there is no necessary systematic

connection between the distance from a region to Hangzhou and its level of digital infrastructure. In terms of income level, the regional income level in China is determined by various factors such as historical foundation, policy positioning, and industrial structure. Taking the spherical distance from Hangzhou as an example, the spherical distance from Anhui to Hangzhou is smaller than that from Shanghai to Hangzhou. However, the income level in Anhui is significantly lower than that in Shanghai, indicating that the “spherical distance to Hangzhou” is not the core geographical variable that determines the regional income level. Robustness checks employing limited-information maximum likelihood (LIML), generalized method of moments (GMM), and iterated GMM (IGMM) yield estimates identical to those obtained via 2SLS. Among them, column ③ of Table 5 shows the 2SLS regression results, while columns ④, ⑤, and ⑥ of Table 5 show the LIML, GMM, and IGMM regression results, respectively. The numerical equivalence across 2SLS, GMM, and IGMM implies exact identification, thereby reinforcing the validity of the specification. Taken together, the evidence demonstrates that, once endogeneity is properly addressed, digital technology penetration continues to exert a significant and robust positive effect on household consumption in the sinking market.

Table 6. Regression results of the endogenous test.

Variable	①	②	③	④	⑤	⑥
score	1.264 *** (48.53)		1.263 *** (15.35)	1.263 *** (15.35)	1.263 *** (15.35)	1.263 *** (15.35)
lngdp	0.184 *** (20.34)	0.154 *** (22.40)	0.184 *** (13.67)	0.184 *** (13.67)	0.184 *** (13.67)	0.184 *** (13.67)
Hca	−1.010 *** (−3.39)	0.505 *** (2.74)	−1.010 *** (−3.36)	−1.010 *** (−3.36)	−1.010 *** (−3.36)	−1.010 *** (−3.36)
Urb	0.599 *** (18.18)	0.186 *** (7.57)	0.599 *** (16.84)	0.599 *** (16.84)	0.599 *** (16.84)	0.599 *** (16.84)
Gov	−0.018 (−0.61)	0.567 *** (19.41)	−0.017 (−0.37)	−0.017 (−0.37)	−0.017 (−0.37)	−0.017 (−0.37)
open	3.486 *** (3.42)	−9.590 *** (−9.47)	3.480 ** (3.24)	3.480 ** (3.24)	3.480 ** (3.24)	3.480 ** (3.24)
dis_s		−0.0001 *** (−16.54)				
F-statistic		453.46				
Wald χ^2 statistic		Prob > F = 0	9117.55 Prob > chi2 = 0	9117.55 Prob > chi2 = 0	9117.55 Prob > chi2 = 0	9117.55 Prob > chi2 = 0
Regional FE	Yes		Yes	Yes	Yes	Yes
Time FE	Yes		Yes	Yes	Yes	Yes
_cons	6.788 *** (79.11)	−1.432 *** (−21.29)	6.786 *** (52.52)	6.786 *** (52.52)	6.786 *** (52.52)	6.786 *** (52.52)
N	3003	3003	3003	3003	3003	3003
r2_a	0.748	0.4680	0.748	0.748	0.748	0.748

Note: ** $p < 0.01$, *** $p < 0.001$.

4.3. Robustness Checks

In order to assess the robustness of the estimation results, a number of approaches are adopted. Specifically, the key independent variable is replaced with alternative measures, its calculation method is modified, higher-order nonlinear terms are introduced, replace instrumental variables and the influence of major public health events is excluded. These procedures serve to verify the stability and reliability of the empirical findings.

4.3.1. Replace the Key Independent Variable

In order to assess the robustness of the estimation results, the key independent variable, digital technology penetration, is substituted for the most widely used digital inclusive financial index. In order to ascertain the stability of the panel, the digital inclusive financial index is divided by 100 in the empirical analysis. The results are displayed in Table 7, column ①. For every 1 percentage point increase in the Digital Inclusive Financial Index, market consumption is predicted to increase by 0.206 units, a result that is significant at the 1% level. The regression coefficient of the overall result is consistent with the benchmark model, and the result is robust. The first hypothesis is thus confirmed.

Table 7. Results of Robustness Tests.

Variable	①	②	③	④	⑤
index	0.206 *** (15.53)				
lngdp	0.194 *** (6.34)	0.250 *** (7.87)	0.232 *** (7.87)	0.200 *** (11.48)	0.221 *** (4.81)
Hca	−2.386 * (−2.33)	−2.538 * (−2.49)	−1.402 (−1.43)	−0.999 *** (−3.35)	−1.543 (−0.61)
Urb	0.834 *** (6.07)	0.966 *** (7.30)	0.919 *** (6.86)	0.615 *** (15.70)	0.857 *** (4.15)
Gov	0.258 * (2.32)	0.409 *** (3.49)	0.259 * (2.46)	0.028 (0.46)	0.449 *** (3.52)
open	5.720 ** (2.87)	4.298 * (2.09)	3.880 * (1.99)	3.040 ** (2.58)	2.984 (1.35)
score			1.558 *** (10.96)	1.159 *** (9.51)	1.130 *** (11.23)
score2			−0.799 *** (−4.34)		
score1		0.088 *** (12.39)			
Regional FE	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes
_cons	6.531 *** (19.64)	6.240 *** (17.27)	6.055 *** (19.27)	6.635 *** (39.78)	6.213 *** (13.07)
N	3003	3003	3003	3003	2079
r2_a	0.782	0.775	0.778	0.747	0.716

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

4.3.2. Modification of the Measurement Approach for the Key Independent Variable

In the benchmark model, the penetration rate of digital technology is calculated using the entropy method. To mitigate potential estimation errors associated with this approach, the principal component analysis method is employed instead to measure the level of digital technology penetration (score1). The regression results, reported in Column ② of Table 7, show that a 1 percentage point increase in the penetration rate of digital technology leads to a 0.088 unit rise in consumption in the sinking market, significant at the 1% level. The direction of the estimated coefficient is consistent with that of the benchmark model, confirming the robustness of the results and supporting Hypothesis 1.

4.3.3. Introduction of Higher-Order Nonlinear Terms

To further validate the appropriateness of adopting a threshold model, higher-order nonlinear terms (score2) of the key independent variable are introduced into the benchmark specification. The regression results, presented in Column ③ of Table 6, indicate that the quadratic term of the key independent variable is negative, revealing a nonlinear relationship. This finding confirms the rationale for employing a nonlinear specification. The overall direction of the estimated coefficients is consistent with the threshold model results, thereby reinforcing robustness and supporting Hypothesis 2.

4.3.4. Replace Instrumental Variables

Referring to Nunn et al. [60], and considering the severe lack of data for prefecture-level cities in 1984 as well as the limited development of digital technology in China in 2000, the mobile phone penetration rate in 2000 was selected as an instrumental variable to replace the spherical distance from prefecture-level cities to Hangzhou. The F-statistic is 100.354 (far greater than the critical value of 10 in the Stock Yago weak instrumental variable test), strongly rejecting the hypothesis of weak instrumental variables. The regression results are shown in column ④ of Table 7, and the overall regression results are consistent with the main effect, indicating that the instrumental variable selection is reasonable and the regression results are robust.

4.3.5. Excluding the Influence of Major Public Health Events

The COVID-19 pandemic from 2020 to 2023 had a profound impact on household consumption in China. Following the robustness testing approach of Yin and Liu [61], the data for 2020–2023, which were affected by major public health shocks, are excluded, and regressions are re-estimated using data from 2011–2019. As shown in Column ⑤ of Table 7, the direction of the estimated coefficients remains consistent with the benchmark model, confirming the robustness of the results.

4.4. Heterogeneity Analysis

China's vast territory is characterized by a regional digital divide in the development of its digital economy [62], which influences the extent of digital technology penetration across regions and consequently leads to varying effects on sustainable household consumption. Following the conventional regional division, this study examines the regional heterogeneity of digital technology penetration in influencing household consumption across the eastern, central, and western regions. As illustrated in Figure 5, the relationship between digital technology penetration and household consumption in the sinking market is uniformly positive across all three regions. Among them, colored dots represent the degree of dispersion.

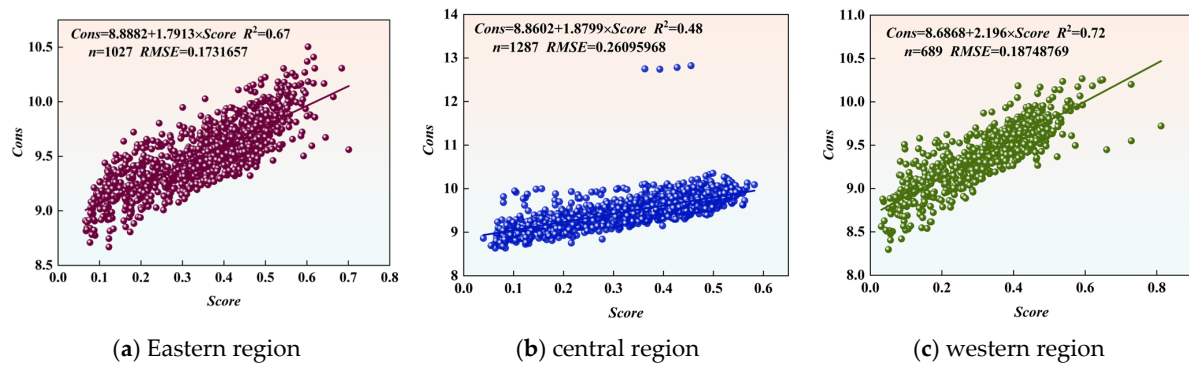


Figure 5. The relationship between digital technology penetration and sustainable household consumption in the sinking market across regions: (a) Eastern region; (b) Central region; (c) Western region. Colored dots represent the degree of dispersion.

Table 8 shows the threshold effect test for different regions. The results show that there is a first-order threshold at the 5% level in the western region, a first-order threshold at the 10% level in the central region, and no human capital threshold in the eastern region.

The regression results are presented in Table 9. Columns ① to ③ present the fixed-effect regression results for the eastern, central, and western regions, respectively, while columns ④ to ⑥ illustrate the threshold effect results for these same regions. The findings of this study demonstrate that the integration of digital technology exerts a considerable positive influence on sustainable consumption in the sinking market across all three primary geographical regions, with statistical significance attained at the 1% level. In the fixed-effect analysis, the impact of digital technology penetration on sustainable sinking market consumption is observed to follow this order: central region > western region > eastern region. Specifically, for every 1% increase in digital technology penetration, consumption in the sinking market increases by 1.016 units in the eastern region, 1.137 units in the central region, and 0.819 units in the western region. Concerning the threshold effects, the impact of digital technology penetration on sustainable sinking market consumption is as follows: western region > central region > eastern region.

Table 8. Threshold effect tests.

Explained Variable	Threshold Variable	Threshold Number	F-Statistic	10%	5%	1%	Threshold	95% Confidence Interval
Cons (East)	Hca	No	/	/	/	/	/	/
Cons (Central)	Hca	Single	34.43	33.5079	45.8860	69.8928	0.0066	[0.0065, 0.0066]
Cons (West)	Hca	Single	38.24	30.8671	35.4819	44.7877	0.0237	[0.0228, 0.0238]

Note: /, represents non-existent.

Table 9. Regional Heterogeneity Analysis of the Impact of Digital Technology Penetration on Sinking Market Consumption.

	①	②	③	④	⑤	⑥
score	1.016 *** (8.58)	1.137 *** (9.01)	0.819 *** (4.25)			
lngdp	0.112 *** (3.55)	0.279 *** (5.00)	0.405 *** (4.83)	0.108 *** (5.70)	0.257 *** (5.88)	0.381 *** (11.86)

Table 9. Cont.

	①	②	③	④	⑤	⑥
Hca	−0.320 (−0.41)	−3.564 (−1.47)	−4.803 ** (−2.43)			
Urb	1.102 *** (5.49)	0.533 ** (2.76)	1.005 *** (4.09)	1.108 *** (15.31)	0.517 ** (3.22)	1.014 *** (9.32)
Gov	0.519 ** (2.89)	0.569 ** (3.27)	0.376 * (1.91)	0.496 *** (5.25)	0.445 ** (2.62)	0.338 *** (3.38)
open	3.908 (1.71)	5.235 (1.75)	−8.448283 (−0.88)	3.976 * (2.42)	4.411 (1.17)	−9.594 (−1.45)
score × I (Hca < 0.0066)				/	1.409 *** (12.51)	
score × I (Hca > 0.0066)					1.107 *** (11.08)	
score × I (Hca < 0.0237)						0.833 *** (11.29)
score × I (Hca > 0.0237)						0.595 *** (7.98)
Regional FE	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
_cons	7.244 *** (18.93)	5.761 *** (9.67)	4.381 *** (5.37)	7.282 *** (35.46)	5.968 *** (13.32)	4.581 *** (14.32)
N	1027	1287	689	1027	1287	689
r2_a	0.913	0.659	0.9050	0.908	0.639	0.898

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. /, represents non-existent.

The possible explanations are as follows: In the eastern region, the overall level of economic development is high, the Internet economy is mature, and the consumer market is approaching saturation. Consequently, the incremental effect driven by digital technology penetration has weakened. Moreover, as the region transitions toward service-oriented and high-tech industries, the role of digital technology penetration in stimulating aggregate consumption has become less pronounced at the macro level. In the central region, the digital infrastructure and consumer market are relatively well-established, yet the traditional market is less developed than in the east. At this stage, the marginal effect of digital technology penetration is at its peak, as it can efficiently reach a large number of potential consumers underserved by traditional retail channels, thereby generating a strong market creation effect. Simultaneously, the region is undergoing a process of consumption upgrading, and digital platforms effectively meet households' demand for more diversified and higher-quality goods and services, creating a strong supply–demand resonance. In the western region, despite policy support through initiatives such as the Western Devel-

opment Strategy, certain areas still face “hard constraints,” including insufficient digital infrastructure coverage and high logistics costs. Furthermore, lower average income levels fundamentally constrain consumption potential. Although digital platforms expand consumer choice, the limited purchasing power of local households weakens the conversion effect of digital technology penetration.

Overall, existing studies have validated the rationality of this paper’s conclusions from multiple dimensions. Firstly, the penetration of digital technology has not only altered consumption behavior at the regional level but also at the firm level. By breaking down regional barriers, digital technology enhances the allocation of regional resources, leading to improved efficiency in resource distribution, which in turn optimizes regional production and consumption choices [63]. Secondly, the infiltration of digital technology injects vitality into enterprises through productivity gains and reduced information asymmetry, thus enabling continuous cycles of reproduction [64]. This ensures the supply of goods from the production side and expands the range of choices available for household consumption. Finally, from a global perspective, there are notable disparities in the penetration of digital technology. Moreover, the proliferation of digital technology exerts a positive influence on ecological conservation and resource utilization efficiency, demonstrating an inclusive effect [65]. In terms of human capital, it has become one of the critical factors for participating in economic activities in the digital era [66]. For China to secure a strategic initiative in digital transformation, it must prioritize and strengthen the cultivation of human capital.

5. Analysis of the Transmission Mechanism of Digital Technology Penetration on Sustainable Household Consumption in the Sinking Market

This study employs Baron and Kenny’s stepwise approach and the Sobel test to sequentially introduce the intermediary variables of household income and financial development level into the baseline model. The objective is to explore whether these factors play a mediating role in the impact of digital technology penetration on sustainable household consumption in the sinking market. Table 10 presents the regression results for the three-stage mediating effect, while Table 10 provides the decomposition of the mediating effect and the results of the Sobel test. In Table 10, Column ① represents the regression results of the baseline model, which is also the first step in testing the mediating effect. Columns ② and ③ present the findings on the mediating variable of household income, while columns ④ and ⑤ offer insights on the mediating variable of financial development level.

Table 10. Mediation effect regression results.

	Inc			Fin	
	①	②	③	④	⑤
score	1.264 *** (41.86)	1.384 *** (68.18)	0.319 *** (7.45)	2.548 *** (18.80)	1.235 *** (38.72)
lngdp	0.184 *** (16.74)	0.169 *** (22.96)	0.068 *** (6.43)	−0.734 *** (−14.91)	0.192 *** (16.91)
Hca	−1.010 *** (−3.99)	−0.519 ** (−3.05)	−0.656 ** (−2.91)	27.404 *** (24.11)	−1.325 *** (−4.79)
Urb	0.599 *** (15.56)	0.632 *** (24.45)	0.167 *** (4.46)	3.042 *** (17.63)	0.564 *** (0.040)

Table 10. Cont.

	Inc			Fin	
	①	②	③	④	⑤
Gov	−0.018 (−0.45)	−0.257 *** (−9.63)	0.158 *** (4.40)	3.303 *** (18.52)	−0.056 (−1.33)
open	3.486 ** (2.59)	6.385 *** (7.06)	−0.874 (−0.72)	−32.075 *** (−5.31)	3.854 ** (2.85)
Inc			0.683 *** (28.27)		
Fin					0.011 ** (2.82)
Regional FE	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes
_cons	6.789 *** (63.85)	7.308 *** (102.29)	1.798 *** (8.98)	6.662 *** (13.97)	6.711 *** (61.24)
N	3003	3003	3003	3003	3003
r2_a	0.748	0.884	0.801	0.467	0.748

Note: ** $p < 0.05$, *** $p < 0.01$.

Firstly, the transmission mechanism of “digital technology penetration → sustainable household income → household consumption” is examined. The first column of Table 10 demonstrates the collective impact of digital technology on sustainable household consumption within the sinking market. The findings of the study demonstrate that the adoption of digital technology has a substantial positive impact on sustainable consumption in the sinking market ($c = 1.264$, $p < 0.01$). The second column of Table 10 examines the impact of digital technology penetration on sustainable household income, demonstrating a substantial positive effect ($a = 1.384$, $p < 0.01$). The third column of the table incorporates both digital technology penetration and sustainable household income in the regression model. Following the adjustment for the impact of digital technology penetration, the findings indicate that household income continues to exert a considerable positive influence on sustainable consumption in the sinking market ($b = 0.683$, $p < 0.05$).

As illustrated in Table 11, the decomposition of the mediating effect is further delineated, in addition to the results of the Sobel test. The Sobel test yielded a highly significant result ($Z = 26.112 > 1.96$, $p = 0.000 < 0.01$), thereby confirming the existence of a significant mediating effect at the 1% level. The direct effect of digital technology penetration on sustainable household consumption is 0.319, and the indirect effect is 0.945, indicating that household income plays a partial mediating role. It is evident that as the pervasiveness of digital technology within the sinking market increases, there is a concomitant rise in both household income and consumption. This finding lends further support to Hypothesis 3. The ratio of the mediating effect to the total effect is 74.7%, indicating that 74.7% of the impact of digital technology penetration on sustainable household consumption is mediated by household income. The findings demonstrate that digital technology penetration augments household income through the creation of new employment and entrepreneurial opportunities, such as in e-commerce and the gig economy. This income increase is subsequently translated into purchasing power, thereby stimulating sustainable consumption. In this process, digital technology acts as an amplifier of household income.

Table 11. Decomposition of the Mediation Effect and Results of the Sobel Test.

Effect	Inc				Fin			
	Est	Std_err	z	$p > z $	Est	Std_err	z	$p > z $
Path a	1.384	0.020	68.181	0.000 ***	2.548	0.135	18.804	0.000 ***
Path b	0.683	0.024	28.267	0.000 ***	0.011	0.004	2.820	0.005 ***
Indirect effect ($a \times b$)	0.945	0.036	26.112	0.000 ***	0.029	0.010	2.789	0.005 ***
Direct effect c'	0.319	0.043	7.450	0.000 ***	1.235	0.032	38.723	0.000 ***
Total effect c	1.264	0.030	41.864	0.000 ***	1.264	0.030	41.864	0.000 ***
Proportion Mediated ($a \times b/c$)	74.7%				2.3%			
Sobel's Z statistic	26.11 ***				2.789 ***			

Note: *** $p < 0.01$.

Secondly, the transmission mechanism of “digital technology penetration → financial development → sustainable household consumption” is examined. The fourth column of Table 10 assesses the impact of digital technology penetration on financial development. The findings indicate that the adoption of digital technology has a substantial and positive effect on financial development ($c = 2.548$, $p < 0.01$). The fifth column incorporates both digital technology penetration and financial development into the regression equation. The findings indicate that, after controlling for the impact of digital technology penetration, financial development continues to exert a significant positive influence on household consumption in the sinking market ($b = 0.011$, $p < 0.05$). As illustrated in Table 11, the subsequent analysis provides a detailed report on the mediating effect decomposition and Sobel test results. The Sobel test was found to be significant ($Z = 2.789 > 1.96$, $p = 0.005$), thereby confirming the existence of a mediating effect that was statistically significant at the 1% level. The total effect of digital technology penetration on sustainable household consumption is 1.264, with a direct effect of 1.235 and an indirect effect of 0.029. This study reveals that the influence of digital technology penetration on sustainable household consumption in the sinking market is partially channeled through financial development. Thus, financial development functions as a transmission mechanism, translating technological advancements into both financial deepening and elevated sustainable consumption. The ratio of the mediating effect to the total effect is 2.3%, suggesting that 2.3% of the impact of digital technology penetration on sustainable household consumption is achieved through financial development. This phenomenon may be attributed to the strong correlation between financial development and economic development levels. The market in question is characterized by a decline in valuation, with the affected entities primarily comprising counties, towns, and rural areas that exhibit underdeveloped economic structures. This limitation impedes the enhancement of financial development, consequently impacting the mediation mechanism. Nevertheless, this mediating effect is significant, suggesting that the “digital technology penetration → financial development → sustainable household consumption” transmission mechanism holds substantial development potential and warrants focused attention. The above results suggest that by alleviating household liquidity constraints, digital technologies (e.g., mobile payments and online microcredit) act as a “lubricant” for consumption, effectively smoothing the path for household spending.

In summary, digital technology penetration does not operate independently; rather, it primarily transmits the digital dividend to the household consumption level through both income and financial channels. It should be noted that, for research convenience and due

to limited data availability below the prefecture level, the correlation between household income and financial development is not significant (0.2927). According to conventional standards of correlation strength, this reflects only a weak relationship (as a coefficient of 0.4 or higher is generally considered practically meaningful). To examine the mechanism through which digital technology penetration influences sustainable consumption in the sinking market, a parallel mediation model is employed. In practice, however, the “income effect” and the “financial inclusion effect” of digital technology penetration are interrelated rather than entirely distinct. While digital finance can directly raise household income, the inclusive financial environment it fosters may further amplify the marginal utility of that income. Consequently, a potential synergy and amplification effect exists between the two mechanisms, suggesting that future research should adopt more sophisticated models to capture this interaction more precisely.

6. Conclusions and Recommendations

The People’s Republic of China is currently experiencing a period of rapid digital development and transitioning from a “production-oriented society” to a “consumption-oriented society.” The sinking market has become a significant area of opportunity for consumers in the latter half of the digital economy, functioning as a stabilising factor to encourage consumption. It is imperative to comprehend the mechanisms through which digital technology facilitates sustainable consumption in the sinking market. This is essential for enhancing the construction of a unified national market and propelling Chinese-style modernization. The present paper is based on theoretical analysis, utilizing data from 231 prefecture-level cities from 2011 to 2023, and employing the entropy method to measure the penetration level of digital technology in the sinking market. The construction of fixed effects models, threshold models, and mediation models forms the basis of this study, which tests the impact of digital technology penetration on sustainable consumption of households in the sinking market. Based on the empirical findings, corresponding policy measures are proposed to further enhance the sustainable driving role of digital technology penetration in the sinking market.

6.1. Conclusions

- (1) Digital technology penetration can effectively enhance the sustainable consumption of households in the sinking market. This conclusion remains robust under various conditions, including the substitution of the key independent variable, modification of the method for calculating the key explanatory variable, the inclusion of higher-order terms for the key explanatory variable, replace instrumental variables and the exclusion of the impact of major public health events.
- (2) There exists a human capital threshold for the promotion of digital technology penetration on the income of households in the sinking market. An interesting phenomenon is observed in the baseline regression: human capital has an inhibitory effect on the consumption of sinking market households at the 10% significance level, which contradicts expectations. This suggests that the synergy between human capital and consumption in the sinking market results from human capital accumulation reaching a certain threshold. Only when human capital accumulation surpasses this threshold can positive changes in both variables be realized, highlighting the importance of human capital accumulation in the sinking market.
- (3) Household income and financial development play a partial mediating role in the impact of digital technology penetration on the sustainable consumption of sinking market households. Specifically, the mediating effect of “digital technology penetration → household income → sustainable household consumption” accounts for

a substantial proportion, aligning with the theory that income is both a core influencing and constraining factor for sustainable consumption. The mediating effect of “digital technology penetration → financial development → sustainable household consumption” constitutes a smaller proportion; however, some mediating effects are statistically significant, suggesting that this path has further development potential and warrants further attention.

- (4) Digital technology penetration is inclusive. Regional heterogeneity analysis reveals that under fixed effects, the impact of digital technology penetration on sustainable consumption in the sinking market follows this order: central region > western region > eastern region. Under the threshold effect, the promotion effect of digital technology penetration is as follows: western region > central region > eastern region. In both fixed effect and threshold effect models, the impact of digital technology penetration on sustainable consumption growth is more pronounced in the central and western regions, indicating that the positive effect of digital technology penetration on sinking market sustainable consumption exhibits an inclusive nature.

6.2. Recommendations

- (1) Comprehensively deepen the penetration and application of digital technology in the sinking market. Firstly, the direct and steady enhancement of sustainable consumption resulting from digital technology penetration is more significant in the central and western regions. Priority must be given to the acceleration of the development of new infrastructures, including 5G base stations, gigabit optical networks, the Internet of Things, and data centres, with a particular focus on central and western regions, counties, and rural areas. It is imperative to direct efforts towards resolving the “last mile” issue of network coverage, thereby ensuring both the accessibility and availability of high-quality network services. Secondly, it is imperative to proactively foster and nurture digital consumption scenarios within the sinking market. The primary objective of enhancing digital technology integration is to promote increased consumption. The exploration of a wide range of application scenarios is imperative to leverage the full potential of this integration. It is recommended that e-commerce platforms and local service providers develop applications that are better suited to the consumption habits of the sinking market (e.g., simplified apps, voice/video shopping). Support new models such as “live-streaming sales” and “community group purchasing” to promote both the upward flow of agricultural products and the downward flow of industrial goods. Organize regional digital consumption festivals and issue targeted digital consumption vouchers.
- (2) Continuously improving the accumulation of human capital. For regions with human capital levels below 0.0068, policies should focus on “literacy” and “achieving standards”. Specifically, we should make every effort to ensure and improve the quality of basic education, and ensure that the vast majority of the young labor force can achieve a high school education or above, which is a key step in promoting sustainable consumption through digital technology. For regions approaching or exceeding 0.0068, the policy focus should shift towards “optimization” and “enhancement”, vigorously developing vocational education and higher education, to fully leverage the driving role of high human capital in consumption upgrading and economic growth.
- (3) Improve the two mechanisms of “digital technology penetration → household income → sustainable household consumption” and “digital technology penetration → financial development → sustainable household consumption”. The key to improving the first mechanism is to cultivate “digital technology+” characteristic industries and new forms of employment, continuously expand income channels, combine digital tech-

nology with residents in the sinking market, and let workers see the benefits brought by digital technology, thereby forming positive incentives. The key to improving the second mechanism is to encourage financial institutions to develop small-scale, inclusive consumer credit and installment products that are more suitable for the credit characteristics and consumption scenarios of households in the sinking market, under the premise of controllable risks, to smooth household income and consumption cycles, and alleviate their liquidity constraints.

- (4) Implement differentiated and precise inclusive policies. As for the central region, building regional digital consumption hubs in core transportation hubs such as Zhengzhou, Wuhan, and Changsha, supporting central cities to hold digital consumption festivals and online exhibitions, enhancing the attractiveness and radiation of the central region in the field of digital consumption, and transforming location advantages into market advantages. As for the western region, in the national new infrastructure investment, it is clear to tilt a higher proportion towards the western region, and it is even more important to ensure the quality of network coverage and affordable network costs in remote rural and pastoral areas. In terms of talent introduction, the “Flexible Digital Talent Introduction and Localized Training” plan is implemented, encouraging eastern experts to serve the western region through forms such as “weekend engineers” and “online consultants”, while cultivating local digital forces rooted in the western region. Further expand the pilot scope of “inclusive finance”, relax the admission of pilot institutions, and provide risk compensation. In terms of the eastern region, the policy focus should shift towards innovative consumption patterns and quality improvement and explore corresponding governance models to provide a demonstration for the whole country; guide the cultivation of “high-end consumer market” and “digital brand matrix”; support the development of experience economy, customized economy, green consumption, etc., in eastern cities. It is particularly important to note that the formulation and implementation of policies are not static, but require regular evaluation of the effectiveness of policies in various regions, timely optimization and adjustment, prevention of policy rigidity, and implementation of rewards and punishments for excellence.

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