



## OPEN Research on the influence mechanism of digital economy on the development of the sports and health industry in China

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Digital technology's quick adoption has given sectors a fresh boost to overcome long-standing growth barriers. The sports and health sector are now dealing with systemic issues such as uneven regional development, poor service delivery, and resource misallocation. Accurately determining the digital economy's driving force in the sports and health sector has emerged as a crucial issue for modernizing health governance and encouraging the creation of new, high-caliber productive forces. By building an evaluation index system for their development, this study determines the development indices of the digital economy and the sports and health industries using panel data from 270 Chinese cities at the prefecture level between 2011 and 2023. Additionally, the bidirectional fixed effect model and the mediation model are used to experimentally assess the direct promoting effect of the digital economy on the growth of the sports and health business, and a systematic analysis of its multi-level transmission mechanism is conducted. The findings of the study show that: (1) The growth of the sports and health sector can be greatly aided by the digital economy, and this conclusion has passed a number of robustness tests. (2) Mechanism analysis shows that through cost-saving effects, the digital economy can indirectly support the growth of the sports and health sector. (3) According to regional heterogeneity analysis, the spatial spillover impact is evident in the western region, which has failed the significance test, whereas the effect is more substantial in the eastern and central regions. The findings of this study demonstrate the important contribution of the digital economy to the growth of the sports and health sector, offering businesses and governments helpful resources.

**Keywords** Sports and health industry, Digital economy, Cost savings, Empirical test, Influence mechanism

The digital economy is becoming the primary driver of industrial change in the context of the acceleration of the global digital transformation, and the sports health sector is going through subversive changes. With an average annual growth rate of 18.6%, the global sports technology industry has surpassed 120 billion US dollars, according to the International Sports Engineering Association's (ISEA) 2023 forecast<sup>1</sup>. The conventional sports industry chain is being rebuilt as a result of the widespread use of digital technology. The world's top economies have established a "technology-industry-policy" linkage development model, ranging from the US Peloton company, which opened a new home fitness track using an intelligent hardware + subscription model, to the European Union, which introduced the "digital Sports 2030" plan to encourage the use of 5G + AR technology in professional sports<sup>2</sup>. A 2022 World Bank study found that the digital economy's marginal efficiency in enhancing the sports industry's efficiency has surpassed traditional aspects by a factor of 2.3. This technology premium has increased since the COVID-19 pandemic<sup>3</sup>. The sports industry's high-quality development is confronted with the pressing need for digital transformation as a significant field that integrates health, cultural, and economic aspects. The Communist Party of China's 20th report explicitly said that the digital economy would strengthen the physical sector and fully support the application of the "sports power" and "healthy China" strategies<sup>4</sup>. There are notable regional features to China's sports and health sector's digital revolution. Technical indicators like virtual experience, intelligent detection, community interaction, and scenario-based services have gradually become the mainstream value demands of mass consumption, and the market demand for cross-border integration products with intelligence and technology is growing due to the ongoing innovation of digital technology in the sports health sector<sup>5</sup>. There are still issues like low R&D and innovation efficiency in the sports and health sector, as well as a mismatch between input and output, despite the fact that investment in digital technology innovation

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is steadily increasing and innovation capabilities have significantly improved. The “Outline for Building a Sports Power” states that “the sports industry should become a pillar industry of the national economy,” which is far from the case here<sup>6</sup>. Digital technology should be used to its full potential, particularly in light of recent public health events like the COVID-19 epidemic and concerns about how to more effectively raise citizens’ health levels. Therefore, the current focus of attention in the growth of the sports and health business is on taking advantage of the potential presented by digital economic development and supporting the industry in lowering company costs and increasing input-output efficiency. According to theory, the Internet of Things, big data, artificial intelligence, and other technologies drive industrial change through three mechanisms: first, smart devices capture motion behavior data continuously; second, cloud computing platforms create dynamic health assessment systems; and third, blockchain technology ensures the profitable circulation of sports data<sup>7</sup>. The worldwide sports health industry’s competitive environment is changing as a result of this technology-driven development paradigm. Nonetheless, using questionnaire surveys and structured interviews, researchers have brought attention to the uneven regional growth of the sports and health sectors<sup>8,9</sup>. According to a 2023 survey conducted by the State Council of China’s Development Research Center, the density of sports health technology businesses in eastern coastal cities is 4.6 times higher than in western regions, and there is a 28-percentage point difference in the number of users of digital fitness applications<sup>10</sup>. Both the global standard set by “cloud broadcasting” technology during the Beijing Winter Olympics and the practical predicament of lagging digitization of grassroots public sports services are reflected in this regional differentiation, which highlights the profound contradictions in China’s digital transformation of the sports and health sector<sup>11</sup>. Important references for this paper have come from previous research. There are, however, comparatively few studies from an empirical standpoint, and the impact of the digital economy on the sports and health industries as well as regional variations is confined to theoretical elaboration. As a result, this study has important policy implications since it builds a panel regression model to investigate how the digital economy affects China’s sports and health sector.

The research contributions of this study are primarily focused on the following areas, which are based on the research background mentioned above. To provide a solid basis for the next empirical research, this paper first develops the assessment index system for the digital economy and sports health sector. Second, in order to improve the results’ reference value, this study incorporates control variables related to the sports industry and uses panel regression analysis of fixed effects and intermediate effects. Lastly, in terms of research hypotheses, the impact of the digital economy on the growth of the sports and health sector was examined. At the same time, the literature templates and pertinent theoretical research models were enhanced. Furthermore, this study discovered the regional heterogeneity effect in the process of encouraging the growth of the sports health sector through the digital economy, which offered theoretical justification for the creation of regional sports industry resources and the formulation of policies.

The rest of this paper is organized as follows: the second chapter reviews the existing literature, the third chapter is the hypothesis part, introduces the causal relationship between the digital economy and the development of sports and health industry; The fourth chapter introduces the index system construction, research methods, data sources and the definition of each variable. Chapter 5 is the empirical test results and analysis, verifies the research hypothesis proposed in Chap. 3, and carries out a series of robustness tests to answer the above research questions. The sixth chapter is the conclusion and discussion.

## Literature review

### Research on the development of digital economy

Digital economy is a new form of economic and social development and a phased concept, with its connotation and extension constantly evolving<sup>7,12</sup>. The definition of concepts, the development of evaluation index systems, and the study of causal relationships are the three primary areas of current research on the digital economy. The idea of the “digital economy,” which was initially put forth in 1996, has grown to be a focus of much research<sup>13</sup>. A largely reliable definition of the digital economy was offered by the G20’s “Digital Economy Development and Cooperation Initiative” in 2016: The term “digital economy” refers to a set of activities that use digital knowledge and information, use information networks as a means of transportation, and optimize economic structure and efficiency through the efficient use of information technology<sup>14</sup>. With the continuous advancement of information technology, the essence of the digital economy is also changing, mainly presenting the following characteristics: Firstly, the information elements relied upon by the digital economy are to a certain extent non-exclusive and non-competitive, and users can obtain and exchange information at a relatively low cost<sup>15</sup>. Second, the growth of digital products can serve additional consumers at “zero marginal cost,” creating a network value-added impact, in contrast to traditional economic operations that are subject to the law of declining marginal returns. Last but not least, the digital economy has made it easier for producers and customers to communicate in real time and encouraged the shift in production methods toward personalization and customization. In the digital age, big data can be used to watch consumers’ online habits, precisely recognizing the immediate demands of client groups to accomplish deeper consumption to a greater degree. Furthermore, the digital economy has increased the frequency of enterprise product and service updates, boosted regional innovation efficiency, and encouraged industrial innovation<sup>16</sup>. This helps to form regional innovation competitive advantages, while alleviating the problem of information asymmetry and improving market efficiency.

The binary and ternary dimensions are the primary focus of the assessment index system being constructed for the growth of the digital economy. The development level of the digital economy, which primarily consists of the resource input and digital revenue generation, is measured in terms of binary dimensions by digital infrastructure and digital industry development<sup>17</sup>. Related to this, the evaluation criteria are based on the input-output thought, which holds that the input of digital economy includes three parts: infrastructure input, digital governance input and digital innovation input, while the output of digital economy includes two forms: digital industrialization and industrial digitalization<sup>18</sup>. Scholars create a multidimensional evaluation standard

of input-technology-output by incorporating technical elements into the binary dimensions mentioned above. The development of production efficiency, the output of scientific and technological advancements, and the superposition of the product realization impact are all driven by technology, which is the fundamental component of the digital economy<sup>19,20</sup>. Based on the connotation of digital economy and the measurement standards of the China Institute of Information Technology, the relevant research divides the digital economy into three aspects: digital infrastructure, digital industrialization and industrial digitalization<sup>21,22</sup>. In general, the construction of the index system of the digital economy mostly depends on the logical construction of input-output, and the multidimensional index is also the embodiment of the output effect.

Regarding the causal relationship research on the development of the digital economy, the relevant literature mainly reflects the promoting effect of the digital economy<sup>23</sup>. At the macro level, digital technologies promote high-quality development by optimizing new input factors, new resource allocation efficiency and new total factor productivity<sup>24</sup>. In addition, in the sports industry, the digital economy also plays a significant role in expanding the scope of employment, adjusting the employment structure, and promoting high-quality and full employment<sup>25</sup>. At the micro level, emerging technologies such as the Internet can create an economic environment that combines economies of scale, economies of scope, and long-tail effects. On this basis, supply and demand can be better matched, and a more complete price mechanism can be formed, thereby enhancing the equilibrium level of the economy. Moreover, some scholars have pointed out that the development of the digital economy will stimulate customers' demand for product diversification. Especially after the outbreak of public health events such as the COVID-19 pandemic, residents' health awareness has gradually increased<sup>26</sup>. The market demand for sports and health products often fails to meet the needs, which has become a focus of social development. However, regarding this issue, previous studies have not provided specific influence mechanisms on what paths the digital economy mainly promotes the healthy development of sports to answer this question.

### Digital research of sports and health industry

The sports and health industry covers many subdivisions such as sporting goods manufacturing, fitness services, health management, and event operation, and its digital transformation presents multi-dimensional characteristics<sup>27</sup>. First, efficiency innovation at the production end. Industrial Internet and flexible manufacturing technology promote the intelligent upgrading of sporting goods. For example, Adidas' Speed factory has reduced the development cycle of new products by 50% through 3D printing and robot customized sneakers<sup>28</sup>. Secondly, the virtual and real consumption scenes are integrated. The COVID-19 pandemic has accelerated the popularity of online fitness models. Peloton's live course users surged 232% in 2020<sup>29</sup>. The Chinese platform Keep has maintained a monthly active user rate of more than 30 million people through the mechanism of "AI body recognition + community incentive"<sup>30</sup>. Such platforms not only provide training content, but also build user health profiles through data accumulation and derive value-added services such as personalized nutrition guidance. Finally, digital technology continues to drive the high-quality development of sports and industries such as healthcare and wellness. Research shows that the digital economy can reduce health inequalities among different income brackets, which plays a significant role in promoting common prosperity. Furthermore, relevant research explains the main reasons for this. The digital economy, by leveraging the public nature and openness of data, can promote the inclusiveness of basic public health services and thereby drive health equity<sup>31</sup>.

This type of activity demonstrates how digital technology is evolving from a supporting tool to the central component of industrial ecological reorganization. Additionally, the sports and health sector have the important qualities of positive externality, a long value chain, a high return rate, low emissions, and resource dependence, all of which are in line with the economic demands and supply of both urban and rural areas. These attributes are also a good place to start if you want to increase residents' incomes, encourage labor employment, and close the gap between urban and rural areas<sup>32-34</sup>. In the people-centered development idea, the sports and health industry is not only conducive to exerting the medical value of sports such as fitness, health care and health care, improving the healthy lifestyle of residents, cultivating a strong sports cultural atmosphere, and promoting social civilization<sup>35,36</sup>.

In general, the current academic research on the development of sports and health industry is relatively rich, but the research on the development of sports and health industry by digital economy is mainly concentrated in the two aspects of theoretical inference and path exploration, and the mechanism of action and empirical research on the empowerment of sports and health industry by digital economy still need to be in-depth. It is mainly reflected in the following aspects: (1) There is no unified consensus on the construction of the evaluation system of the development of the sports health industry and the evaluation index system of the development of the digital economy, and the establishment of the index system needs to be improved; (2) When studying the development of digital economy and sports and health industry, the existing literatures pay more attention to theoretical elaboration, and few hypotheses are proposed and supplemented with empirical research; (3) In terms of research objects, the current research mainly focuses on the relationship between digital economy and the development of sports and health industry at the national level, and there is relatively little specific research combining micro-regional characteristics. In view of this, in order to make the digital economy better lead the high-quality development of the sports health industry, this paper takes 270 prefecture-level cities in China as the research object, and deeply explores the status quo of spatial regional development and the evolution law of the time process by constructing the evaluation system of the development of the digital economy and the development evaluation system of the sports health industry. And through the construction of fixed effect model and intermediary effect model to clarify the digital economy on the development of sports health industry.

## Mechanism analysis and research hypothesis

### The direct role of digital economy on the development of sports and health industry

Currently, issues like industrial agglomeration, a lack of information sharing, restricted funding sources, and a lack of innovation are hindering the growth of the sports and health sectors. The resources of all links in the sports and health industry chain are relatively dispersed, which results in a low degree of linkage between related industries and a lack of information sharing, which lowers the resource utilization efficiency of the entire industry. This is because the sports and health industry involve a wide range of industries, but the industrial composition and the relationships between various industries are not reasonable<sup>37</sup>. The digital economy exemplifies the comprehensive application of digital technologies, which enhance industrial agglomeration and improve information sharing. Meanwhile, digital communication technology can break the physical boundaries of space, reduce the transportation distance between regions, and also enhance the virtual aggregation and interaction among industries, promoting the high-quality development of industries<sup>38</sup>. Therefore, the digital economy provides information sharing and industry aggregation, which can effectively promote the high-quality development of the sports and health industry. On the other hand, challenges such as limited financing channels and insufficient innovation hinder the development of the sports and health industry. The sports and health industry has the characteristics of long investment cycle, large capital demand and high-risk bearing, which conflicts with the attributes of financial credit loans with low flexibility, short term and high cost. There are certain difficulties in credit financing for industrial development, which has become a bottleneck restricting industrial development<sup>39</sup>. Meanwhile, as the sports and health industry involves many high-tech industries, it requires a relatively high economic foundation to support it. Therefore, the development of the digital economy has played a significant role in attracting government subsidies, business investment, and promoting enterprise innovation. This is because the development of the digital economy helps enhance information sharing among enterprises and reduce the uncertainty risks in the market, thereby facilitating enterprises to better obtain external financing. At the same time, in terms of innovation incentives, the development of the digital economy provides good financial support for enterprises, improves the value effect of innovation patents, and ultimately helps to promote the high-quality development of enterprises<sup>40,41</sup>.

According to the summary, this paper believes that the development of digital economy can promote the high-quality development of sports and health industry from the aspects of strengthening information sharing and alleviating financing difficulties. Based on this, this paper proposes hypothesis 1.

H1: Digital economy can effectively promote the development of sports and health industry.

### Indirect effects of digital economy on the development of sports and health industry

The digital economy helps to improve the efficiency of enterprises' total factor allocation and reduce transaction costs<sup>42</sup>. Schumpeter's innovation theory holds that innovation is the addition of technology elements within an industry to optimize resource allocation and information resource sharing, and its core subject is "entrepreneur", which lies in whether an enterprise can effectively operate the "new combination" added with innovative elements<sup>43</sup>. Therefore, the digital economy reduces the transaction costs, one is to ease the capital-led financing constraints<sup>44</sup>. Sports small and medium-sized enterprises are affected by macro factors, and their living conditions are difficult. The main reason is that under the influence of information asymmetry, the financing level of banks and other financial institutions to enterprises has declined, resulting in the reduction of total factor productivity of enterprises, the industrial scale is still the same, and the industrial resilience is fragile. However, digital technology can give full play to the borderless characteristics of data, enabling both credit parties to achieve double transparency of credit record and repayment ability, which is conducive to financial institutions to accurately judge the production and operation status of sports-related enterprises, improve the efficiency of credit resource allocation, and effectively reduce the transaction costs in the production and activity process of sports and health enterprises<sup>45</sup>. The second is to enhance the technology-led innovation capability. The wide application of digital technology can encourage sports enterprises to realize the transformation and upgrading of traditional technology to improve total factor productivity. From the perspective of enterprise costs, digital technology can effectively reduce the operational and organizational management costs of enterprises, enabling them to allocate more funds to the upgrading of traditional equipment and structural optimization, thereby enhancing production efficiency<sup>46</sup>. From the perspective of collaborative innovation, digital technology has accelerated the frequency of flow among various sports entities, broken through the practical obstacles of fragmented information, fragmented resources and knowledge islands among research institutions, universities, sports and health enterprises, and government organizations, reduced the information search costs of enterprises, and improved the transaction efficiency of the sports market. From the perspective of principal-agent costs, the principal-agent costs in the sports and health industry include the costs incurred by the owner for supervising and managing, such as performance monitoring and contract formulation. Digital technology can utilize data sharing platforms to reduce the information monopoly of management and lower the sensitivity of supervision costs. Meanwhile, digital platforms can also simplify the supply chain hierarchy of the sports and health industry and reduce the agency problems in the intermediate links.

In addition, the digital economy helps to create economies of scale and reduce marginal costs<sup>47</sup>. The expansion of external economies of scale, product economies of scale and enterprise economies of scale in the sports and health industry should not only rely on the technical empowerment of the digital economy and its unique intermediation, dematerialization and decentralization to optimize the internal division of labor in the sports and health industry, improve labor production efficiency, enrich resource sharing and increase product innovation, but also make use of the network externalities of the digital economy. Expand the sports customer base, form a chain process of digital sports health product design and sales, reduce the marginal cost of the industry, so as to achieve economies of scale in the sports health industry. Based on this, hypothesis 2 is proposed in this paper.

H2: The digital economy reduces the production cost of enterprises through the cost saving effect, and then has a significant impact on the development of sports and health industry.

### Regional heterogeneity effect of digital economy on the development of sports and health industry

The investment in the existing sports and health industry is mainly concentrated in the field of medicine, rehabilitation and medical equipment, and the distribution of funds is extremely uneven, especially the high-tech industry and capital-intensive industry in the sports and health industry, the risk of scientific and technological innovation is large, the demand for funds is large, and the short board of financial constraints is becoming more obvious. The digital economy helps to realize the open sharing of resources, accelerate the flow of various production factors between regions, and break the constraints of the application of digital technology in space. The digital economy promotes the low-cost diffusion of information, strengthens the long-distance, cross-time and space connections that have been achieved in the information age, and improves the speed and accuracy of connections. Promote the organic combination of labor, capital, data and other elements in different Spaces, so that the breadth and depth of cross-regional integration of resources in the health industry are enhanced<sup>48</sup>. However, there is a significant spatial imbalance in China's new infrastructure. According to data from China's Ministry of Industry and Information Technology, the density of 5G base stations in the eastern prefecture-level cities in 2023 is 3.7 times that of the western region, resulting in a difference in the penetration efficiency of digital technology. The concentration of digital sports and health talents presents a pattern of "strong in the east and weak in the west"<sup>49</sup>. According to data from the Ministry of Education, the number of students majoring in sports science and rehabilitation in eastern universities is 2.8 times that of western universities. Hangzhou relies on Zhejiang University and other universities to form a pool of digital sports talents, and its e-sports coach supply accounts for 23% of the country. Based on this, hypothesis 3 is proposed in this paper.

H3: Digital economy can drive the development of sports and health industry, and there will be regional heterogeneity.

### Research design

#### Construction of index evaluation system

In order to ensure the scientific and logical selection of evaluation indicators, this paper constructs the index system reasonably on the basis of the above theoretical analysis<sup>31</sup>. It has formed the industrial base, industrial input, industrial support, industrial demand, digital infrastructure, digital service capability and digital industry income generation, and has 25 specific indicators in 7 dimensions of 3 systems, as shown in Tables 1 and 2.

The data in this paper are mainly from China Statistical Yearbook, China Sports Statistical Yearbook, China Health and Family Planning Statistical Yearbook, etc. Among them, for the data that has not been officially released or is missing, this paper adopts the linear interpolation method for supplementation. It should be noted that the weights and development indices of each evaluation index are calculated by referring to relevant studies, using the entropy method and the coupled coordination model. The specific operation process will be referred to existing studies and will not be elaborated here<sup>36</sup>.

#### Model construction

In order to further test the relationship between the direct effect of digital economy on the development level of sports and health industry, and verify the above hypothesis H1, the following model is designed:

System	Dimensionality	Index	Attribute	Weight
Sports industry	Industrial base	Number of sports venues X1	+	0.0500
		Added value of sports industry X2	+	0.1063
	Industrial input	Proportion of added value of sports industry in GDP X3	+	0.1625
		Number of employees in culture, sports and entertainment X4	+	0.2188
		Expenditure on education, sports and culture X5	+	0.2750
	Industry support	Number of registered enterprises in the sports industry X6	+	0.1813
		Number of sports social organizations X7	+	0.0722
	Industrial demand	Number of people doing regular physical exercise X8	+	0.1339
Health industry	Industrial base	Total health expenditure X9	+	0.1209
	Industrial input	Growth rate of investment in fixed assets in health and social work X10	+	0.0625
	Industry support	Number of medical institutions X11	+	0.0750
		Number of listed companies in health industry X12	+	0.0875
		Number of health and social work practitioners X13	+	0.0291
		Number of registered enterprises in health and hygiene industry X14	+	0.1250
	Industrial demand	Number of participants in basic medical insurance at the end of the year X15	+	0.1750
		Health care expenditure X16	+	0.3250

**Table 1.** Evaluation index system of sports and health industry development.

System	Dimensionality	Index	Attribute
Digital infrastructure	Mobile phone penetration X1	+	0.0516
	Number of Internet access ports X2	+	0.0887
	Optical cable density X3	+	0.0414
Digital service capability	The proportion of Internet broadband users X4	+	0.0887
	Number of mobile phone base stations X5	+	0.0673
	Number of legal entities in the information transmission, software and information technology service industries X6	+	0.1480
Digital industry revenue generation	E-commerce sales X7	+	0.1263
	Telecom main business income X8	+	0.2392
	Software revenue as a percentage of GDP X9	+	0.1488

**Table 2.** Digital economy development evaluation index system.

$$\begin{aligned}
 Shi_{it} = & \alpha_0 + \alpha_1 Dig_{it} + \alpha_2 Lnpgdp_{it} \\
 & + \alpha_3 Pfdi_{it} + \alpha_4 Fai_{it} + \alpha_5 Lntb_{it} \\
 & + \alpha_6 Lnpeo_{it} + \alpha_7 Gra_{it} + \mu_t + \theta_i + \omega_{it}
 \end{aligned} \quad (1)$$

where,  $Shi_{it}$  is the development index of sports and health industry in year t, and  $Dig_{it}$  is the development index of digital economy in year t.  $Lnpgdp_{it}$ ,  $Pfdi_{it}$ ,  $Fai_{it}$ ,  $Lntb_{it}$ ,  $Lnpeo_{it}$ ,  $Gra_{it}$  are the series control variables,  $\mu_{it}$  is the year fixed effect,  $\theta_{it}$  is the province fixed effect,  $\alpha$  is the constant term,  $\omega_{it}$  is the random disturbance term.

In addition, according to the hypothesis H2 and H3 above, the digital economy will not only directly affect the development of the sports and health industry, but also indirectly urge the development of the sports and health industry through the cost saving effect. Therefore, the following mediation model is designed<sup>50</sup>:

$$\begin{aligned}
 Shi_{it} = & \alpha_0 + a Dig_{it} + \alpha_2 Lnpgdp_{it} \\
 & + \alpha_3 Pfdi_{it} + \alpha_4 Fai_{it} + \alpha_5 Lntb_{it} \\
 & + \alpha_6 Lnpeo_{it} + \alpha_7 Gra_{it} + \mu_t + \theta_i + \omega_{it}
 \end{aligned} \quad (2)$$

$$\begin{aligned}
 Mediation_{it} = & \alpha_0 + b Dig_{it} + \alpha_2 Lnpgdp_{it} \\
 & + \alpha_3 Pfdi_{it} + \alpha_4 Fai_{it} + \alpha_5 Lntb_{it} \\
 & + \alpha_6 Lnpeo_{it} + \alpha_7 Gra_{it} + \mu_t + \theta_i + \omega_{it}
 \end{aligned} \quad (3)$$

$$\begin{aligned}
 Shi_{it} = & \alpha_0 + a' Dig_{it} + c Mediation_{it} + \alpha_2 Lnpgdp_{it} \\
 & + \alpha_3 Pfdi_{it} + \alpha_4 Fai_{it} + \alpha_5 Lntb_{it} + \alpha_6 Lnpeo_{it} \\
 & + \alpha_7 Gra_{it} + \mu_t + \theta_i + \omega_{it}
 \end{aligned} \quad (4)$$

where,  $Mediation_{it}$  is the intermediary variable,  $a$  is the overall effect of digital economy driving the development of sports and health industry,  $b$  is the effect of digital economy on the intermediary variable,  $a'$  is the direct effect of digital economy on the development of sports and health industry, and  $c$  is the indirect effect of intermediary variable on the development of sports and health industry. The connection between the total effect and the direct and indirect effects is:  $a = a' + b * c$ .

## Variable description

### Explained variables

The explained variables were represented by the development index ( $Shi_{it}$ ) measured by the sports health industry development evaluation index system. In addition, the sports industry dimension development index ( $Spo_{it}$ ) and the health industry dimension development Index ( $Hea_{it}$ ) were selected as the explained variables.

### Explanatory variables

Digital economy development index ( $Dig_{it}$ ) is selected as the core explanatory variable to test the impact of digital economy on the development of sports and health industry.

### Control variables

In order to control the influence of other factors on the sports and health industry, this study combines the possible impact of other factors on the sports and health industry in the literature review in the second part and the mechanism analysis in the third part, and selects the following variables as the control variables for the next study. (1) With economic development, the increase in residents' income and the rise in per capita disposable income, there will be more funds available for sports and health consumption. Therefore, the level of economic development ( $LnPgdp$ ) is selected, and the logarithm of the per capita GDP value is taken as the control variable. (2) The development of the sports and health industry and the development of sports and health products require a large amount of capital investment. Therefore, the net inflow level of foreign investment ( $Pfdi$ ) is selected to reflect the production materials such as technology, capital and equipment brought by foreign investors to the sports and health industry. (3) Fixed asset investment ( $Fai$ ) can be used to build infrastructure such as sports

venues and outdoor sports fields, which provide a material basis for the development of the sports and health industry. Therefore, fixed asset investment is selected as the control variable. (4) Convenient transportation can accelerate the flow of elements such as personnel, materials and technologies needed by the sports and health industry. Therefore, the traffic level ( $Lntb$ ), that is, the logarithm of the number of civilian cars owned, is selected as the control variable. (5) A large population base means that more people are likely to participate in sports activities, thereby increasing the demand for sports health products and services. Therefore, population size ( $Lnpeo$ ), the logarithm of the permanent resident population in the region, was selected as the control variable. (6) Parks, green Spaces and tree-lined avenues with high green coverage provide residents with low-cost outdoor sports venues, which can promote the development of mass fitness in the sports and health industry. Therefore, the green coverage rate of the built-up area ( $Gra$ ) was selected as the control variable.

#### Intermediary variables

The operating cost ratio ( $Pro$ ) of an enterprise is an internal manifestation of the improvement in the enterprise's efficiency, which is the proportion of operating costs to operating income. The higher the value, the higher the production and transaction costs of the enterprise, which is not conducive to the operation and sustainable development of the enterprise. The lower the value, the more efficient the internal operation of the enterprise is. Based on the mechanism analysis in the previous text, it is believed that data in digital technology, as a key production factor, can weaken the cost constraint of resource scarcity on sports and health enterprises in the process of input and use. At the same time, it can also enhance the ability of enterprises to obtain and identify market information, thereby reducing transaction costs such as information search and decision-making. Therefore, this paper selects the enterprise operating cost rate to quantify the cost-saving effect.

#### Data source and processing

In order to clearly reflect the time dynamic relationship of the impact of digital economy on the development of sports and health industry, and to have sufficient control samples, this paper selects the panel data of 270 prefecture-level cities in China from 2011 to 2023 for empirical analysis. The relevant data of the above variables are from China Statistical Yearbook and Statistical Bulletin of National Economic and Social Development. For the missing data, linear interpolation method is adopted in this paper to facilitate the systematic study below. Table 3 shows the descriptive statistical results of each variable.

## Research results and analysis

### Analysis of benchmark regression results

Table 4 reports the empirical regression results of the direct effect of digital economy driving the development of sports and health industry. The impact models of the digital economy on the dimensions of the sports and health industries are found in models (1) and (2). According to the regression results, the growth of the sports and health industries can be greatly aided by the digital economy. This finding has surpassed the significance level of 1%. Model (3) represents the direct effect of digital economy on the development level of sports health without adding control variables. The result is positive and passes the significance test of 1%, indicating that digital economy has a positive promoting effect on the development of sports health industry. Model (4) is the regression result of adding control variables and the fixed effect of control region and time. The regression coefficient passes the significance test of 10%, and  $R^2$  also shows a significant improvement, indicating that the effect of digital economy on the development level of sports and health industry is still a positive promotion trend, which verifies the hypothesis H1 in the above analysis. Further analysis reveals that after adding the control variables, the corresponding coefficients have decreased significantly compared with the previous model, indicating that the selection of the control variables is reasonable. It has largely controlled other potential factors affecting the explained variables and also brought accuracy to the acquisition of the results. Lastly, to prevent endogeneity issues like data interpolation discrepancies and singular values. Consequently, all numbers were subjected to a 1% tail reduction. The processed regression results are displayed in model (5). The robustness of the empirical data is further confirmed by the regression coefficient marginally decreasing and the regression results still passing the 1% significance test. Compared with the results of related studies, Wei et al. suggests

Variable	Variable symbol	Variable information	Mean	SD	Max	Min	N
Explained variable	$Shi$	Sports and health industry	0.7210	0.2302	0.9512	0.2214	3510
	$Spo$	Sports industry	0.6512	0.2011	0.9301	0.1533	3510
	$Hea$	Health industry	0.7215	0.2236	0.9617	0.1945	3510
Explanatory variables	$Dig$	Digital economy	0.4222	0.2048	0.8923	0.0101	3510
Intermediary variables	$Pro$	Enterprise operating cost rate	0.1241	0.0228	0.1082	0.0112	3510
Control variables	$LnPgdp$	Economic development level	9.6221	2.3748	12.2876	1.1128	3510
	$Pfdi$	The net inflow level of foreign investment	0.1621	0.8357	0.8974	-0.1401	3510
	$Fai$	Fixed asset investment	0.1029	0.2114	0.6625	-1.3851	3510
	$Lntb$	Traffic level	15.3218	3.2278	19.3745	5.1451	3510
	$Lnpeo$	Population size	-1.1884	1.9385	0.2144	-2.3472	3510
	$Gra$	Green coverage rate of the built-up area	0.3514	0.1173	0.2574	0.1278	3510

**Table 3.** Descriptive statistical results of each variable.

Variable	(1) SPO	(2) Hea	(1) Shi	(2) Shi	(5) Shi
Dig	0.2611*** (3.55)	0.1755*** (5.14)	0.1842*** (4.88)	0.1733* (1.99)	0.1714* (2.66)
LnPgdp	0.1445 (0.26)	0.1778 (0.11)		- 0.0475 (- 0.22)	- 0.0411 (- 0.22)
Pfdi	- 0.2692* (- 1.89)	- 0.1455 (1.01)		- 0.0341 (- 0.17)	- 0.0327 (- 0.18)
Fai	- 0.1123 (- 0.98)	- 0.2247 (- 0.44)		- 0.1277 (- 0.73)	- 0.1251 (- 0.52)
Lntb	0.8632 (0.12)	0.1472* (1.84)		- 0.0110 (- 0.78)	- 0.0124 (- 0.75)
Lnpeo	0.3914*** (5.94)	0.1433*** (3.02)		- 0.7141* (- 1.59)	- 0.7121* (- 1.55)
Gra	0.8122*** (3.14)	0.1198* (1.99)		1.89937*** (4.97)	1.8997*** (4.94)
Cons	0.6112*** (9.66)	0.5557*** (8.55)	0.4578*** (15.11)	0.5984*** (3.82)	0.5143*** (3.35)
Regional	YES	YES	YES	YES	YES
Time	YES	YES	YES	YES	YES
N	3240	3240	3510	3510	3240
R <sup>2</sup>	0.8125	0.9322	0.8333	0.8533	0.8632

**Table 4.** Baseline regression results. \* $P < 0.1$ , \*\* $P < 0.05$ , \*\*\* $P < 0.01$ ; The values in parentheses are the Z-test values.

Variable	(1) Pro	(2) Shi
Dig	- 0.1388* (- 1.97)	0.2344* (1.87)
Pro		- 0.1133* (- 1.83)
LnPgdp	0.1597 (0.44)	- 0.1274 (- 0.66)
Pfdi	0.0169 (0.44)	- 0.0286 (- 1.01)
Fai	0.0127** (2.27)	- 0.0238 (- 0.52)
Lntb	- 0.1444*** (- 4.25)	- 0.3871 (- 0.21)
Lnpeo	- 0.3683*** (- 8.35)	- 1.8341*** (- 3.88)
Gra	- 0.1233* (- 1.88)	0.7317* (1.17)
Cons	- 0.1477** (- 2.88)	0.7429* (1.92)
Regional	YES	YES
Time	YES	YES
N	3510	3510
R <sup>2</sup>	0.9877	0.9987

**Table 5.** Regression results of mechanism analysis. \* $P < 0.1$ , \*\* $P < 0.05$ , \*\*\* $P < 0.01$ ; The values in parentheses are the Z-test values.

that the digital economy can promote the level of medical and health care services, with an impact coefficient of 0.009<sup>51</sup>. However, in this study, considering the multi-industry integration attribute of the sports and health industry, after constructing the index system and controlling other potential influencing variables, the regression coefficient of the development level of the sports and health industry is 0.1733. The digital economy has a relatively obvious promoting effect on the development of the sports and health industry, once again proving that the digital economy can significantly enhance the development of the sports and health industry.

The regression results of control variables showed that both *Lnpeo* and *Gra* passed the significance test. Among them, *Gra* plays a positive role in promoting the high-quality development of the sports health industry, indicating that the natural ecological environment is closely related to the development of the sports health industry, and once again proves the fact that the sports health industry is a green industry and a happy industry. The population size has a negative effect, which may be due to the fact that although the increase of population size will stabilize the consumption level, it will also cause damage to the ecological environment, weaken the ability of sustainable development, and thus damage the high-quality development of the sports and health industry. In addition, *LnPgdp*, *Fai*, *Lntb* and *Pfdi* failed to pass the significance test, due to the mismatch between investment funds and the development of the sports and health industry, the failure to fully implement hardware and software facilities and services, and the lack of market guidance. Therefore, the macro-adjustment of the government should be strengthened.

### Mechanism analysis

Model (1) in Table 5 reports the impact of digital economy on enterprise cost, and the results show that the regression coefficient is -0.1388, and both pass the significance test, indicating that digital economy can significantly restrain the cost of sports enterprises and improve the cost profit margin. The above conclusions are consistent with the results of related studies<sup>52</sup>. Further analysis shows that cost saving effect plays a significant intermediary role in the process of digital economy driving the development of sports and health industry. First of all, the regression coefficient of cost saving effect and digital economy on the development of sports and

health industry is significantly negative, indicating that digital economy indirectly promotes the development of sports and health industry by effectively inhibiting the production cost of enterprises. From the perspective of regression coefficient, the development level of sports and health industry is improved by 11.33% through cost saving, which verifies hypothesis H2. From the regression significance of the explained variables in model (2), the cost saving effect plays a partial mediating role.

### Robustness test

#### *Change the method of variable measurement*

This study adopts the entropy method to measure the development indices of the sports and health industry and the digital economy. Considering that the calculation results of the explained variable and the core explained variable are more accurate and scientific, the principal component analysis method was adopted to re-measure the development index of the sports and health industry and the digital economy, and the calculation results were re-conducted for panel regression<sup>53</sup>. The results are shown in models (1) and (2) in Table 6. It can be seen that the estimation results have no significant difference from the above text, indicating that the conclusion obtained in this paper is robust and reliable.

#### *Alter the sample interval*

Due to the rapid growth of the sports and health industry after The State Council issued the “Several Opinions on Accelerating the Development of the Sports Industry and Promoting Sports Consumption” in 2014, the digital economy also continued to develop under the guidance of relevant policies in 2014. Therefore, considering the impact of policy changes on the results, this paper takes 2014 as the time node and selects the panel data from 2014 to 2020 for regression again to prove the robustness of the above test. The results are shown in Model (3) of Table 6. The estimation results are consistent with the above text, indicating that the digital economy does contribute to promoting the development of the sports and health industry.

#### *Add control variables*

When considering that there are unobserved variables in the model that simultaneously affect the digital economy and the sports and health industry, it will lead to bias in the estimation results, thereby generating endogeneity problems. Therefore, the level of new marketization and the number of sports-related patents are regarded as omission control variables. The selection of the above variables is mainly based on the consideration that the higher the level of marketization, the more people will pay attention to and participate in sports activities, thereby promoting the growth of the sports and health industry. Meanwhile, the more sports-related patents there are, the more new technologies and materials will be applied to the sports and health industry, further enhancing the competitiveness of the sports and health industry. Model (4) in Table 6 shows that the promoting effect of the digital economy on the sports and health industry still holds true, and the regression coefficient of the digital economy is significant at the 1% level.

#### *Instrumental variable method*

In order to eliminate the influence of the current period and eliminate the endogeneity problem caused by some reverse causal relationships, drawing on relevant research methods, the core explanatory variable digital economic development and all control variables use the values of the lag period<sup>54</sup>. The regression results are shown in Model (5) of Table 6. It can be found that the impact of the digital economy on the sports and health industry remains significantly positive, and the research conclusion remains unchanged.

#### *Heteroscedasticity test*

In this paper, the White test method is adopted to conduct heteroscedasticity tests on the model to further determine whether it has heteroscedasticity. The White test results are shown in Table 7. As shown in Table 7, the adjoint probability of the statistic R2 of the White test is 0.9157, which is significantly higher than the conventional test level of 0.1. Therefore, the null hypothesis of the White test is accepted, and it is considered that there is no heteroscedasticity in the residual sequence of the original equation.

#### *Unit root test and stationarity test*

In the empirical analysis process, to verify the stationarity of the data and prevent the occurrence of “pseudo-regression” in the model, the treatment method for data variables is to conduct a unit root test on the selected

Variable	(1) Shi	(2) Shi	(3) Shi	(4) Shi	(5) Shi
Dig	0.1331*** (7.87)	0.1324*** (7.59)	0.1024* (1.82)	0.1474*** (6.22)	0.0889*** (5.93)
Control variable	NO	YES	YES	YES	YES
Cons	3.8474*** (14.87)	3.6732*** (15.66)	0.7428* (1.87)	2.8389*** (12.35)	2.9894*** (11.88)
Regional	NO	YES	YES	YES	YES
Time	NO	YES	YES	YES	YES
N	3510	3510	1890	3510	3510
R <sup>2</sup>	0.8971	0.8988	0.8475	0.8935	0.8857

**Table 6.** Regression results of robustness test.  $P < 0.1$ ,  $**P < 0.05$ ,  $***P < 0.01$ ; The values in parentheses are the Z-test values.

F-statistic	0.2357	Prob. F	0.9014
R-squared	0.8837	Prob. Chi-squared	0.9157

**Table 7.** White test results.

Variable	(1) Hadri test		(2) LLC test		Stability
	Coefficient	P	Coefficient	P	
Shi	2.4211	0.0000	-2.6714	0.0001	+
Dig	3.8544	0.0001	-3.5521	0.0000	+
Pro	1.2041	0.0000	-3.9801	0.0000	+
LnPgdp	4.2577	0.0002	-2.8514	0.0000	+
Pfdi	0.9985	0.0002	-7.0198	0.0001	+
Fai	5.1143	0.0001	-12.021	0.0002	+
Lntb	4.0987	0.0000	-10.0414	0.0002	+
Lnpeo	3.5710	0.0000	-2.1577	0.0001	+
Gra	3.3607	0.0002	-7.1505	0.0001	+

**Table 8.** Results of unit root test.

Variable	(1) Eastern region	(2) Central region	(3) Western region
Dig	0.2422*** (5.79)	0.1244** (2.74)	0.2044 (0.55)
LnPgdp	0.2247 (0.08)	1.0586 (1.01)	3.8665* (2.67)
Pfdi	-0.0151 (-1.02)	-0.1738 (-1.15)	0.8329 (1.23)
Fai	-0.0881 (-0.12)	0.2247* (1.99)	-1.585 (-1.15)
Lntb	0.1764* (1.99)	4.2442 (1.02)	1.2495 (0.17)
Lnpeo	0.6538 (0.77)	-3.4398* (-2.85)	3.1423* (1.88)
Gra	-1.1314* (-1.82)	11.7674* (2.77)	15.5487 (1.22)
Cons	0.1144* (1.88)	14.2124* (1.77)	2.3470* (2.17)
Regional	YES	YES	YES
Time	YES	YES	YES
N	1183	1521	806
R <sup>2</sup>	0.9658	0.9936	0.9977

**Table 9.** Regression results of heterogeneity analysis. \* $P < 0.1$ , \*\* $P < 0.05$ , \*\*\* $P < 0.01$ ; The values in parentheses are the Z-test values.

variables. The unit root test employs two methods: Hadri test and LLC test (Table 8). Regardless of whether it is the Hadri test or the LLC test, the P-values of all variables are less than 0.05, indicating that the null hypothesis is rejected at the significance level. All variables are stationary sequences and can be directly used for subsequent panel regression analysis without the need for differential or other stabilization processing.

### Heterogeneity analysis

In order to further investigate the regional heterogeneity of the development of the digital economy on the development of the sports and health industry, the eastern, central and western parts of China were classified and compared according to the geographical location of China. The results of models (1), (2) and (3) in Table 9 show that, among the 270 prefecture-level cities in China during the study period, the digital economy in the eastern and central regions can significantly promote the development of the sports and health industry and pass the significance test. From the results of the regression coefficient, it can be seen that the eastern region has the greatest influence level. This is because the eastern region has advantages such as a strong economic development level, complete infrastructure configuration, and huge population resources, which can easily form a powerful “siphon effect”, enabling various production factors of the sports and health industry to rapidly gather in this region, thereby achieving the formation of the sports and health industry chain to a greater extent. This brings about economies of scale and economies of scope. In addition, the economically developed eastern and central regions have attracted the inflow of innovative talents, providing a solid talent foundation for the research and development of sports and health technologies. The western region did not pass the significance test, mainly because the sports health resources and economic development level of the western region did not have the obvious advantages of the eastern and central regions. Moreover, the market size in the western region is relatively small, and the potential of the digital economy has not been fully unleashed. In addition, it is also

possible that the development of digital economy in the western region has a lagging effect on the promotion of the sports and health industry, which further verifies hypothesis H3.

## Conclusion and discussion

### Conclusion

This study progressively builds an assessment index system for the development levels of the digital economy and the sports and health business, based on an analysis of the theoretical mechanisms via which the latter supports the former's growth. The development levels of the digital economy and sports and health are then measured using the entropy method and the coupled coordination model, respectively. The direct effects and transmission mechanisms of the digital economy on the growth of the sports and health sectors are then empirically examined. The following are the primary conclusions: (1) The sports and health sectors benefit greatly from the digital economy. Results from the robustness and endogeneity tests were both statistically significant and in agreement with the benchmark test. (2) The cost-saving effect is a significant transmission mechanism for the digital economy to support the growth of the sports and health sector, and it partially mediates this process, according to the mediating effect test. (3) The role that the digital economy plays in fostering the growth of the sports and health sectors varies significantly by region. While the western region has failed the significance test, the eastern and central regions are more affected. This is mostly because of the impact of the amount of per capita consumption and regional economic development.

### Policy recommendations

This study demonstrated regional variability and validated the direct promotion effect of the digital economy on the sports and health industries as well as the transmission mechanism of the cost reduction path. Based on this, a sustainable enabling ecosystem must be constructed in the future from the standpoint of multi-body cooperation between the government, businesses, and consumers, in addition to regional development disparities.

At the macro level, the government needs to strengthen top-level design and institutional supply. It is evident from the aforementioned regression coefficients that the digital economy has an impact coefficient of 0.1733 on the sports and health sector. Although the benefits of digital technology are not well established, there is a great deal of room for future advancement. Furthermore, government agencies including the Ministry of Finance, the General Administration of Sport of China, and the National Development and Reform Commission should be in charge of the digital economy's development because of its strategic significance and technical complexity. The optimization of the governance framework and the balanced arrangement of digital infrastructure should be the main priorities of a five-year plan cycle. Given its strong economic foundation, the eastern region should expedite the construction of new infrastructure, including 5G and AI computing power centers, before 2030, according to the regional heterogeneity results of the eastern region (impact coefficient of 0.2422), central region (impact coefficient of 0.1244), and western region (insignificant impact coefficient of 0.2044). In the meantime, efforts will be made to support the pilot projects of "sports health - digital economy" industrial clusters in areas like the Yangtze River Delta and the Pearl River Delta by establishing goals for the regional coordination mechanism. The central and western regions should make up for the shortcomings of digital infrastructure through special transfer payments and increased financing from financial institutions, and give priority to the layout of inclusive projects such as smart sports parks and remote health management. At the same time, it is necessary to improve the rules for the circulation of data elements, establish classification and grading standards for sports and health data (such as exercise behavior data and health record data), promote cross-regional interconnection of government and enterprise data sharing platforms, and break the constraints of "data silos" on industrial collaboration.

At the meso-level, enterprises need to deepen technological innovation and the integration of business forms. Based on the empirical results mentioned above, the key to the digital transformation of the sports and health industry lies in the product technological innovation of sports and health-related enterprises, which helps to reduce the production costs of sports and health enterprises and form economies of scale. Therefore, on the one hand, sports equipment manufacturers should be encouraged to use electronic payment and financial innovation to reduce transaction costs and enhance financial inclusion. It should be noted that during this process, the sports and health industry association needs to implement financial supervision to ensure the stability of the financial system. On the other hand, it is advocated that sports and health enterprises, universities and research institutions establish public platforms for obtaining sports and health data technology, pay attention to the technological improvement of big data cleaning and obtaining effective information for enterprises and individuals, and reduce the transportation cost of information "icebergs" for cross-regional transportation of sports and health products and services.

At the micro level, consumers need to enhance their digital literacy and depth of participation. Consumers are both drivers of demand and providers of data elements. It is necessary to enhance users' operational capabilities of intelligent sports equipment and online health management tools through digital skills training and lower the threshold for the use of technology. At the same time, by leveraging blockchain technology, a mechanism for confirming rights to personal health data and distributing benefits is established to encourage consumers to actively share their sports and health data, promoting the formation of a positive cycle of "data contribution - service optimization - experience improvement". In addition, it is necessary to guide the public to form a digital healthy lifestyle through community education, such as using social platforms to build sports check-in communities to enhance behavioral stickiness.

Lastly, there are certain research limitations with this study. The following are the primary issues: The linear interpolation method, which has significant drawbacks, is used to supplement some missing data because research data availability is generally challenging. Furthermore, the development of the assessment index system

lacks micro-regional practices and mostly draws from the researchers' own experiences as well as references to earlier practices. It is anticipated that as research continues to advance, more precise and methodical approaches to indication selection will be possible to investigate in the future. Further research can be done on the rule-building problem of digital sports service commerce in the context of globalization, as well as the reshaping mechanism of the health sector ecosystem by emerging technologies like the metaverse and generative AI.

## Data availability

The dataset used in this study is available from the corresponding author upon request.

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## Author contributions

H.S.: Writing-review and editing, writing-original draft, visualization, resources, methodology, investigation, data curation. M.C.: Writing-original draft, project administration, methodology, investigation, writing-review and editing. F.J.: Writing-review and editing, formal analysis, investigation.

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## Declarations

## Competing interests

The authors declare no competing interests.

## Additional information

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