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Article

Does the digital economy promote the green total factor productivity of the sporting goods manufacturing industry? Province-level evidence from China

Xiao Yang*, Zhengfa Sheng[1]

International College, Krirk University, Bangkok 10220, Thailand
*** Corresponding author:** Xiao Yang, yyhzai1@163.com

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Abstract: Based on digital technology, the digital economy has typical characteristics of high efficiency, greenness, intelligence, innovation, strong penetration and so on, which can promote the sporting goods manufacturing industry (SGMI) to realize the goal of green development. This study selects panel data from 30 provinces in China over the period of 2011 to 2022. And the green total factor productivity of the sporting goods manufacturing industry (SGTFP) is used to reflect the green development of SGMI. The level of digital economy development (DIG) and the SGTFP are measured by using the entropy method and the Super-SBM model with undesirable outputs. Based on the method of coupling coordination degree model, the coordinated development degree of DIG and SGTFP is analyzed first. Then, by making use of the fixed effect model, intermediary effect model and spatial Durbin model, the influence of DIG on the green development of SGMI and its mechanism are empirically studied. The results show that DIG, SGTFP and the degree of their coupling and coordination are generally on the rise. The benchmark regression results show that the coefficient of DIG on SGTFP is 0.213; that is, the digital economy can significantly promote the improvement of green development in SGMI. According to the analysis of the spatial Durbin model, the impact of the digital economy on SGTFP has a certain spatial spillover, that is, the development of digital economy in the region will have a certain promoting effect on the green development of SGMI in the surrounding region. The intermediary effect model analyzes the influence mechanism and finds that the digital economy mainly boosts SGTFP through green innovation technology and energy consumption structure.

Keywords: digital economy; the green total factor productivity; the sporting goods manufacturing industry; fixed effect model; intermediary effect model; coupling cooperation degree model

1. Introduction

Green development is a comprehensive and sustainable process of economic, social, and natural systems, in which the effective and efficient development of the economic system fundamentally relies on green growth. That is, production and consumption have the characteristics of low material consumption and low emissions, and realize the decoupling of economic growth and energy and resource consumption (Wang et al., 2022). Green development emphasizes the adjustment of the relationship between man and the natural environment. It is not a problem-oriented end treatment, nor is it the adjustment of a certain link of the industrial chain. It is the control of the entire process from production to consumption (Dong, 2022), so it is an inevitable requirement for promoting the transformation of the national economy from extensive development to intensive development.

In recent years, as a happy, healthy and green industry, the sporting goods manufacturing industry (SGMI) has developed more and more vigorously in the context of meeting the needs of people's better life, with steady growth rate, continuous optimization of industrial structure, more reasonable industrial layout, and diversified consumption formats. And green development has become a grand new trend for SGMI development all over the world (Wei et al., 2023). While promoting industrial growth, the green development of SGMI should constantly strengthen the control of the whole process of sports products from production to consumption, make full use of technological innovation and compensation measures, and make every effort to bring down the energy consumption, material consumption, and CO_2 emissions in the sports manufacturing and sports service industries. Under the goal of "double carbon", accelerating the green development of SGMI has practical significance to promote the adjustment of industrial structure. The Opinions of the State Council in China point out that it is of great important to improve the strategy driven by scientific and technological innovation, promoting the constructing of sports brands, developing high-tech sports products, and increasing the added value of sports products (Ouyang, 2024; Ren and Huang, 2022). The deep integration of green and intelligent technology into the whole industry chain of SGMI and the overall transformation effect of the digital economy enabling SGMI have practical significance for driving the intelligent and green development of SGMI.

In 2023, China's State Council proposed that guided by energy conservation and carbon reduction, product renewal and recycling should be jointly promoted to provide strong support for the "double carbon" target. Under the reverse effect of the "double carbon" target, SGMI urgently needs to achieve high-quality development of the industry by reducing energy consumption and reducing pollutant emissions. The green and intelligent technology is deeply integrated into the whole sporting goods industry chain, and the digital economy enables the overall transformation effect of the sporting goods industry has practical significance for driving the intelligent and green development of SGMI.

Since the reform and opening up for more than 40 years, the overall output of China's SGMI is large, but the competitiveness is not strong, and most of the sporting goods manufacturing enterprises are still in the low-end link of the industrial chain. Under the constraints of the "double carbon" goal, China's SGMI urgently needs to change the development model of relying on factors such as cheap labor, resources and land to become a global brand enterprise processing plant. The digital economy based on digital information has the advantages of low marginal cost, less resource consumption, sensitive to the market, strong innovation ability, and sharing, which is in line with the new development concept and is conducive to promoting the green development of the SGMI. In recent years, with the development of the Internet, big data and intelligent technology, China's SGMI began to gradually use big data to create a green development cycle system between enterprises, on the one hand, improve the production efficiency of enterprises, reduce the production of low added value and high energy consumption products, and accelerate the green transformation of sporting goods manufacturing. On the other hand, it promotes the high-end development of the SGMI.

With the in-depth mining of digital technology, the integration of digital economy and real economy has become an important driving method for high-level and high-quality economic development. The "dividend" effect generated by the green transformation of the sports industry driven by the digital economy has gradually attracted the attention of the academic community, which is generally summarized in three aspects: (1) From the perspective of the research mechanism, the digital economy enables the green development of the sports industry by optimizing the industrial structure, improving the allocation of factors, enhancing innovation and digital governance, and helps the intelligent and green development of sports goods enterprises by strengthening technological innovation such as production, circulation and sales (Ruan et al., 2022). The mechanism is summarized as follows: promote the green design and development of sporting goods by systematic optimization of enterprises, reduce manufacturing costs and pay attention to the use of cyclical resources, promote the green production process of sporting goods by optimizing production technology with digital technology, promote the green sporting goods industry chain with accurate matching of supply and demand information, and promote the green recycling of sporting goods by building a waste recycling system. (2) From the perspective of research factors, the SGMI chain turns the "manufacturing" of sporting goods to "intelligent manufacturing" by accelerating the development of digital technology, realizing the elimination of backward production capacity, optimizing the energy consumption structure and carbon emission reduction, optimizing the industrial structure, reducing resource waste and improving resource concentration through innovative science and technology, improving the urban economic level and urbanization level and other factors. To achieve the purpose of reducing the transaction cost of innovative subjects, stimulating regional innovation vitality and improving the breadth of digital coverage, and then improve the operation quality and green development efficiency of sporting goods manufacturing enterprises. (3) From the perspective of research methods, by referring to relevant literature, most scholars use models such as space spillover and Vector Autoregression models, or based on theories such as Theory of Planned Behavior and impulse response function, to quantitatively or qualitatively analyse the positive impact of green innovation on the growth of SGMI, and the willingness of green technology innovation actors and other influencing factors (Wang et al., 2022; Pei et al., 2018). And using spatial Durbin, spatial lag and other models to clarify the geographical location, population size and other factors have enhanced the space spillover effect of the digital economy on driving the green development of industries (Pan et al., 2021).

To sum up, there are abundant literatures on the digital economy empowering China's manufacturing and industrial green development, but there are few researches on the impact of the digital economy (DIG) on the green total factor productivity of the sporting goods manufacturing industry (SGTFP) in the existing literatures, and the coordination between the two is ignored. In addition, the impact mechanism of DIG on SGTFP needs to be further explored. Based on this, this paper aims to discuss the impact of DIG on SGTFP and its mechanism. Contributions of this study are presented as follows: (1) the level of DIG and SGTFP of 30 provinces in China over the period of 2011 to 2022 are calculated, and the coordination degree between the two is measured with the coupling cooperation degree model, in order to reflect the coordination relationship between DIG and SGTFP; (2) the direct impact and spillover effects of DIG on SGTFP are analyzed by using fixed effect model and spatial Durbin model, in order to provide implications for SGTFP and expand the research framework of digital economy effect; (3) the mediation effect model is used to test the impact mechanism of DIG on SGTFP, and to reveal the intermediary role of green technology innovation capability (GRE) and energy consumption structure (ENG) in the process of digital economy affecting the green development of SGMI.

2. Theoretical analysis

2.1. Direct effect of the DIG on the SGTFP

With the rapid development of DIG, the integration of digital technology and the real economy is accelerating, which also provides impetus for the transformation and upgrading of the traditional SGMI. Additionally, a number of new services, new formats and new models have emerged, laying a solid foundation for the formation of a modern SGMI system. Besides, with its special technical attributes, strong network effect and other advantages, DIG can not only generate a technology spillover impact on the traditional SGMI, but also restrain the negative effect brought by the impact of technology to stimulate the digital upgrading and transformation of the traditional SGMI. At the same time, application of digital technology in traditional SGMI will greatly reduce the intensity of energy consumption, and promote energy conservation and ultimately promote the green development of SGMI. On the other hand, information technology innovation promotes the effective integration of all kinds of information flows, alleviates the problem of information asymmetry, guides the efficient allocation of resources, promotes the green transformation of SGMI, and thus improves the SGTFP. The internal mechanism of how the digital economy drives the green development of SGMI is reflected in the following three aspects:

First, changes in the allocation of production factors. Production factor allocation refers to the process of reasonable allocation of various production factors such as labor, land, capital, data and technology among different industries and sectors (Huang and Zhang, 2022; Li, 2021; Shen, 2022). On the one hand, from the perspective of market communication, with new models such as "urban sharing economy" and "intelligent manufacturing" blooming, special attributes such as aesthetics and comfort of sporting goods, relying on digital technology, are integrated into the process of material selection, product research and development, so that information islands are transformed into information collaborative management (Han and Liu, 2022). From the perspective of top-level supervision, digital technology has opened up the traditional regulatory channels of elements (Hyysalo, 2009) and transformed the traditional government-led regulatory form into a multi-directional regulatory model of government, society and enterprises, greatly strengthening the awareness of corporate environmental responsibility. On the other hand, the use of digital technology means to establish a "cloud production line" to monitor, manage and evaluate the environmental conditions in the allocation process of sporting goods production factors (Wang et al., 2022). Sporting goods manufacturers can obtain real-time data in the production—distribution and exchange—consumption process based on digital technology, and use intelligent and precise characteristics to build sporting goods energy consumption analysis model and energy management system. Second, it promotes the innovation and optimization of the industrial structure. On the one hand, from the perspective of the supply design-service structure, the digital economy is deeply integrated in the industrial structure process of sporting goods design and research and development, material procurement and manufacturing, brand operation and promotion, product wholesale and retail and after-sales service, and so on. It changes the organizational form of the traditional SGMI, and realizes the digital and green development of the whole process from design and research and development to after-sales service (Chai, 2021). Shorten the production cycle of sporting goods, extend the life cycle of sporting goods, and constantly optimize product circulation channels. On the other hand, from the perspective of human capital structure, the scale efficiency and technical efficiency brought by personnel flow under traditional conditions are low, and the technological innovation brought by the digital economy will replace the traditional inefficient and low-quality production work, promote more professional sporting goods manufacturing technicians and R&D personnel to enter the digital emerging field, and help the enterprise's internal clean production and pollution control technology accumulation. Provide manpower support for enterprises to save energy, reduce emissions and develop green economy. Third, digital governance is pioneering and leading. The openness of traditional government information is facing a new situation of order reform, system reshaping and power transformation, timely promoting the deep integration of digital technology into the modern governance system, and promoting the efficient supply and demand docking of sports products and services. In addition, a large number of new formats and models such as sports entertainment and sporting goods fairs have emerged, extending the social relationship between enterprises and consumer individuals, and expanding the digital governance objects, governance structures, and governance methods. Digital governance relies on sensors and governance platforms to collect data on the ecological chain of the SGMI, such as waste emissions, water consumption and energy consumption. Digital governance technology can trace the entire process of the SGMI from the purchase of raw materials to production and then to scrap through the construction of a controllable sporting goods ecological governance platform, and realize the green development of the SGMI from the bottom.

So, Hypothesis H1 is put forward as follows: DIG has a positive role in promoting SGTFP.

2.2. Mediating effect of DIG on enhancing SGTFP

The purpose of green technology application is to reduce environmental impact or improve environmental quality through technical means. Sports manufacturing enterprises and sports service enterprises can integrate digital economy and green technology to establish environmental monitoring and early warning system, renewable energy intelligent management system, ecological smart city system and circular economy system to achieve green transformation of SGMI (Shen et al., 2020). Digitalization has innovated resource utilization technology, effectively improved the utilization efficiency of production factors in sports event venues and sports manufacturing enterprises, and comprehensively reduced production energy consumption. At the same time, relying on 5G and Internet technology, open industrial information and data sharing, generate knowledge spillover effect, and promote the green development of SGMI (Li, 2021).

As discussed above, Hypothesis H2 is proposed: DIG can promote SGTFP by enhancing green technology innovation ability.

With the development of digital economy, clean energy is more competitive in the market, and digital technology helps sporting goods manufacturing enterprises to accurately manage and monitor the production process, reduce the proportion of fossil energy consumption, improve energy utilization efficiency and optimize the energy consumption structure, and realize the fine management of energy. From the perspective of the production and consumption side of the SGMI, digital technology is integrated in the material selection, research and development design and other stages, and green materials such as bioplastics and natural fibers are selected through virtual screening, data simulation and other means to reduce the comprehensive utilization of harmful adhesives, coal and other fossil fuels (Lin, 2022). In the stages of goods transportation and product exchange, electronic data exchange technology is integrated to obtain sports goods transportation routes, identify and analyse logistics channels with high transportation efficiency in advance, improve the visualization of transportation process, reduce vehicle exhaust and other waste emissions to optimize the energy structure of sports goods transport-exchange. In the stages of product consumption and waste recycling, we integrate electronic money circulation channels and customer relationship management systems to establish data stores, and provide online second-hand markets and recycling markets, so that products can go back and forth from where to achieve the upgrading of the energy structure at the end of sporting goods consumption and recycling.

Based on this, the research hypothesis H3 is proposed: DIG can help the green development of SGMI by optimizing the energy consumption structure.

2.3. Spillover effect of DIG on SGTFP

One of the most significant features of the digital economy is that it realizes the efficient transmission of information and compresses the distance of space and time, strengthens the spatio-temporal compressibility and dynamic interaction of regional economic network space. Regional economic activities have obvious spatial correlation. Cui and Li (2019) used provincial panel data to demonstrate the spatial spillover effect of China’s Internet development. Furthermore, Yang and Jiang (2021) illustrated the spatial spillover effect of the digital economy on regional total factor productivity. In addition, some scholars have tested the spatial spillover effect of DIG on high-quality urban development and regional innovation performance (Cui and Wu, 2024). Therefore, it is also possible that the development of DIG in a region will boost the green development of SGMI in its neighbouring regions.

As discussed above, Hypothesis H4 is put forward as follows: DIG has a spatial spillover effect on SGTFP of its neighbouring regions.

3. Materials and methods

3.1. The super-efficiency SBM model

In this study, the green development level of SGMI is reflected by SGTFP. In this paper, the Super-SBM model with undesirable output is used to calculate the SGTFP for the following two reasons: First, in the output process, the productive sports service industry is deeply related to high-carbon emission industries such as warehousing and logistics, which is linked to the large consumption of resources and energy closely (Wang et al., 2022). These will have a severe negative effect on the environment. Therefore, these negative outputs should also be considered when considering the output of SGMI. Second, in the ordinary SBM model, a decision-making unit (DMU) with an efficiency level of more than 1 and a DMU with an efficiency level of exactly 1 is assigned a value of 1, making it impossible to distinguish between a DMU with an efficiency value of over 1 and a DMU with an efficiency value of 1 (Fare et al., 1994). However, the super-SBM model with undesirable output directly includes the relaxation variable into the objective function, effectively avoiding the above problems (Rosamo, et al., 2018).

The basic principle is as follows: suppose that there are *n* DMUs in the production process of SGMI, and each DMU is composed of an input vector, a desirable output and an undesirable output (Tone, 2002). Three sets of vectors

$$(x \in R^m, y^\varepsilon \in R^a \text{ and } y^f \in R^b)$$

are used to represent input, desirable output and undesirable output respectively, where *m* represents *m* types of input factors, *a* represents the desirable output of a types and *b* represents undesirable output of *b* types.

If the matrix is defined as

$$X = [x_1,\cdots\cdots,x_n] \in R^{m\times n}, Y^\varepsilon = [y_1^\varepsilon,\cdots\cdots,y_n^\varepsilon] \in R^{a\times n} \text{and} Y^f = [y_1^f,\cdots\cdots,y_n^f] \in R^{b\times n}$$

then model with undesirable output is:

$$\begin{cases} and\ \rho^* = min \dfrac{1 + \frac{1}{m}\sum_{i=1}^{m}\frac{D_i^-}{x_{ik}}}{1 - \frac{1}{a+b}\left(\sum_{r=1}^{a}\frac{D_r^e}{y_{rk}^e} + \sum_{h=1}^{b}\frac{D_h^f}{y_{hk}^f}\right)} \\ and\ s.t. \displaystyle\sum_{j=1,j\neq k}^{n} x_{ij}\lambda_j \le x_{ik} + D_i^- \\ and \displaystyle\sum_{j=1,j\neq k}^{n} y_{rj}^e\lambda_j \ge y_{rk}^e - D_r^e \\ and \displaystyle\sum_{j=1,j\neq k}^{b} y_{hj}^f\lambda_j \le y_{hk}^f + D_h^f \\ and\ 1 - \dfrac{1}{a+b}\left(\displaystyle\sum_{r=1}^{a}\frac{D_r^e}{y_{rk}^e} + \sum_{h=1}^{b}\frac{D_h^f}{y_{hk}^f}\right) > 0 \\ and\ D^- \ge 0, D^e \ge 0, D^f \ge 0 \end{cases} \tag{1}$$

3.2. Entropy evaluation method

In the practice of comprehensive evaluation method, there are many evaluation methods. According to the different weights determined, there are subjective weighted evaluation methods and objective weighted evaluation method. Objective weighted evaluation method can objectively and accurately evaluate the research object, because it determines the weight value through the principle of information entropy (Yin and Yu, 2022), so this paper also adopts objective weighted method to calculate the weight of each index. The evaluation model of improved entropy method is as follows:

1) Index selection: With r years, n provinces, and m indicators, $x_{\theta ij}$ is the *jth* index value of province *i* in θth year.

2) Standardization of indicators: Because different indicators have different dimensions and units, it is necessary to standardize:

The positive index standardization: $x'_{\theta ij} = x_{\theta ij}/x_{max}$

The negative index standardization: $x'_{\theta ij} = x\theta ij_{min}$

3) Determine index weight: $y_{\theta ij} = x'_{\theta ij}/\sum_{\theta}\sum_{i} x'_{\theta ij}$

4) Calculate the entropy of the *jth* index: $e_j = -k\sum_{e}\sum_{i} y_{ij}\ \text{In}(y_{\theta ij})\,, k > 0, k = \text{In}(rn)$

5) Calculate the weight of each indicator: $w_j = g_j/\sum_j g_j$

6) Calculate the comprehensive score of the DIG of each province: $DIG_{\theta i} = \sum_i (w_j x'_{\theta ij})$

3.3. Variable selection

3.3.1. Explained variable

In this paper, SGTFP is the explained variable. The non-angular, non-radial super-SBM model with constant returns to scale was used to estimate SGTFP. Compared with the traditional DEA model, the super-SBM model can avoid the problems of variable relaxation and radial measurement errors. Indicators should be selected for the super-SBM model. Input indicators of SGMI mainly include capital input indicator, labor input and energy input (Chen, 2019). Capital input can be represented by the total sporting goods manufacturing assets. Labor input reflected by the average employment in the SGMI. Energy input can be reflected by the ratio of energy consumption to the finished product. Desirable output indicators include the economic benefit indicator and environmental benefit indicator. Economic benefit can be reflected by the main business income of sports goods manufacturing and the total profit of SGMI. Environmental benefitcan be replected by the ratio of Areen cover area to the total assets. Undesirable output can be reflected by the negative economic output and the environmental negative output. And the negative economic output is reflected by the ratio of fiscal expenditure on energy conservation to the income from main business. Environmental negative output is reflected by 4 indicators, which are the ratio of SO_2 emissions to the main business income of industrial enterprises above designated size, the ratio of the urban wastewater discharge to the main business income, the smoke and dust emissions of industrial enterprises above designated size/main income and the ratio of the solid waste discharge to the main income of industrial enterprises above designated size. All indicators are given in **Table 1**.

Table 1. Indicators of SGTFP.

Variables	Primary index	Secondary index	Data source
Input indicators	Capital input	Total sporting goods manufacturing assets	China Industrial Statistics Yearbook
	Labor input	Average employment in the SGMI	China Industrial Statistics Yearbook
	Energy input	Energy consumption/finished goods	China Energy statistical Database
Desirable output indicators	economic benefit	Main business income of sports goods manufacturing	China macroeconomic statistics database
		Total profit of SGMI	China Economic Census Statistical Yearbook
	environmental benefit	Green cover area/total assets	China Environmental Statistical Yearbook
Undesirable output indicators	Negative economic output	Fiscal expenditure on energy conservation/income from main business	China Statistical Yearbook
	Environmental negative output	SO_2 emissions/Main business income of industrial enterprises above designated size	China Industrial Statistics Yearbook
		Urban wastewater discharge/main business income	China Environmental Statistical Yearbook
		Smoke and dust emissions of industrial enterprises above designated size/main income	China Industrial Statistics Yearbook
		Solid waste discharge/main income of industrial enterprises above designated size	China Industrial Statistics Yearbook

3.3.2. Explanatory variable

DIG is the core explanatory variable in this study. Based on the practice of Lu and Ren (2022) and other scholars, this paper constructs three first-level indicators of digital economy development carrier, digital industry and industrial digitalization (**Table 2**), and comprehensively evaluates the DIG in 30 provinces from 2011 to 2022 by using entropy method.

Table 2. Measurement index system of DIG level.

Primary indicators	Secondary indicators	Tertiary indicators
Digital economy development carrier	Digital infrastructure	Number of Internet domain names
		Optical cable line length
		Mobile phone base station
Digital industry	Digital service	Telecommunications business as a percentage of GDP
		Software revenue as a percentage of GDP
Industrial digitization	Innovative development	The R&D expenditure of industrial enterprises above designated size accounted for the GDP of the region
		R&D personnel of industrial enterprises above designated size are equivalent in time
		Mobile phone penetration
		Number of patent applications

3.3.3. Mediating variables

In this study, green technology innovation capability (GRE) and energy consumption structure (ENG) were used as mediating variables. Green technology innovation ability, according to the green and low-carbon technology patent classification system (State Intellectual Property Office, 2023), patent types are divided into design, invention and utility model patents, taking into account the time lag of patent applications, the number of green patents obtained and the proportion of green patent applications are adopted as the measurement index of green technology innovation ability of SGMI (Yuan et al., 2023). Energy consumption structure (ENG), the optimization of energy consumption structure is a key step to ensure energy conservation and emission reduction of sporting goods manufacturing enterprises (Yin and Yu, 2022). The energy consumption structure is usually reflected by selecting the proportion of a certain type of energy consumption in the total energy consumption of the current period, and the proportion of coal consumption and total energy consumption is used to characterize the energy consumption structure of SGMI by referring to Chai et al. (2021).

3.3.4. Control variables

The control variables are selected as following: (1) the economic development level (*Pgdp*), reflected by the logarithm of per capita GDP (Ouyang et al., 2024); (2) the industrial structure (*Str*), represented by the ratio of the value added of the tertiary industry to that of the secondary industry (Li and Liu, 2021); (3) the urbanization level (*Urb*), represented by urban population density; (4) foreign direct investment (*Fdi*), expressed by the proportion of foreign direct investment to GDP in the current year (Xu and Hou, 2012); and (5) environmental regulation (*Env*), expressed by the comprehensive utilization rate of general industrial solid waste as a proxy variable (Yuan et al., 2023).

3.4. Model elaboration

3.4.1. Coupling cooperation degree model

The coupling coordination degree model is often used to analyze the degree of cooperation among multiple interacting subsystems to realize the efficient operation of the whole system (Wang et al., 2024). The development level of China's digital economy and SGTFP are affected by development orientation, resource allocation and other factors, and there are large regional differences. Therefore, the coupling coordination degree model is used to analyze the coordinated development of the two. The coupling coordination degree model established is as follows:

$$C = \sqrt[2]{\frac{DIG \cdot SGTFP}{(DIG + SGTFP)^2}} \tag{2}$$

$$U = \sqrt{C \cdot D} \tag{3}$$

$$D = \beta \cdot DIG + \gamma \cdot SGTFP \tag{4}$$

In Equation (2), C is the coupling degree. Referring to other researches, let $\beta = \gamma = 0.5$. The evaluation criterion of coupling coordination is shown in **Table 3**.

Table 3. Evaluation criteria of coupling coordination degree.

Coordination degree interval	Coordination state type	Coordination degree interval	Coordination state type
(0,0.200]	Very low coordination	(0.500,0.600]	Primary coordination
(0.200,0.300]	Low coordination	(0.600,0.700]	Intermediate coordination
(0.300,0.400]	Low-to-medium coordination	(0.700,0.800]	Good coordination
(0.400,0.500]	Narrowly coordination	(0.800,1)	Quality coordination

3.4.2. Fixed effect model

This paper uses provincial panel data to demonstrate the direct impact of digital economy driving SGD. The model is set as Equation (5):

$$SGTFP_{it} = \alpha_0 + \beta_1 DIG_{it} + \sum_{k=1}^{n} \lambda_k Col_{it,k} + \mu_i + \upsilon_t + \xi_{it} \tag{5}$$

In Equation (5), $SGTFP_{it}$ is the explained variable, DIG_{it} is the explanatory variable, and $Col_{it,k}$ is the control variable.

3.4.3. The mediating effect model

According to hypothesis H2 and hypothesis H3, DIG promotes the green development of SGMI through green innovation technology and energy consumption structure. With reference to relevant studies, an intermediary effect model is established to test the impact mechanism of the digital economy on SGTFP.

$$Med_{it} = \lambda_0 + \lambda_1 DIG_{it} + \lambda_2 Col_{it} + u_i + \nu_t + \xi_{it} \tag{6}$$

$$SGTFP_{it} = \eta_0 + \eta_1 DIG_{it} + \eta_2 Med_{it} + \eta_3 Col_{it} + u_i + \nu_t + \xi_{it} \tag{7}$$

Equation (6) represents the impact of digital economy on intermediary variables, and Equation (7) represents the impact of digital economy and intermediary variables on SGTFP.

3.4.4. The spatial Durbin model

Considering that the regional digital economy and SGTFP may have strong spatial dependence, the spatial econometric model is used to estimate. If both spatial autoregressive and spatial errors exist, spatial Durbin model can be used to explain them (Anselin, 2008). Considering the spatial correlation between digital economy and SGTFP, the spatial Durbin model is used here for estimation (Equation (8)):

$$SGTFP_{it} = \alpha_0 + \rho \sum_{j=1}^{n} W_{ij}\, SGTFP_{jt} + \beta X_{it} + \theta \sum_{j=1}^{n} W_{ij}\, X_{jt} + \varphi Col_{it} + \phi \sum_{j=1}^{n} W_{ij}\, Col_{jt} + \upsilon_t + \varepsilon_{it} \tag{8}$$

In Equation (8), W_{ij} is the spatial weight matrix; ρ is the spatial correlation coefficient. W_{ij} is characterized by the reciprocal of the geographical distance between 30 provinces in our country. The geographical distance is obtained by calculating the longitude and latitude coordinates of China's provinces.

3.5. Data sources

Considering the systematic nature of indicators and the availability of data, this paper conducts quantitative analysis based on the panel data of 30 provinces and cities (autonomous regions) in China from 2011 to 2022. Due to the lack of data in Tibet Autonomous Region, Hong Kong, Macao and Taiwan, this paper does not include the data of these provinces in the empirical analysis. The data mainly come from EPS database, China Regional Economy Database, China Macroeconomic Data Platform, Peking University Digital Financial Inclusion Index, etc. For some missing data, interpolation method is used to complete. SPSS and R language software were used for data analysis.

4. Results and discussion

4.1. Results of coupling cooperation degree measurement

First, at the national level, the degree of coupling coordination between DIG and SGTFP increased year by year during the study period, from a serious mismatch in 2011 to a good coordination in 2022. Secondly, from the perspective of regional division, the eastern region took the lead in entering the intermediate coordination stage in 2014, the central region entered the intermediate coordination stage in 2015, and the western region entered the intermediate coordination stage in 2016. By 2022, Beijing, Tianjin and Shanghai will enter the development stage of Quality coordination, and the coupling coordination degree will reach 0.854, 0.803 and 0.861; 10 provinces, including Shandong, Guangdong and Zhejiang, will enter the stage of good coordination; 15 provinces, including Henan and Hebei, will be in the intermediate coordination association. Gansu and Qinghai provinces are in the primary coordination stage (**Table 4**). It further indicates that the coordinated development of China's digital economy and the green development of SGMI are getting better.

Table 4. Coordination degree of SGTFP and DIG by provinces in 2022.

Province	*D* value	Coordination degree	Province	D value	Coordination degree
Beijing	0.853	Quality coordination	Chongqing	0.732	Good coordination
Tianjin	0.812	Quality coordination	Guangxi	0.674	Intermediate coordination
Shanghai	0.866	Quality coordination	Guizhou	0.661	Intermediate coordination
Anhui	0.754	Good coordination	Neimenggu	0.656	Intermediate coordination
Jiangxi	0.731	Good coordination	Ningxia	0.643	Intermediate coordination
Henan	0.698	Intermediate coordination	Shannxi	0.642	Intermediate coordination
Hunan	0.721	Good coordination	Yunnan	0.642	Intermediate coordination
Hubei	0.671	Intermediate coordination	Xinjiang	0.641	Intermediate coordination
Shanxi	0.654	Intermediate coordination	Gansu	0.634	Intermediate coordination
Sichuang	0.739	Good coordination	Qinghai	0.624	Intermediate coordination
Zhejiang	0.791	Good coordination	Guangdong	0.761	Intermediate coordination
Jiangsu	0.762	Good coordination	Hebei	0.639	Intermediate coordination
Shandong	0.753	Good coordination	Jilin	0.665	Intermediate coordination
Fujian	0.710	Good coordination	Heilongjiang	0.576	Primary coordination
Hainan	0.664	Intermediate coordination	Liaoning	0.575	Primary coordination

4.2. Results of the benchmarking regression model

First, the stationarity test is carried out on the panel data. All variables reject the null hypothesis of unit root, and the panel data has good stationarity. Then the model setting test is carried out. The F-test results of panel setting all show that the fixed effect is more suitable. The regression results of DIG on SGTFP are as follows (**Table 5**), and column (1) contains only DIG. The results show that DIG has a significant positive effect on SGTFP, and the regression coefficient is positive and significant at 5% confidence level. Control variables were gradually added into columns (2)–(6), and the coefficient size and significance level of DIG did not change significantly compared with column (1), indicating that DIG had a relatively robust effect on SGTFP. Hypothesis H1 is verified, that is, the digital economy is conducive to promoting the green development of SGMI.

Table 5. Benchmark regression results.

Variables	SGTFP					
	model (1)	**model (2)**	**model (3)**	**model (4)**	**model (5)**	**model (6)**
DIG	0.308** (2.579)	0.273** (2.760)	0.251** (3.111)	0.244** (2.621)	0.226** (2.875)	0.213** (3.116)
Pgdp		0.243*** (3.710)	0.216** (2.998)	0.209*** (3.432)	0.184*** (2.754)	0.157*** (3.276)
Str			0.051 (1.760)	0.049 (1.343)	0.040 (1.070)	0.033 (1.125)
Urb				−0.091* (−1.975)	−0.086* (−2.105)	−0.071* (−2.164)
Fdi					0.099 (0.961)	0.083 (1.060)
Env						0.106*** (3.604)
N	360	360	360	360	360	360
Constant	−0.008 (−0.579)	−0.073** (−2.613)	−0.651 (−0.111)	−0.244 (−1.621)	−0.826** (−2.875)	−0.135* (−2.116)
Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Province fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Adj. R^2	0.655	0.658	0.664	0.668	0.671	0.674

Note: *, **, and *** respectively denote significant at confidence levels of 10%, 5%, and 1%.

In model (6), the regression coefficient of Pgdp on SGTFP is significantly positive, indicating that economic growth can effectively promote the green development of SGMI. That is, the higher the degree of economic development is, the stronger the green development ability of SGMI. The regression coefficient of Str on SGTFP is positive but not significant. That is, the current industrial structure does not have a significant impact on the green development of sports goods, indicating that the internal structure of the secondary and tertiary industries needs to be further optimized, and a modern industrial pattern with a reasonable layout and ecological environment friendliness has not yet been formed. The regression coefficient of Urb on SGTFP is negative and not significant. The rapid and extensive urbanization mode leads to an expansion of urban land and population scale, causing problems such as resource and environmental damage, which hinders the improvement of the green development ability of SGMI. At the same time, the regression coefficient of *Fdi* on SGTFP is positive but not significant. The regression coefficients of *Env* on the SGTFP are significant positive. The increased intensity of environmental regulations also forces enterprises to reduce pollutant emissions of sports industrial production processes.

4.3. Results of the spatial Durbin model

By calculating the spatial Moran'I index of SGTFP and DIG in each province, it can be seen that the green development of China's SGMI and digital economy both have a significant spatial correlation respectively, and the spatial distribution is clustered. Therefore, the spatial Durbin model is used to estimate, and the regression analysis results show that the impact coefficient of digital economy on SGTFP in the region is 0.208 (significantly positive), indicating that DIG has a positive role in promoting SGTFP in the region. The W × DIG regression coefficient is the spillover value of the influence of digital economy on the green development of SGMI in surrounding areas. The regression coefficient is 0.421 ($P < 5\%$), indicating that the development level of local digital economy has strong diffusion effect and scale group effect on the green development of SGMI, and promotes the green development of SGMI in surrounding regions, which verifies H4.

In order to further analyse the spatial spillover effect of digital economy on China's SGMI, the spatial effect is decomposed into direct effect, indirect effect and total effect. Similarly, variables are controlled to enhance the robustness of empirical results. As shown in **Table 6**, the regression coefficients of direct effect, indirect effect and total effect on the SGTFP driven by digital economy are 0.351, 0.711 and 1.062, and have passed the significance test. This indicates that DE not only promotes the green development of local SGMI, but also has a regional spatial spillover effect on the development of other regional SGMI. The possible reason is that the development of DE drives the "competition" effect in other regions and promotes the green and sustainable development of SGMI.

Table 6. Estimation results of the spatial Durbin model.

Variables	**Elasticity coefficient**	**Direct effect**	**Indirect effect**	**Total effect**
DIG	0.208*(2.216)	0.351**(3.203)	0.711*(2.437)	1.062*(2.135)
W×DIG	0.421*(2.285)	-	-	-
Control variables	Yes	Yes	Yes	Yes
ρ	0.464***(4.211)	-	-	-
R-squared	0.053	-	-	-
Log-Likelihood	154.542	-	-	-

Note: *, **, and *** respectively denote significant at confidence levels of 10%, 5%, and 1%.

4.4. Results of the mediating effect model

In order to further demonstrate the indirect influence mechanism of the digital economy driving the green development of China's SGMI, two indirect influence mechanisms of green technology innovation capability (GRE) and energy consumption structure (ENG) were selected to analyse the intermediary effect analysis.

When *GRE* is used as the intermediary variable, as shown in the second column of **Table 7**, the regression coefficient of digital economy on GRE is significantly positive, indicating that there is a significant positive relationship between digital economy and green technology innovation ability. The regression coefficient of digital economy on green technology innovation ability is 0.091 and passes the significance test of 10%, that is, every time the digital economy increases by 1 unit, the digital economy will increase by 1 unit. The level of green technology innovation ability will be significantly increased by 0.091 units. As shown in column 3 of **Table 7**, the regression coefficient of green technology innovation ability on SGTFP is 0.176, passing the 5% significance test. Therefore, green technology innovation ability plays a part of the intermediary effect in the digital economy driving the green development of China's SGMI, and the calculated effect ratio is 16.192%, so hypothesis H2 is verified.

When ENG is used as the intermediary variable, as shown in column 5 of **Table 7**, the regression coefficient of DE on ENG is significantly negative, indicating that there is a significant negative relationship between DE and ENG. The regression coefficient of DE on green technology innovation ability is −0.087 and passes the significance test of 10%, that is, if the digital economy increases by 1 unit, ENG will be significantly reduced by 0.087 units. As shown in column 6 of **Table 7**, the regression coefficient of *ENG* on SGTFP is −0.236 and passes the 5% significance test. Therefore, ENG plays a part of the intermediary effect in the green development of China's SGMI driven by DE, and the calculated effect ratio is 9.639%, so hypothesis H3 is verified.

Table 7. Regression results of intermediary effects.

Variable	GRE	STGFP	Variable	ENG	STGFP
DIG	0.091*(2.131)	0.176**(2.783)	*DIG*	−0.087*(−2.053)	0.192**(2.943)
GRE	-	0.379*(2.233)	*ENG*	-	−0.236**(−2.321)
Mediating effect ratio	-	16.192%	Mediating effect ratio	-	9.639%

Note: * and ** denote significant at confidence levels of 10% and 5%.

5. Conclusion and policy implications

Based on the panel data of 30 provinces in Chinese from 2011 to 2022, this study uses the Super-SBM model to measure the SGTFP, and uses the entropy weight method to measure DIG. The coordination degree between the digital economy and SGTFP was calculated using a coupling cooperation model. And the direct, indirect, and spatial spillover effects of the digital economy on the SGTFP were tested using a regression model. The main conclusions drawn are as follows:

1) During the study period, both the development level of China's digital economy and the STGFP showed an increasing trend; and the coupling coordination degree of the two also showed an increasing trend. It shows that the coordination between digital economy and green development of SGMI is getting better and better.

2) Digital economy has a direct impact on the green development of SGMI, and there is a significant spatial spillover effect. The development level of local digital economy has strong diffusion effect and scale group effect on the green development of SGMI, which can effectively promote the green development of SGMI in surrounding areas.

3) In the process of digital economy driving the green development of SGMI, green technology innovation ability and energy consumption structure play an intermediary role. By increasing the number of green patents obtained, the digital economy enhances the green technology innovation ability of sports enterprises, and further drives the green development of SGMI. By optimizing the energy consumption structure, the digital economy makes up for the energy consumption of sporting goods in the production-exchange value link, and promotes the green development of SGMI, but the variable itself has a significant inhibitory effect on SGMI.

Based on the above research conclusions, the implications are put forward as follows:

1) Accelerate the construction of digital infrastructure and build a digital technology platform for SGMI. Guided by the strategic top-level design of national development, strengthen the construction of sports goods network infrastructure, and further play the important role of digital economy in driving the green development of SGMI (Chai, 2021). The development of China's digital economy is uneven between regions, such as strong in the east and weak in the west, hot in the east and cold in the west. The eastern region should make use of its innovative advantages in artificial intelligence, big data centers, block chain, and Internet of Things technology to speed up the construction of infrastructure to drive the development of the central and western regions (Ouyang, 2024). The western region can rely on its own cost advantages to accelerate the investment of funds and talents in the construction of industrial parks, and provide digital infrastructure support for the development and promotion of new formats of SGMI (Dong, 2022).

2) In view of the spillover effect of the digital economy driving the green development of SGMI, local governments should build the integrated layout of digital infrastructure, promote cross-regional collaboration, and give full play to the radiating role of the digital economy. Improve the breadth and depth of coordination between digital technology and SGMI, and give full play to the spatial contribution of the digital economy to the green transformation of sports (Lin and Liu, 2022). Actively develop green elements, and continue to promote the basic ecology of sporting goods manufacturing industry. Strengthen the dynamic coupling between the green elements of sporting goods and the digital economy, resolve the constraints such as overcapacity and increase of pollutant emissions caused by capital intensity through the spatial spillover effect of sporting goods manufacturing industry, effectively play the spillover effect of the green elements driven by the digital economy to the surrounding area, and urge the sporting goods manufacturing enterprises to formulate reasonable environmental rules and regulations. Avoid falling into the "stain first, cure later" trap.

3) It is essential to establish a green technology innovation consortium that is beneficial to market operation, promote the sporting goods industry, sports colleges, enterprises, and scientific research institutions to achieve "bundling", and improve the incremental benefit of green technology innovation. In addition, the implementation of high-tech talent preferential policies, talent reward system and other measures, improve the talent introduction system, by increasing research investment or the establishment of technological achievements conversion funds and other ways to "bring forth the new", give play to the "group effect" of human resources (Ren andHuang, 2022).

4) Take green technology innovation ability as the core driving force, build a green technology innovation system for SGMI, and promote the deep coordination of "industry, university and research". On the one hand, China should take innovative elements as the theme and build a "green technology innovation ecosystem" for the SGMI. Accelerate the construction of the green technology innovation ecosystem of SGMI, make up for the lack of innovation of sports enterprises themselves, and promote green technology innovation of the whole industrial chain. We will promote energy governance and build a new model of "multi-body" low-carbon environmental protection development. In the digital era, fully apply digital technologies such as

machine learning and big data to monitor energy use in SGMI, identify energy governance bottlenecks, and improve energy governance efficiency.

5) Promote energy transformation, and promote the development of renewable energy in the SGMI. SGMI is an important part of the secondary industry, and fossil energy will occupy a high proportion in its energy consumption structure for a long period of time in the future. We should make use of digital technology to promote the low-carbon energy transformation of the SGMI, accelerate the development of clean energy such as tidal energy and solar energy, and realize the transformation of fossil energy consumption to clean energy consumption mode. To achieve the purpose of two-way optimization of economy and energy saving. At the same time, encourage sporting goods manufacturing enterprises to increase the capital investment in production equipment and product raw material renewal, and restrict the subject and object of energy consumption of sporting goods manufacturing enterprises to reduce the excessive dependence on traditional fossil energy for economic development. In addition, local governments should promote energy governance and build a new model of "multi-body" low-carbon environmental protection development. In the era of digital energy, fully apply machine learning, big data and other digital technologies, integrate energy governance into the production, transportation and consumption of sporting goods and other links, with the help of digital technology to analyze the energy consumption data of the SGMI, monitor energy use, find out the bottleneck of energy governance, improve the efficiency of energy governance, by strengthening the cooperation between provinces and cities in energy governance.

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