Heliyon 9 (2023) e22707

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

The green economic impact of a green comprehensive industry agglomeration: An example from the sports industry

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ARTICLE INFO

Keywords:
Green economic efficiency
Green comprehensive industry
Sports industry agglomeration
Super-sbm model
Dynamic spatial durbin model

ABSTRACT

The optimization of industrial structure and layout is essential for promoting the high-quality development of the regional economy. As a typical example of a green comprehensive industry, the agglomerations of the sports industry have the potential to release additional green benefits. Consequently, this paper uses the balanced panel data of 30 provinces, municipalities, and autonomous regions in China from 1998 to 2021 as samples and, based on the strategic background of China's dual-carbon target and the re-interpretation of the green economy, uses the Super-SBM model to re-measure the green economic efficiency of each region and applies the dynamic spatial Durbin model and the dynamic panel system GMM model to evaluate the direct effect, mediating mechanism, spatial spillover effect, and heterogeneity effect of sports industry agglomeration on the regional green economic efficiency. Empirical findings indicate that: (1) The improvement of green economic efficiency under China's dual-carbon target has the characteristics of dynamic accumulation, and there is a siphon effect between neighboring regions. (2) The effects of sports industry agglomeration on local green economy efficiency show an "inverted U-shape" with a positive spatial spillover effect on the green economy efficiency of neighboring regions; this conclusion is robust. (3) The green economy effect of sports industry agglomeration is more significant in the central and western regions, regions with strict environmental regulations, and regions with a higher willingness for resident participation in sports due to industrial density, compliance costs, and characteristics of sports industry development. (4) Sports industry agglomeration can promote regional green economy efficiency by escaping natural resource dependence and increasing healthy human capital; technological innovation, rationalization of industrial structure, and labor transfer serve as "inverted U-shaped" mediators between sports industry agglomeration and regional green economy efficiency. This study expands the meso- and spatial-level perspectives of the impact of the agglomeration of green industries and comprehensive industries on green development. It is of great theoretical and practical importance for promoting the construction of a regional green industrial system and the high-quality development of the green economy.

1. Introduction

Since the 1960s, the shortcomings of the extensive economic development model centered on producing and consuming material

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https://doi.org/10.1016/j.heliyon.2023.e22707
Received 19 June 2023; Received in revised form 7 November 2023; Accepted 16 November 2023
Available online 25 November 2023
2405-8440/

wealth have come to light, and resource depletion, climate deterioration, frequent natural disasters, and other resource dilemmas and ecological crises have emerged as problems that humanity must urgently address. In this context, countries are trying to find new power sources and new growth points that can achieve energy savings and emission reduction, and China, the United States, Japan, South Korea, and other countries have adopted clean energy investment, low-carbon social construction, and other ways to accelerate the conversion of kinetic energy. An intensive, efficient, and sustainable green development model is gradually becoming a strategic choice for all countries [1]. China's green transformation has received unprecedented attention as a country with the world's most complex natural environment and socio-economic conditions [2]. In 2015, the Chinese government put forward the development concept of "green, innovation, coordination, open, and sharing," elevating green development to the height of the national strategy. The white paper "China's Green Development in a New Era" was published in 2023, expanding China's green development's global map.

Many studies have shown that optimizing the industrial layout and adjusting the industrial structure are the fundamental ways of transforming the economic development mode [[3,4]]. Promoting green upgrading and layout optimization of industries and achieving the green and sustainable development of the economy have also become the frontiers of cross-disciplinary research in geography and economics. As an essential factor in shaping the spatial structure of industries, the agglomeration economy generated by industrial agglomeration can effectively improve the efficiency of resource allocation and total factor productivity, typical of industrial spatial organization in the industrialized era. Traditional industrial agglomerations bring negative externalities such as increased energy consumption and environmental pollution while improving the quality of economic growth. Following the energy crisis, the United States, Japan, and other countries have led in developing emerging green industries, such as green energy and the circular economy. Green industries are characterized by resource intensification and recycling, which can effectively break through traditional industrial agglomerations' resource and environmental dilemmas. However, green industries are typically characterized by low returns, long investment cycles, and uncertain risks, making it challenging to attract large-scale investment and form a mode of agglomeration development.

In recent years, due to the impact of the COVID-19 pandemic, all countries have been in an economic downturn. As a particular industrial economy to overcome the economic recession, the sports industry's pillar function in the national economy has attracted attention [5]. As a typical green industry with low pollution and energy consumption, sports industry agglomeration can effectively help construct a green industry system. Moreover, as a comprehensive industry across secondary and tertiary industries, the sports industry has the advantageous characteristics of high correlation and a strong driving force, which can attract capital, talent, and other high-quality resources through the linkage and extension of the industrial chain and value chain, ease the dilemma of financing difficulties in green industries, and multiply the advantages of industrial agglomeration by multiples.

The existing literature, which is closely related to the study of this paper, can be categorized into three broad categories.

The first is research on industrial agglomeration and the economy. From the perspective of influence mechanisms, industrial agglomeration can promote regional economic efficiency through industrial correlation, knowledge and technology spillover, sharing of factor resources, and amplifying the effect of inter-firm cooperation and competition [6–8]. From the agglomeration mode perspective, specialization agglomeration mainly reduces production costs and improves regional labor productivity by deepening the division of labor in the industry and sharing the industry information database [9,10]. Diversification agglomeration, on the other hand, contributes to regional economic development by enhancing the matching of upstream and downstream associated enterprises and accelerating knowledge and technology spillover [11,12]. From the perspective of causality, due to factor interaction [4], the positive feedback mechanism of economic growth [13], and the self-growth effect of agglomeration [14], industrial agglomeration and economic growth have a bidirectional causal relationship that promotes each other. In addition, a few scholars believe there is a threshold, "inverted U-shaped," and other non-linear relationships between industrial agglomeration and regional economic growth [15,16].

The second is research on industrial agglomeration and the environment. Existing studies on the relationship between industrial agglomeration and the environment have been more contentious, including divergent perspectives on positive and negative externalities. Proponents of the "positive externality theory" believe that industrial agglomeration can not only reduce the degree of environmental pollution at source by promoting technological spillover and technological innovation [17], enhancing residents' awareness of environmental protection and enterprises' awareness of competition [18], but also promote the comprehensive pollution treatment rate of the agglomeration site increased by generating the increasing returns-to-scale for pollution treatment [19]; Proponents of the "negative externality theory" emphasize that industrial agglomeration will not only directly affect the air, land and water bodies through increased pollutant emissions and overexploitation of land, cause environmental degradation [20–22], but also through the scale and structural effects of industrial agglomeration result in increased resource and energy consumption [23], FDI inflow and pollution localization [24], population growth, and increased resource waste [25], all of which result in the further deterioration of environmental pollution.

The third is research on industrial agglomeration and the green economy. It is generally believed that the agglomeration of productive services represented by the financial industry can help improve regional innovation vitality and efficiency by bringing together talent, information, and capital [26]. Pollution-intensive industrial agglomerations push industrial enterprises to scale pollution control and production mode standardization; new energy industrial agglomerations are conducive to improving the efficiency of green innovation. A significant positive correlation exists between the two and green development performance [27,28]. Specialization agglomeration of high-tech industries intensifies product homogenization and vicious price competition of low-end products, negatively impacting regional green development; diversification agglomeration forms an innovation driver via complementary knowledge and technology spillover to improve green economic efficiency in agglomerations [29]. The relationship between manufacturing agglomeration and green economic efficiency is still controversial. However, the synergistic agglomeration of manufacturing and service industries can significantly enhance regional green economic efficiency by promoting the progress of green technology [30,31].

In conclusion, most of the above literature examines the impact of industrial agglomeration on green development from the economic or environmental effects perspective. In contrast, relatively little literature examines the direct relationship between the two. No literature analyzes, from the perspective of green industry or comprehensive industrial agglomeration, the improvement of the mechanism of the impact of industrial agglomeration on regional green development. In addition, most studies ignore the path-dependent characteristics and spatial spillover effects of green development. Based on the above background, this article takes China as an example. Using dynamic panel models, examine the mechanism and spatial relationship between the representative green comprehensive industry—sports industry agglomeration—and regional green economic efficiency, hoping to provide valuable policy implications for promoting the high-quality development of the industry and the greening and upgrading of the economic structure in various countries.

2. Theoretical analysis and research hypothesis

2.1. Direct effects of sports industry agglomeration on green development

According to the Statistical Classification of Sports Industry (2019) and Industrial Classification for National Economic Activities (GB/T 4754-2017), China's sports industry can be divided into two industrial categories, namely, sports manufacturing and sports services, as well as 11 major industry categories, including sports competition and performance activities and sports management activities. Because the sector's affiliations are broad and diverse, the sports industry agglomeration can keep the commonality of a single-industry specialization agglomeration and enjoy the diversification agglomeration effect between heterogeneous industries given by the "structural dividend." According to the new economic geography theory, the concentration of the sports industry in a specific region can exponentially amplify the interactions and correlations among sports enterprises under the decentralized layout, generating effects of labor reservoirs, intermediate inputs, and knowledge spillovers and promoting economic symbiosis. However, expanding the scale of agglomeration in the sports industry will have a limited impact on agglomeration benefits. According to Williamson's hypothesis and the theory of the optimal scale of industrial agglomeration [32], the industrial agglomeration scale has a Pareto optimum. When the agglomeration exceeds the optimal value, it results in crowding and crowding-out effects that are detrimental to the green transformation of the regional economy.

2.1.1. Positive externalities of sports industry agglomeration

From the perspective of a single-industry agglomeration, improving financial competitiveness is the core of its development strategy for the labor-capital-intensive sports manufacturing industry. On the one hand, the MAR externality generated by the sports manufacturing industry agglomeration can, by sharing the specialized labor market, production factors, and public infrastructure [33], deepen the industrial division of labor, optimize resource allocation while enhancing labor productivity, and help its value chain climb. On the other hand, sports manufacturing agglomerations can form a closed-loop production process through the correlation effect of input and output, promote the recycling and use of by-products in the production and processing processes, increase the added value of products and services while reducing energy consumption, and help promote the intensive transformation of the regional economy. For the knowledge- and technology-intensive sports service industry, improving service and technological innovation is essential for its sustainable development. Industrial agglomeration leads to the concentration of economic activities within the industry in the same area, and the shortening of the information spread distance is conducive to the service industry's timely grasp of market information and timely adjustment of service strategies according to the changes in market demand, thus enhancing service efficiency. At the same time, the efficient information dissemination network formed in the agglomeration area can accelerate the knowledge and technology spillover among enterprises in the cluster, which is conducive to improving the efficiency of technological learning and technological innovation among enterprises and promoting the sustainable promotion of regional total factor productivity.

From the perspective of industrial synergistic agglomeration, the labor reservoir effect is shown by the fact that the sports manufacturing industry in the agglomeration area has access to a greater variety of professional services and a thicker pool of shared labor, which is conducive to reducing the cost of searching for and hiring professional labor. The effect of intermediate inputs shows that economies of scale and the competitive effects created by agglomeration can promote the production of intermediate inputs on a large scale and reduce the prices of intermediate services. At the same time, the geographical agglomeration of the sports industry can break the information and data barriers among enterprises within the industry and between enterprises and consumers, form a dynamic, complex, and balanced supply-and-demand matching chain, and reduce product transport and transaction costs due to "asymmetric information" and "limited rationality." The knowledge spillover effect is shown in the fact that the heterogeneous sports industry agglomeration helps to form a public knowledge base of the regional sports industry, which promotes the manifestation of the invisible knowledge that is difficult to transmit under the decentralized layout of the industry [34] and then reduces the sports enterprises' learning and exchange costs of green innovation knowledge. The scale benefit brought by the above cost-saving effect encourages sports enterprises to invest more energy and resources in green technology research and development and value chain extension, which effectively helps regional economic green transformation and upgrading.

In addition, as a green comprehensive industry with sports competition performance activities and sports fitness leisure activities as the leading industries, the sports industry has a strong correlation and integration effect. Through inter-industry correlation, sports industry agglomeration can promote the development and ecological agglomeration of clean service industries such as tourism, media, accommodation, leasing, and exhibition to form a green economic pulling force of the sports industry radiating the surrounding industries. It can also accelerate integration with culture, health, and other people's livelihood industries, accumulate healthy human capital, improve people's livelihoods and well-being while improving labor productivity, and achieve both economic and social benefits. The Matthew effect mentioned above, generated by the sports industry agglomeration, will attract more high-quality investment and resources to the sports industry and its related industries, further expanding their market scale, generating a cyclic cumulative effect, and amplifying the positive externalities of the sports industry agglomeration by multiples.

2.1.2. Negative externalities of sports industry agglomeration

The negative externalities of sports industry agglomeration can be categorized as crowding and crowding-out effects.

The crowding effect is shown in that, on the one hand, excessive agglomeration in the sports industry can result in the loss of synergistic dividends among sports enterprises and the intensification of vicious competition, destroying the market operation system and triggering the imbalance of cluster governance and factor allocation, resulting in a decline in sports enterprises' production quality and operational efficiency. On the other hand, the capacity expansion brought about by the agglomeration of the sports industry will not only accelerate energy consumption and pollutant emissions, resulting in a shortage of regional resources and a decline in the carrying capacity of the environment, but it will also make marginal factor output continue to decline due to the continuous increase in factor inputs, negatively impacting regional sustainable development.

The crowding-out effect is shown in that, firstly, excessive agglomeration of the sports industry will cause an over-density of regional enterprises and population, bringing problems such as traffic jams, resource shortages, and environmental pollution, resulting in higher costs and lower quality of local production and life, squeezing the escape of high-level sports enterprises, other green enterprises, and highly qualified labor, inhibiting the ability of the regional green economy to grow. Secondly, as the level of agglomeration in the sports industry improves, the limited regional market capacity and resource endowment will exacerbate the competitive effect among sports enterprises [35]. To quickly seize market shares, local enterprises are inclined to increase short-term economic benefits through scale expansion, and non-productive cost expenditures, such as scientific research investment and information transmission, are squeezed, weakening the vitality of regional green innovation.

In summary, the first research hypothesis could, therefore, be stated as follows.

H1. The relationship between sports industry agglomeration and regional green economy development is "inverted U-shaped."."

2.2. Mechanisms of sports industry agglomeration on green development

2.2.1. Technology innovation effects

When the scale of sports industry agglomeration is small, the network dividend generated by agglomeration can accelerate the inter-infiltration and complementary integration of knowledge, technology, and information among heterogeneous enterprises, improve the technology integration capability and technological innovation efficiency of sports enterprises, and provide a driving force for regional green development. At the same time, according to Poter's externality hypothesis, the expansion of the sports industry agglomeration scale will also intensify the competition among homogeneous enterprises within the industry regarding resource factors and market shares, compelling enterprises to continuously optimize their production processes, improve energy conservation and emission reduction, and continue to promote technological innovation to maintain their competitive advantages, thereby boosting the intensive and efficient transformation of the regional economy. In addition, sports industry agglomeration is conducive to the formation of sports industry bases and sports industry parks that integrate the resources and policy dividends of enterprises, universities, and research institutes, helping sports enterprises to break the bottleneck of research and development, improve the rate and efficiency of innovative technology application transformation, and provide an excellent technical environment for regional green development. However, when the scale of sports industry agglomeration is too large, the agglomeration makes it easy to make information, and technology communication and spillover only occur within the industry, causing path dependence and a technology lock-in effect and forming a closed system with industrial boundaries, which is not conducive to enhancing the efficiency of the region's overall green economy.

Consequently, the second research hypothesis of this paper is as follows.

H2. Technological innovation plays an inverted U-shaped mediating role between sports industry agglomeration and green economy efficiency.

2.2.2. Natural resource decoupling effects

One is the embedding effect. The synergistic agglomeration of the sports manufacturing industry and the sports service industry is not only conducive to the sports manufacturing industry's adoption of information technology, modern management technology, financial leasing, and other productive elements of the sports service industry in place of traditional energy consumption, but it is also conducive to the sports service industry's proliferation of low-carbon, environmentally friendly, and clean technologies into the sports manufacturing industry, thus realizing the decoupling of the development of the sports industry from energy consumption. The second is the effect of consumption structure adjustment. Sports competition performance activities and sports fitness leisure activities dominate the sports industry. Under the guidance of the dominant industry, the sports industry agglomeration can further promote the transition of the sports consumption structure from physical consumption to ornamental and participatory consumption with the characteristics of the short cycle, low energy consumption, and recycling, and then reduce the dependence of industrial development on natural resources while revitalizing the vitality of the regional market, pushing the development of the region towards the transformation of green production.

Consequently, the third research hypothesis of this paper is as follows.

H3. Natural resource decoupling plays a promoting role in the relationship between sports industry agglomeration and green economy efficiency.

2.2.3. Industrial layout adjustment effects

Rationalization of industrial structure requires that factors of production be reasonably distributed among industries according to the structure of demand to alleviate resource mismatch, avoid resource waste, and promote the transformation of economic development modes from extensive to intensive.

When the scale of sports industry agglomeration is small, spatial concentration accelerates the flow of resources and factors. Driven by the principle of high and low rates of return, the production factors will flow from the low-efficiency and high-pollution sectors to the high-efficiency and low-pollution sectors to realize the optimal allocation of resources. At the same time, geospatial concentration is conducive to matching supply and demand among upstream and downstream industries, radiation and correlation among horizontal industries, and horizontal and vertical knowledge and technology spillovers, compelling the transformation of local resource allocation and industrial structure toward rationalization and efficiency. In addition, the proximity of the sports industry and related industries can squeeze the production and survival space of the secondary industry, especially the heavy industry, which has strong negative externalities, and improve the distortion of the local market failure and resource allocation, causing the ratio of local factor inputs to outputs to adjust in the direction of equalization.

When the scale of the sports industry agglomeration is large, further agglomeration will deteriorate the inter-enterprise competition effect, and the sports enterprises in the agglomeration area will blindly expand production to maintain their market share, resulting in overcapacity. In addition, the innovation inertia and technology locking effect caused by excessive accumulation will cause the primary products and homogenized products in the sports industry to consume more factor resources, thereby exacerbating the inefficiency of regional resource allocation and not conducive to the transformation of the local industrial structure into energy-saving and emission-reduction new business forms.

Consequently, the fourth research hypothesis of this paper is as follows.

H4. Industrial restructuring plays an inverted U-shaped mediating role between sports industry agglomeration and green economy efficiency.

2.2.4. Labor transfer effects

The concentration of the labor force in a specific region can not only promote the improvement of regional production efficiency and the intensive transformation of economic growth through the accumulation of human capital but also accelerate the spillover of knowledge and technology by increasing the frequency of interaction among heterogeneous talents and injecting new kinetic energy into the green development of the region.

Intra-regional and inter-regional transfers are the two labor transfer effects caused by sports industry agglomerations. In the early stages of agglomeration, the economies of scale generated by the sports industry agglomeration are conducive to the expansion of its upstream and downstream industrial chain links and driving the development of cultural, tourism, medical, and other related industries, forming a strong labor absorption capacity, promoting the re-employment of local unemployed, and the inter-industry transfer of labor in other industries. Simultaneously, the agglomeration's price index and local market effect will form a "siphon" for the surrounding labor force, promoting the localization transfer of high-quality human capital from the surrounding areas. In the late stage of agglomeration, the vicious competition effect generated by over-agglomeration will reduce the profits of sports enterprises and the rate of return on labor. Simultaneously, the crowding effect of agglomeration will make the cost of living increase and the quality of life in the agglomeration area diminish. Both will result in the transfer of high-quality labor across industries and regions.

Consequently, the fifth research hypothesis of this paper is as follows.

H5. Labor transfer plays an inverted U-shaped mediating role between sports industry agglomeration and green economy efficiency.

2.2.5. Healthy human capital effects

From the perspective of the health human capital effect of sports industry agglomeration, sports industry agglomeration can provide convenience for all types of people to participate in sports activities by providing more diversified products and services and better sports public infrastructure to better utilize the sports industry's auxiliary role in disease prevention and health promotion. Meanwhile, sports industry agglomeration is conducive to accelerating the integration process of culture, sports, and the healthcare industry, realizing mutual support and functional complementarity among the three industries, and promoting the sustainable improvement of the overall health level of Chinese residents through a combination of active conservation and passive prevention and treatment.

From the perspective of the green economic effect of health human capital, on the one hand, the theory of health demand shows that health-related consumption and investment can increase the current utility and future benefits of residents and contribute to the improvement of regional social benefits [36]. On the other hand, Li and Zhang's [37] study shows that an increase in healthy human capital can directly promote regional economic growth by improving labor productivity, as well as promote the regional economic growth model's transition from factor-driven to innovation-driven by promoting the accumulation of education human capital, thereby realizing an overall improvement in regional total factor productivity.

Consequently, the sixth research hypothesis of this paper is as follows.

H6. Healthy human capital plays a promoting role in the relationship between sports industry agglomeration and green economy efficiency.

2.3. Spatial spillover effects of sports industry agglomeration on green development

Firstly, the knowledge and technology spillover effect generated by sports industry agglomerations appears to be unrestricted geographically. In reality, industries in neighboring areas also communicate, imitate, and learn from one another. The behavior of sports industry agglomerations to improve the efficiency of the regional green economy plays a demonstration and leading role in developing the sports industry in neighboring areas. Secondly, spatial proximity is conducive to the flow of inter-regional factors. According to the trickle-down theory, limited by the regional carrying capacity of resources and the environment, when the sports industry agglomeration reaches a specific scale, it usually chooses cross-regional synergistic development with similar or complementary enterprises in neighboring areas, which then leads neighboring areas to expand their industrial scale and enrich their enterprise types, promoting the improvement of the efficiency of its green economy. Moreover, green economy effects include economic and environmental effects, while both have significant spatial autocorrelation effects within a specific spatial range [38]. Through the spatial correlation between economy and environment, the agglomeration of sports industries in a specific region affects the local green economy's efficiency and neighboring regions' green development level.

Therefore, the seventh research hypothesis proposed is as follows.

H7. The impact of sports industry agglomeration on green economy efficiency has a spatial spillover effect.

The previous theoretical analysis is illustrated in Fig. 1.

3. Materials and methods

3.1. Index construction and data source

Thirty provinces, cities, and autonomous regions (excluding Hong Kong, Macau, Taiwan, and Tibet due to data availability) were used as research objects, and the sample interval was from 1998 to 2021. On the construction of the index, the original data of $PM_{2.5}$ are from the Atmospheric Composition Analysis Group of Washington University, the carbon emission data is based on the 2006 IPCC CO_2 emission equation, and the rest of the data are from the China Stock Market & Accounting Research Database (CSMAR), the China

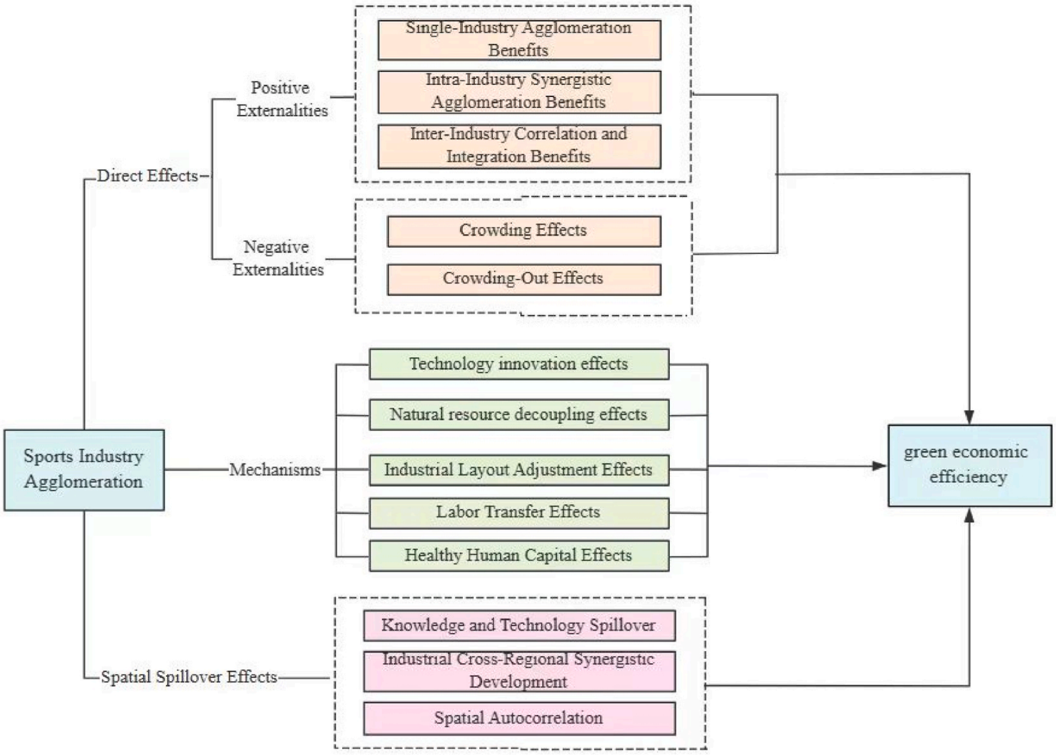

Fig. 1. The effect path of sports industry agglomeration on green economy efficiency.

Statistical Yearbook, the China Statistical Yearbook of Environment, the Information Network Database of the Development Research Center of the State Council (DRCNET), the National Bureau of Statistics, the EPS database, the CEIC database, the China City Statistical Yearbook, regional Statistical Yearbooks, and Statistical Communique. In addition, missing data are reconstructed using linear interpolation and growth rates. In order to avoid the influence of outliers, all continuous variables are winsorized at the 1 % level. All nominal variables have been transformed into real variables using either the GDP deflator or the consumer price index.

3.1.1. *Explained variable*

According to relevant theoretical achievements, the green economy can be defined as a sustainable economy that coordinates and integrates economic, social, and ecological aspects under the dual constraints of resource capacity and environmental carrying capacity. Therefore, this paper refers to the approach of Tone [39] and adopts the super-SBM model that considers the desirable outputs of economic, social, and ecological benefits as well as the undesirable outputs of environmental pollution to measure regional green economy efficiency, and GTFP marks it. In addition, in terms of the selection of basic indicators, the study further optimizes and supplements the existing green economy measurement system by taking into account the strategic context of China's dual-carbon target and the latest interpretation of green economy while following the principles of scientificity, representativeness, and accessibility.

3.1.1.1. Input index. Following Adam Smith's theory of the three factors of production, production factors can be divided into three main categories: labor, land, and capital. Among them, labor input refers to the sum of the physical and intellectual strength humans provide in production and living. It is measured by the number of social workers in each region at the end of the year. Land input includes not only the land itself but all the natural resources, mainly energy and water. They are measured by the area of the regional built-up area, total energy consumption, and total water consumption, respectively. Capital input refers to all the factors of production that are produced and put into the reproduction process. Using the perpetual inventory proposed by Zhang et al. [40] to measure it, the formula is as follows:

$$K_{i,t} = (1\text{-}\delta)\times K_{i,t\text{-}1} + I_{i,t} \tag{1}$$

Among them, $K_{i,t\text{-}1}$ and $K_{i,t}$, respectively, represents the fixed capital stock of the region i in periods t-1 and t; δ represents the depreciation rate of fixed assets at 9.6 %; $I_{i,t}$ represents the real fixed asset investment of area i in period t; and K_0 represents that the base capital stock is obtained by dividing the fixed asset investment of each region in the base period by 10 %.

3.1.1.2. Desirable output index. According to the definition of a green economy, desirable outputs should consider the sustainability of economic, social, and ecological benefits. Regarding economic benefits, the real regional GDP is used to measure the present level of economic development, and the real total retail sales of social consumer goods are used to predict future economic prosperity. Equity and people's well-being are two key indices to measure social benefits. The average salary of urban residents can measure the current situation of social equity and well-being. In contrast, as a powerful means of sustainably advancing social equity and improving people's well-being, fiscal revenues can effectively predict future changes in societal benefits. Regarding ecological benefits, the park green space area is used to evaluate the present ecological level and sustainability of the region.

3.1.1.3. Undesirable output index. Environmental pollution is an essential negative externality product of economic development, divided into three types. Air pollution is measured by its primary pollutants: regional $PM_{2.5}$ concentration and SO_2 emissions. Considering fundamental development principles under China's "dual-carbon" strategic objective of reducing pollution and carbon reduction, this paper examines carbon emissions as the other vital indexes of undesirable outputs. Water pollution is measured by the primary pollutants in the water body—COD emissions (from industrial sources and sources of livelihood). Air and water pollution are

Table 1
Regional GTFP Index Measurement system.

First-level index	Second-level index	Third-level index	Units
Input index	Labor input	Number of social employees at the end of the year	10000 people
	Land input	Total energy consumption	10000 tons of standard coal
		Area of built-up area	square kilometer
		Total water consumption	10000 cubic meters
	Capital input	Real capital stock (equation (1))	100 million RMB
desirable output	Economic benefits	Real regional GDP	100 million RMB
		Real total retail sales of social consumer goods	100 million RMB
	Social benefits	Fiscal revenues	100 million RMB
		Average salary of urban residents	RMB
	Ecological benefits	Park green space area	hectare
undesirable output	Air pollution	SO_2 emissions	10000 tons
		$PM_{2.5}$ concentration	microgram per cubic meter
		CO_2 emissions	10000 tons
	Water pollution	COD emissions	10000 tons
	Soil pollution	The sum of applying pesticides and fertilizers	10000 tons

essential factors causing soil pollution and will not be repeated. Agricultural pollution is another crucial factor causing soil pollution, using the sum of applying pesticides and fertilizers to characterize it.

In order to alleviate the possible correlation among the indexes within the desirable and undesirable outputs, respectively, and the bias in the measurement of efficiency caused by the insufficient number of decision-making units, the entropy method has been used to synthesize the basic indicators of the desirable and undesirable outputs into a composite index of the desirable and undesirable outputs, respectively. Specific index variables are shown in Table 1.

3.1.2. Core explanatory variable

Regional industrial agglomeration level measures include the Gini coefficient, Herfindahl index, EG index, and location entropy. However, all the above indicators ignore the spatial distribution of economic activities, resulting in the weak comparability of the relevant indexes among regions. In order to comprehensively consider the scale and spatial characteristics of regional industrial agglomeration, this paper refers to the study of Koo [41] and adopts the ratio of the density of employed persons in urban units of the sports industry in each region to the number of employed persons in urban units of the sports industry in the whole country as a proxy variable for the level of regional sports industry agglomeration, namely:

$$ICA_{jt} = q_{jt} \Big/ \sum_j q_{jt} s_j \tag{2}$$

Among them, q_{jt} represents the number of employed persons in urban units of the sports industry in the j region; $\sum_j q_{jt}$ is the number of employed persons in urban units of the sports industry in the whole country; s_j is the built-up area of the j area.

3.1.3. Mediating variables

3.1.3.1. Technological innovation (TI). Using the sum of domestic patent applications per capita for invention, utility model, and design patents measures the technological innovation level.

3.1.3.2. Natural resource dependence (NRD). Natural resource dependence is measured using the ratio of employed persons in urban units of extractive industries in the region to the total number of employed persons.

3.1.3.3. Rationalization of industrial structure (ISR). The level of rationalization of industrial structures is measured using the reciprocal of the Theil index. The larger the Theil index, the greater the deviation of the industrial structure from that in economic equilibrium. The formula is as equation (3):

$$ISR_{jt} = GDP_{jmt}\ ln\left(GDP_{jmt} \big/ Labor_{jmt}\right) \tag{3}$$

Among them, GDP_{jmt} represents the share of the output value of industry m in region j in the regional GDP in period t, and B denotes the share of the number of employed persons in industry m in region j in the total number of employed persons in the region j in period t ($m = 1, 2, 3$).

3.1.3.4. Labor transfer (LT). According to the theoretical analysis, the labor transfer caused by sports industry agglomeration includes three parts. One is the change in the labor absorption capacity of the tertiary industry itself in the agglomeration region; the second is the transfer of labor between the primary and secondary industries and the tertiary industry in the agglomeration region; and the third is the inter-regional transfer of labor. Therefore, this study adopts the difference between the number of employed persons in the tertiary industry in the present period and the previous period of the region as a proportion of the total population to represent the labor force transfer.

3.1.3.5. Healthy human capital (HHC). This study uses regional population mortality rates as a reverse proxy variable for the regional healthy human capital level.

3.1.4. Control variables

To further control the impact of sports industry agglomeration on regional green economic efficiency and to reduce the problems of model identification and the reliability of empirical findings caused by omitted variables, set the following control variables.

3.1.4.1. Level of economic development (PGDP). Residents of areas with higher economic development are generally more environmentally conscious. However, excessive economic growth also frequently means excessive energy consumption and increased environmental pollution. The level of economic development is measured by regional per capita real GDP.

3.1.4.2. Level of opening up (OPEN). A higher level of openness facilitates the host country's introduction of advanced environmental protection production technology. However, at the same time, the localization transfer of foreign backward production capacity will also exacerbate environmental pollution in the host country [42]. Total foreign direct investment is adjusted to be converted into RMB according to the current exchange rate, and its ratio to regional GDP is used as a measure of the level of opening up.

3.1.4.3. Environmental regulation (ER). The Porter hypothesis proposes that environmental regulation can promote the green transformation of enterprise production by increasing the cost of pollution treatment for enterprises. This paper selects the ratio of each region's total investment in industrial pollution control to its gross domestic product to measure the regional environmental regulation level.

3.1.4.4. Population concentration degree (PCD). Population concentration is conducive to improving regional resource allocation efficiency, but it also accelerates regional resource consumption and deteriorates the regional ecological environment. The degree of population concentration is measured by regional urban population density.

3.1.4.5. Level of public infrastructure construction (PIC). Public infrastructure can play a sharing effect in resource allocation, production, and pollution treatment and promote the efficiency of the regional green economy. Use the number of public transport vehicles per 10,000 people to reflect the level of public infrastructure construction.

The descriptive statistics of all variables are shown in Table 2.

3.2. Model setting

3.2.1. Spatial weight matrix setting

A spatial weight matrix is an essential tool to portray the interrelationship among spatial units, and constructing a spatial weight matrix is also a prerequisite for spatial econometric analysis. Currently, there are multiple methods to construct spatial weight matrices, and different weight matrices reflect inter-regional correlations from different aspects, and the regression results also have significant differences. Referring to the suggestion of Elhorst [43], this paper chooses the spatial geography weight matrix based on exogenous geographical location information for spatial econometric analysis. Then, it uses the spatial economic weight matrix based on economic information to test the regression conclusion.

3.2.1.1. Geographical distance spatial weight matrix

$$W^d_{i,j}=\begin{cases} 1/d_{i,j} & i \neq j \\ 0 & i = j \end{cases} \quad i,j=1,2,\dots,n \tag{4}$$

Among them, $d_{i,j}$ represents the distance between the geographical centers of areas i and j.

3.2.1.2. Economic distance spatial weight matrix

$$W^m_{i,j}=W^d_{i,j}\times diag\left(\overline{Y}_1/\overline{Y},\overline{Y}_2/\overline{Y},\dots,\overline{Y}_n/\overline{Y}\right) \tag{5}$$

$$i,j=1,2,\dots,n$$

Among them, $\overline{Y}_i$ is the arithmetic mean of the annual per capita GDP of area i during the sample period; $\overline{Y}$ is the arithmetic mean of the annual per capita GDP of all regions in China during the sample period; and $W^d_{i,j}$ is the spatial weight matrix of geographical distance.

3.2.2. Spatial econometric model setting

3.2.2.1. Baseline model. The study by Yuan et al. [35] shows that industrial agglomeration has a spatial spillover effect on green

Table 2
Descriptive statistics of variables.

Variable	N	Mean	Variance	Minimum	Maximum
GTFP	720	0.5300	0.2801	0.1369	1.5186
ICA	720	0.0314	0.0294	0.0052	0.1781
TI	720	0.0011	0.0018	0.0000	0.0085
NRD	720	0.0089	0.0097	0.0001	0.0493
ISR	720	0.2306	0.1456	0.0067	0.7234
LT	720	0.0050	0.0093	−0.0298	0.0378
HHC	720	6.1416	0.7814	4.4100	8.0700
PGDP	720	3.5663	2.9416	0.3668	13.7039
ER	720	0.0015	0.0014	0.0001	0.0073
OPEN	720	0.4985	0.5735	0.0587	3.8069
PCD	720	0.2311	0.1362	0.0189	0.5821
PIC	720	10.7464	3.8281	3.9000	24.3100

Note: In order to increase the readability of the data, the PGDP value is reduced by 100 times, the same below.

development. Consequently, it introduces a spatial econometric model to conduct the empirical analysis. Common spatial econometric models include the spatial Durbin model (SDM), the spatial autoregressive model (SAR), and the spatial error model (SEM). The SDM model contains spatial lag operators for both explained and explanatory variables and has the relative advantage of simultaneously analyzing the spatial spillover effects of both explained and explanatory variables [44]. Therefore, this paper selects the SDM model as the baseline model for empirical analysis and sets up the model as follows:

$$GTFP_{it}= \beta_0+\rho W_{ij}GTFP_{it}+\beta ICA_{it}+\gamma X_{it}+\theta W_{ij}ICA_{it}+\delta W_{ij}X_{it}+ \mu_i+ v_t+ \varepsilon_{it} \tag{6}$$

Among them, $GTFP_{it}$ is the explained variable, represents green economy efficiency. ICA_{it} is the core explanatory variable, namely the sports industry agglomeration index. X_{it} is the control variable. i and t represent region and year, respectively. ρ is the spatial autocorrelation coefficient. W_{ij} is the spatial weight matrix. β_0 is constant. β and γ are general regression coefficients of explanatory variable. θ and δ are spatial regression coefficients of explanatory variables. μ_i is a region-fixed effect. v_t is a time-fixed effect. ε_{it} is a random error term.

3.2.2.2. Extended model. Firstly, consider that regional green economy efficiency changes may have lagging effects, such as path dependence and dynamic accumulation. Secondly, the theoretical mechanism indicates that there may be a nonlinear relationship between sports industry agglomeration and the regional green economy's efficiency. Thus, to test the time inertia of green development and the nonlinear effect of sports industry agglomeration, incorporating the first-order lag term of green economy efficiency and the quadratic term of sports industry agglomeration simultaneously, based on the baseline model, set up the following dynamic spatial Durbin model:

$$GTFP_{it}= \beta_0+\alpha GTFP_{i,t-1}+\rho W_{ij}GTFP_{it}+\beta_1 ICA_{it}+\beta_2 ICA_{it}^2+\gamma X_{it}+ \theta_1 W_{ij}ICA_{it}+ \theta_2 W_{ij}ICA_{it}^2 +\delta W_{ij}X_{it}+\mu_i+ v_t+\varepsilon_{it} \tag{7}$$

Among them, α is the time lag coefficient, and the other symbols are interpreted following formula (6).

3.2.2.3. Mediating effect model. Furthermore, in order to analyze the specific mechanism by which sports industry agglomeration affects regional green economy efficiency, the following dynamic panel mediating effect model is constructed, referring to the design ideas of the mediating effect causal step method proposed by Baron and Kenny [45]:

$$GTFP_{it} = \varphi_0 + \alpha_1 GTFP_{i,t-1} + \lambda_1 ICA_{it} + \lambda_2 ICA_{it}^2 + \gamma_1 X_{1it} + \mu_i + v_t + \varepsilon_{1it} \tag{8}$$

$$Media_{it} = \varphi_1 + \alpha_2 Media_{i,t-1} + \lambda_3 ICA_{it} + \lambda_4 ICA_{it}^2 + \gamma_2 X_{2it} + \mu_i + v_t + \varepsilon_{2it} \tag{9}$$

Table 3
Spatial correlation test.

Year	Moran'I					
	GTFP	TI	RD	ISR	LT	PD
1999	0.065***	−0.028	0.053***	−0.011	−0.057	−0.059
	(0.002)	(0.789)	(0.004)	(0.411)	(0.458)	(0.427)
2001	0.017*	−0.032	0.052*	−0.034	−0.013	−0.035
	(0.092)	(0.922)	(0.081)	(0.998)	(0.437)	(0.978)
2003	0.041**	−0.031	0.019*	−0.028	−0.031	−0.054
	(0.017)	(0.894)	(0.065)	(0.843)	(0.912)	(0.541)
2005	0.037**	−0.032	0.000	−0.002	−0.015	−0.036
	(0.025)	(0.941)	(0.213)	(0.281)	(0.510)	(0.967)
2007	0.024*	−0.032	−0.012	0.012	−0.057	−0.037
	(0.064)	(0.929)	(0.420)	(0.129)	(0.435)	(0.932)
2009	0.026*	−0.027	−0.007	0.012	−0.048	−0.006
	(0.058)	(0.809)	(0.313)	(0.125)	(0.631)	(0.364)
2011	0.041**	−0.016	−0.011	−0.022	−0.052	−0.060
	(0.017)	(0.552)	(0.357)	(0.689)	(0.513)	(0.413)
2013	0.046**	−0.006	−0.011	0.003	−0.055	−0.057
	(0.012)	(0.352)	(0.370)	(0.243)	(0.456)	(0.473)
2015	0.036**	−0.020	−0.013	0.000	−0.055	−0.028
	(0.028)	(0.624)	(0.395)	(0.275)	(0.497)	(0.833)
2017	0.020***	−0.020	−0.019	−0.006	−0.043	−0.063
	(0.003)	(0.631)	(0.490)	(0.356)	(0.759)	(0.362)
2019	0.022*	−0.024	−0.012	0.003	−0.069	−0.060
	(0.072)	(0.742)	(0.341)	(0.226)	(0.261)	(0.422)
2021	0.030**	−0.028	−0.014	−0.029	−0.018	−0.061
	(0.042)	(0.841)	(0.360)	(0.860)	(0.411)	(0.399)

Note: the figures in parentheses are p-values for the z-statistic; ***, **and * indicate significant at the level of 1 %, 5 % and 10 %, respectively.

$$GTFP_{it} = \varphi_2 + \alpha_3 GTFP_{i,t-1} + \lambda_5 Media_{it} + \lambda_6 ICA_{it} + \lambda_7 ICA_{it}^2 + \gamma_3 X_{3it} + \mu_i + \nu_t + \varepsilon_{3it} \quad (10)$$

Among them, $Media_{it}$ is the mediating variable, including technological innovation (TI), natural resource dependence (NRD), industrial structure rationalization (ISR), labor transfer (LT), and healthy human capital (HHC); φ is the constant term; λ is the general regression coefficient of the main explanatory variables; and the other symbols are interpreted following formula (6).

4. Empirical results and analysis

4.1. Model suitability test

4.1.1. Spatial correlation test

Global spatial autocorrelation can be used to illustrate the characterization of the overall spatial agglomeration of the observed variables in the study area, usually measured by the global Moran'I index. As shown in Table 3, under the spatial geographic weight matrix (equation (4)), the P-value of the global Moran'I index corresponding to the green economic efficiency of each region in China from 1998 to 2021 is less than 0.1, indicating that China's green economic development has significant spatial autocorrelation, which also confirms the reasonableness of the baseline regression using the spatial econometric model in this study. In the mediating variables, except for natural resource dependence in a few years for which the Moran'I index P-value is less than 0.1, others do not have spatial autocorrelation, confirming the reasonableness of using a non-spatial dynamic panel mediating effect model to test the mediating mechanism in this study.

4.1.2. Selection of spatial econometric models

As shown in Table 4, firstly, based on the results of the LM and robust LM tests, either the SAR or SEM model is an acceptable option. Secondly, the LR and Wald tests demonstrate that the SDM model cannot be simplified to a SAR or SEM model. Thirdly, the Hausman and LR tests show that the fixed effect model that includes time and space should be selected. Eventually, the SDM model with time-and-space fixed effects was chosen for spatial econometric analysis.

4.2. Baseline regression analysis

In order to compare and test the robustness of the parameter estimates in the regression models, this paper also presents the estimation results of the time-and-space fixed effects SAR model and SEM model, as shown in Table 5. Comparing the regression results in columns (1)–(3), it can be seen that, whether ignoring some factors with spatial correlation affecting the regional green economic efficiency (SAR model), considering only the spatial spillover effects of the explanatory variables (SEM model), or considering the spatial lag factors of the explanatory variables and the explained variables at the same time (equation (7)), the magnitude, direction, and significance level of the coefficients and quadratic term coefficients of sports industry agglomeration have not changed significantly. It also confirms the existence of the impact of the sports industry agglomeration on green economy efficiency.

From the regression results in columns (1)–(3) of Tables 5 and it can be seen that the regression coefficient of the first-order lag term of GTFP is significantly positive, indicating that the change in green economic efficiency is dynamic and continuous. The possible reasons for this are: from the input side, labor and land inputs are long-term, energy inputs are highly dependent, and capital accumulation is dynamic; from the output side, the promotion of the work of China's economic growth, people's livelihood improvement, and environmental protection are continuous, thereby making the level of green development in the previous period positively impact the promotion of green economic efficiency in the current period.

As can be seen from the regression results in column (3) of Table 5, the spatial autocorrelation coefficient of GTFP is significantly negative, indicating that the synergistic development between regions in China is low and there are significant gaps and heterogeneity in the development model, making green economic development have imbalanced and insufficient characteristics, producing a siphoning effect among neighboring regions. That means the green economic development of a region will be negatively affected by

Table 4
Selection of spatial econometric models.

	Statistical value	P
Moran's I	1614.0700	0.0000
LM-error	1770.9190	0.0000
Robust-LM-error	12.9350	0.0000
LM-lag	169.7840	0.0000
Robust-LM-lag	17.9300	0.0005
LR-spatial error	15.1400	0.0017
LR-spatial lag	20.7300	0.0139
Wald-spatial error	16.3600	0.0375
Wald-spatial lag	14.1900	0.0008
Hausman	46.86	0.0000
LR-area	106.66	0.0000
LR-time	1614.0700	0.0000

Table 5
Baseline regression results.

Variable	(1) Dynamic SEM	(2) Dynamic SAR	(3) Dynamic SDM
L.GTFP	0.8742***	0.8712***	0.8491***
	(43.59)	(43.85)	(40.08)
ICA	0.7222**	0.7751**	0.9602***
	(2.12)	(2.29)	(2.71)
ICA^2	−4.4634**	−4.6041**	−5.3562***
	(-2.34)	(-2.44)	(-2.72)
PGDP	0.6940*	0.6660*	0.7520*
	(1.78)	(1.72)	(1.90)
TI	9.6517**	9.8916***	10.2525***
	(2.52)	(2.59)	(2.65)
OPEN	0.0196***	0.0187**	0.0136*
	(2.61)	(2.54)	(1.67)
ER	3.9643	3.6229	4.5225**
	(1.57)	(1.45)	(2.33)
PIC	0.0055***	0.0054***	0.0054***
	(4.22)	(4.24)	(3.89)
PCD	−1.7900	−2.1200	−1.9400
	(-0.61)	(-0.73)	(-0.65)
W × L.GTFP			−0.1957
			(-1.01)
W × ICA			5.1241**
			(2.25)
W × ICA^2			−27.8000*
			(-1.68)
W × PGDP			−2.72
			(-1.09)
W × TI			62.4964**
			(2.16)
W × OPEN			−0.0571
			(-0.81)
W × ER			−7.7419
			(-0.40)
W × PIC			0.0159
			(1.50)
W × PCD			−0.0000
			(−1.30)
Spatial rho		−0.2953***	−0.4011**
		(-2.68)	(-2.45)
Spatial lambda	−0.2811**		
	(-2.35)		
Variance sigma2_e	0.0030***	0.0030***	0.0029***
	(18.53)	(18.64)	(18.60)
Log-likelihood	1021.1663	1022.5588	1030.1307
Regional fixed effect	YES	YES	YES
Time fixed effect	YES	YES	YES
R^2	0.7837	0.8107	0.7731

Note:the figures in parentheses are the Z statistical values of the coefficient; ***, **and * indicate significant at the level of 1 %, 5 % and 10 %, respectively, as shown in the following tables.

the green development level of the surrounding areas, which is consistent with the findings of Feng et al. [46].

ICA's general and spatial regression coefficients passed the 1 % and 5 % significance tests, respectively. It demonstrates that sports industry agglomeration has both direct and indirect effects on the efficiency of the regional green economy.

4.3. Decomposition of the spatial spillover effect

When the explained variable has significant spatial autocorrelation, the estimated value of the SDM model cannot accurately measure the degree of influence between variables [47]. Consequently, it uses the partial differential method to decompose the impact of sports industry agglomeration on regional green economic efficiency into direct and indirect effects to distinguish further and investigate the local effect and spatial feedback effect caused by a change in the sports industry agglomeration level.

The impact of sports industry agglomeration on regional green economic efficiency is "inverted U-shaped" among the direct effects. It indicates that moderate agglomeration of the sports industry can generate effects of labor reservoirs, intermediate inputs, and knowledge spillovers and promote the green transformation of the regional economy. However, excessive agglomeration of the sports industry will have crowding and crowding-out effects, curbing regional green development level improvement. The H1 hypothesis is certified. Among the indirect effects, the impact of sports industry agglomeration on the regional green economic efficiency is significantly positive, indicating that the behavior that sports industry agglomeration improves the local green economy efficiency has a demonstration and leading role, which can lead neighboring areas to improve their green development level; thus, hypothesis H7 is confirmed.

Directly, PGDP has a positive impact on regional GTFP, while indirectly, it has a negative impact. Meanwhile, both regression coefficients are statistically significant. On the one hand, areas with a higher level of economic development can attract more and better external resources because they possess an excellent economic environment. The accumulation of innovative resources, talents, and technology boosts the local mode of production, adjusting in a more efficient and environmentally friendly direction, thereby improving the local green economy efficiency; on the other hand, the agglomeration effect of high-quality factors generated in areas with higher levels of economic development will hinder the process of introducing talents and technologies in neighboring areas, thereby hindering the improvement of green economy efficiency in neighboring areas.

Both the direct and indirect effects of TI on regional GTFP were significantly positive. On the one hand, the invention and use of technologically innovative products, especially green technologically innovative products, may significantly improve energy use efficiency, thus reducing pollutant emissions while conserving resources [48], improving the efficiency of local green development. On the other hand, technological innovation can play a spillover effect through the cross-regional linkage of forward and backward industrial chains, drive the neighboring regions to improve production technology and production structure, and thus help the neighboring regions to improve the level of green development.

The direct effect of OPEN on regional GTFP is significantly positive, and the indirect effect is not significant. This result shows that opening up can promote the green transformation of the regional economy by promoting the inflow of innovative factors such as high-quality capital, labor, and technology [49]. However, this innovation effect is closed and does not produce spatial interaction due to the consideration of a technological monopoly.

The direct impact of ER on regional GTFP is significantly positive. A higher level of environmental regulation can incentivize enterprises to increase R&D investment and improve production methods and technologies with high pollution and low efficiency, ultimately achieving double promotion of regional economic output and environmental quality.

The direct effect of PIC on regional GTFP is significantly positive, showing that a higher level of infrastructure development can help the construction of the local economic circulation system by providing efficient information dissemination networks and transportation networks, which produce sharing and cost-saving effects.

The direct and indirect effects of PCD on regional GTFP are insignificant because, on the one hand, higher population concentration means sufficient labor reserves support local economic development. On the other hand, it also means that the region is under heavy pressure regarding ecological protection and resource use. The two mechanisms cancel each other out, resulting in a zero effect of population concentration on regional GTFP.

4.4. Robustness test

To ensure the accuracy of the above research findings, conduct the robustness test from the following four perspectives.

4.4.1. Replace the spatial weight matrix

The spatial economic weight matrix (equation (5)), which describes the economic relationship between regions, is used to replace

Table 6
Decomposition of spatial effects.

Variable	(1)	(2)
	Direct effect	Indirect effect
L.GTFP	0.8583***	−0.3904***
	(40.25)	(-3.32)
ICA	0.8726***	3.3573**
	(2.60)	(2.26)
ICA^2	−4.8015***	−17.7000
	(-2.57)	(-1.45)
PGDP	0.8050**	−2.3200**
	(2.04)	(-2.19)
TI	9.2972**	43.6880**
	(2.50)	(2.04)
OPEN	0.0145*	−0.0449
	(1.77)	(-0.84)
ER	4.7940**	−7.6711
	(2.12)	(-0.56)
PIC	0.0053***	0.0101
	(3.97)	(1.29)
PCD	−1.6100	−20.4000
	(−0.59)	(−1.15)
R^2	0.7731	

the spatial geographic weight matrix, which describes the positional relationship between regions.

4.4.2. Replace the explanatory variable

Referring to the study of Zhou et al. [50], the industry weight index (CI) is used as a substitute index for the level of regional sports industry agglomeration, namely as equation (11):

$$ICA_{jt} = q_{jt} \Big/ \sum_{j} q_{jt} \tag{11}$$

The symbols are interpreted following equation (2)

4.4.3. Replace the measurement method of the explained variable

Referring to the research method of Fukuyama and Weber [51], the regional green economic efficiency was re-measured by applying the non-radial, non-angle SBM-DDF function based on the VRS assumption under the framework of DEA.

4.4.4. Replace regression model

In order to effectively avoid the problem of model endogeneity caused by the bidirectional causality between sports industry agglomeration and regional green economy development, equation (6) was re-estimated by using the systematic GMM method proposed by Blundell and Bond [52] that allows for the presence of heteroskedasticity in the random error term and serial correlation, among other advantages.

Table 7 reveals that the size and symbol of the regression coefficients for each variable in columns (1)–(3) are basically identical to those in Table 6, indicating that the empirical conclusion of this paper is robust to some extent.

4.5. Heterogeneity test

4.5.1. Based on regional distribution

China's industrial agglomeration is economically oriented [53]. Since the reform and opening up, the eastern coastal regions have developed rapidly due to high-quality endowment resources, such as their locational conditions and policy dividends. The level of economic development between the eastern and central-western regions has gradually opened the gap. To test the heterogeneity of the impact of sports industry agglomeration on regional green economic efficiency across economic regions, divide the sample into two groups: eastern and central-western.

The test results in Table 8 indicate that the results of subsample regression differ, and the regression results of the central and western regions show a similar trend to those of full-sample regression, while in the eastern region, the impact of the sports industry agglomeration on the efficiency of the green economy is insignificant. These are the reasons for this phenomenon: The amount of capital, the level of human capital, and the density of resources in the eastern region are significantly more significant than in the central-western regions, attracting many enterprises and industrial agglomerations. On the one hand, too many industries accelerate energy consumption and centralized pollutant discharge, resulting in a shortage of regional resources and a decline in the environment's carrying capacity. Under this locational condition, the agglomeration of the sports industry will intensify the crowding level of local industrial agglomerations, putting pressure on the renewable capacity of local resources and environmental carrying capacity. On

Table 7
Robustness test results.

Variable	(1)		(2)		(3)		(4) SYS-GMM
	Direct effect	Indirect effect	Direct effect	Indirect effect	Direct effect	Indirect effect	
L.GTFP	0.8611***	−0.3076**	0.8530***	−0.2587**	0.77168***	0.1256	1.0319***
	(39.25)	(-2.50)	(39.40)	(-2.00)	(30.63)	(1.41)	(11.79)
ICA	0.8897***	3.4011**	0.0560***	0.1433**	0.2965*	0.1749***	3.0599**
	(2.58)	(2.37)	(3.26)	(2.17)	(1.82)	(2.89)	(2.47)
ICA^2	−4.9032**	−14.3000	−0.0174***	−0.0298	−1.2405**	−5.3541	−13.0000***
	(-2.49)	(-1.54)	(-3.66)	(-1.38)	(-2.54)	(-1.28)	(−4.70)
PGDP	0.7830*	−1.1300*	0.6780*	−1.4600	0.3140*	−2.2700***	1.5000***
	(1.95)	(-1.89)	(1.76)	(-0.81)	(1.74)	(-3.53)	(4.19)
TI	9.6129**	22.2763	12.4461***	25.9160*	4.3031**	6.4497	10.9005**
	(2.54)	(1.30)	(3.33)	(1.77)	(2.32)	(0.89)	(2.06)
OPEN	0.0164**	−0.0326	−0.0152*	−0.0101	0.0140***	−0.0075	−0.0326
	(1.96)	(-0.55)	(-1.85)	(-0.17)	(3.55)	(-0.41)	(-1.60)
ER	3.9865	−6.7265	4.2507**	−3.7998	1.8343	−3.6037	2.0782***
	(1.53)	(-0.53)	(2.10)	(-0.25)	(1.45)	(-0.75)	(4.98)
PIC	0.0053***	0.0054	0.0053***	0.0024	0.0023***	0.0064**	0.0026
	(3.90)	(0.81)	(4.01)	(0.35)	(3.62)	(2.38)	(1.34)
PCD	−1.3100	−3.3100	−4.0800	−11.4000	3.2000**	−9.8700	−1.2200
	(-0.47)	(-0.17)	(-1.48)	(−0.54)	(2.37)	(-1.58)	(-0.81)
R^2	0.8038		0.8177		0.7482		–

Table 8
Regional heterogeneity test.

Variable	Central and western regions		Eastern regions	
	Direct effect	Indirect effect	Direct effect	Indirect effect
L.GTFP	0.6563***	−0.1820	0.9421***	−0.2093
	(19.89)	(-1.36)	(23.58)	(-1.24)
ICA	5.8134***	40.2740*	1.6129	15.4115
	(2.69)	(1.81)	(0.50)	(1.20)
ICA^2	−247.0010***	−1882.2140	−63.2950	−105.5500
	(-3.10)	(−1.11)	(-0.83)	(-0.42)
Control variable	YES		YES	
Fixed effect	YES		YES	
Observed value	456		264	
R^2	0.8270		0.8864	

the other hand, the limited factor endowment and nearly saturated enterprise amounts in the eastern region will intensify the vicious competition between enterprises. While backward infrastructure and technical means, limited policy resources, and imperfect industrial systems hinder the development of sports enterprises, their factor resources and living space are squeezed by superior enterprises, and expanding the sports industry's agglomeration scale is challenging. Under a high industrial density layout, the external effects generated by the sports industry agglomeration are offset by the crowding and crowding-out effects generated by industrial development in eastern regions on local sports industry agglomerations, making it have an insignificant impact on green economic efficiency. While the central-western regions are vast and the level of economic agglomeration is low, the industry has a hollowed-out layout, and the local industrial density has yet to have a crowding-out effect on the development of the sports industry. The positive and negative externalities of sports industry agglomeration can be in full play.

4.5.2. *Based on the degree of environmental regulation*

Environmental regulation can improve regional economic and environmental benefits via technological innovation, screening foreign investment, and adjusting the industrial structure, among other channels. In regions with different degrees of environmental regulation, the level of green development varies significantly [54]. Consequently, this paper divides the samples into two groups, high and low, based on the median of environmental regulation variables, to examine the heterogeneity of the effect of sports industry agglomeration on green economy efficiency in regions with different degrees of environmental regulation.

Table 9 shows that the results of sub-regional regression and full-sample regression differ. The regression results of regions with strict environmental regulations parallel those of full-sample regression. However, its optimal value is improved compared to the full sample. While the sports industry agglomeration coefficient is insignificant in regions with relaxed environmental regulations. The reason is that, for the areas with strict environmental regulation, on the one hand, the compliance cost with strict environmental regulation can guide clean and efficient sports enterprises into the agglomeration areas and polluting and inefficient sports enterprises out. By strengthening the spatial self-selection effect of enterprises at all levels, it reduces the pressure on local environmental governance; on the other hand, sports industry agglomeration can enlarge a competitive effect among enterprises, whereas the punitive measures of strict environmental regulation can push competition and technological innovation transition towards energy saving and emission reduction directions, promoting the local sports industry's healthy development and thereby delaying the appearance of the inflection point of the sports industry agglomeration effect. For the relaxed environmental regulation areas, the phenomenon of vague definitions of environmental property rights and insufficient investment in environmental protection leads to the possibility of pollution emission climbing or imitation behavior of sports enterprises in the agglomeration area, coupled with relaxed environmental regulation areas undertaking the transfer of polluting sports enterprises from strict environmental regulation areas, causing the sports industry agglomeration in the areas to lose their thrust on regional green economic efficiency.

Table 9
Heterogeneity test of environmental regulation Intensity.

Variable	Low environmental regulation		High environmental regulation	
	Direct effect	Indirect effect	Direct effect	Indirect effect
L.GTFP	0.4595***	−0.4093**	0.3088***	0.0095
	(7.68)	(-2.14)	(4.66)	(0.09)
ICA	0.2752	−0.7613	0.1697**	0.3495*
	(0.56)	(-0.50)	(2.26)	(1.87)
ICA^2	−0.9450	2.2880	−0.2171*	−0.4487
	(-0.15)	(1.17)	(-1.72)	(-1.36)
Control variable	YES		YES	
Fixed effect	YES		YES	
Observed value	240		240	
R^2	0.2944		0.1166	

4.5.3. Based on the willingness for resident participation in sports

High participation and intense radiation are characteristics of the sports industry. The positive externalities of sports industry agglomeration depend considerably on people's willingness to participate in sports, which drives their demand for the products and services of sports and related industries. It has been shown that the willingness of residents to participate in sports is highly positively correlated with their income and education level [55]. In order to test the heterogeneity of the impact of sports industry agglomeration on the regional green economy under the residents' different willingness to participate in sports, this paper uses the mean value of the standardized regional residents' income level and education level to measure residents' participation willingness. It divides the sample into two groups of high and low participation willingness, with its median as the boundary.

As shown in Table 10, the results of sub-sample regression indicate that, compared to areas with low willingness to participate in sports, the timing of the occurrence of negative externalities of the sports industry agglomeration in areas with high willingness is delayed in areas with high sports participation willingness. Meanwhile, the positive externality of the sports industry agglomeration only has a spatial spillover effect in areas with a high willingness to participate in sports. The reason is that, on the one hand, sports, as a health industry, is an essential part of people's well-being. In regions where residents' willingness to participate in sports is high, the dynamic matching chain of supply and demand formed by the sports industry agglomeration can better convert the potential demand for sports with purchasing conditions into adequate satisfaction of the demand for sports and improve the utility level of the local residents while promoting the growth of the regional economy. Then, the negative environmental effects of the sports industry agglomeration can be somewhat offset. On the other hand, the optimization effect of industrial structure generated by sports industry agglomeration can push the transformation of sports consumption structure from physical consumption to strong correlational ornamental and participatory consumption. For regions with a high willingness of residents to participate in sports, the sports industry agglomeration can drive the development of local and neighboring sports industries and related industries such as tourism, catering, and accommodation by increasing the sports consumption of local residents for participation and spectacle, thereby improving the local and neighboring green economy efficiency.

4.6. Mediating effect test

The regression results in columns (1)–(11) of Tables 11–13 have p-values less than 0.1 for the AR(1) statistic and more than 0.1 for the AR(2) statistic and the Sargan statistic, showing that the mediating effect test using the dynamic panel system GMM model (equations ((8),(9),(10))) is reasonable.

Table 11 shows the process of testing the mediating effect of technological innovation. Firstly, from column (1), it can be seen that the "inverted U-shaped" relationship between sports industry agglomeration and regional green economic efficiency is significant. Secondly, from columns (2) and (3), the test results show that the impact of sports industry agglomeration on technological innovation is "inverted U-shaped"; technological innovation on green economic efficiency is significantly positive; the "inverted U-shaped" relationship between sports industry agglomeration and regional green economy efficiency remains significant after the introduction of a mediating variable. The above means that technological innovation plays an inverted U-shaped mediating role between sports industry agglomeration and green economy efficiency, and hypothesis H2 is confirmed.

Table 12 shows the process of testing the mediating effect of natural resource dependence and industrial structure rationalization. Column (3) shows that the "inverted U-shaped" relationship between sports industry agglomeration and regional green economic efficiency is significant. From columns (4)–(7), the test results show that the regression coefficients of sports industry agglomeration on natural resource dependence and natural resource dependence on green economic efficiency are significantly negative; the impact of sports industry agglomeration on industrial structure rationalization is "inverted U-shaped" and industrial structure rationalization on green economic efficiency is significantly positive; the "inverted U-shaped" relationship between sports industry agglomeration and regional green economy efficiency remains significant after the introduction of a mediating variable. The above means that natural resource dependence partially positively mediates between sports industry agglomeration and green economy efficiency; industrial structure rationalization plays an inverted U-shaped mediating role between sports industry agglomeration and green economy efficiency. Hypotheses H3 and H4 are confirmed.

Table 13 shows the process of testing the mediating effect of labor transfer and healthy human capital. Column (3) shows that the

Table 10
Heterogeneity test of willingness to participate in sports.

Variable	Low participation willingness		High participation willingness	
	Direct effect	Indirect effect	Direct effect	Indirect effect
L.GTFP	0.5672***	−0.6004**	0.9211***	−0.3079***
	(13.81)	(-4.47)	(36.69)	(-2.77)
ICA	0.8881*	0.8903	1.8274***	5.4023**
	(1.64)	(0.44)	(3.77)	(2.17)
ICA^2	−10.1000**	1.7924	−10.5000***	−41.0000
	(-2.48)	(0.13)	(-4.13)	(-1.08)
Control variable	YES		YES	
Fixed effect	YES		YES	
Observed value	360		360	
R^2	0.7278		0.5029	

Table 11
Mediating effect test of technological innovation.

Variable	(1)	(2)	(3)
	GTFP	TI	GTFP
L.GTFP	O.9895***		1.0319***
	(14.96)		(11.79)
L.TI		1.0242***	
		(11.17)	
ICA	3.2503***	0.0273***	3.0599**
	(2.57)	(2.10)	(2.47)
ICA^2	−12.9000***	−0.1426**	−13.0000***
	(-8.80)	(−2.14)	(−4.70)
TI			10.9005**
			(2.06)
_cons	−0.0778*	−0.0006*	−0.1313*
	(−1.92)	(−1.74)	(−1.78)
Control variable	YES	YES	YES
AR(1)	0.035	0.011	0.059
AR(2)	0.395	0.200	0.477
Sargan	0.767	0.172	0.896
Observed value	720	720	720

Table 12
Mediating effect test of NRD and ISR.

Variable	(3)	(4)	(5)	(6)	(7)
	GTFP	NRD	GTFP	ISR	GTFP
L.GTFP	1.0319***		0.8957***		0.9136***
	(11.79)		(25.04)		(20.28)
L.NRD		0.9508***			
		(29.70)			
L.ISR				1.0342***	
				(14.14)	
ICA	3.0599**	−0.0519**	1.4877**	1.4180***	1.3822**
	(2.47)	(-2.20)	(2.42)	(2.66)	(2.37)
ICA^2	−13.0000***	0.1784	−7.0730***	−4.8388**	−6.1081**
	(−4.70)	(1.44)	(−2.56)	(−2.29)	(−2.31)
NRD			−0.2821***		
			(−4.23)		
ISR					0.0618***
					(3.39)
_cons	−0.1313*	0.0011	−0.0319	−0.0246	−0.0242
	(−1.78)	(0.78)	(−0.92)	(−0.84)	(−0.82)
Control variable	YES	YES	YES	YES	YES
AR(1)	0.059	0.030	0.076	0.007	0.085
AR(2)	0.477	0.105	0.620	0.790	0.496
Sargan	0.896	0.790	0.498	0.940	0.425
Observed value	720	720	720	720	720

"inverted U-shaped" relationship between sports industry agglomeration and regional green economic efficiency is significant. From columns (8)–(11), the test results show that the impact of sports industry agglomeration on labor transfer is "inverted U-shaped" and labor transfer on green economic efficiency is significantly positive; the regression coefficients of sports industry agglomeration on healthy human capital and healthy human capital on green economic efficiency are significantly negative; the "inverted U-shaped" relationship between sports industry agglomeration and regional green economy efficiency remains significant after the introduction of a mediating variable. The above means that labor transfer plays an inverted U-shaped mediating role between sports industry agglomeration and green economy efficiency; healthy human capital partially positively mediates between sports industry agglomeration and green economy efficiency. Hypotheses H5 and H6 are confirmed.

5. Conclusions and discussions

5.1. Conclusions

Based on balanced panel data from 30 provinces, cities, and autonomous regions in China from 1998 to 2021, the impact of sports industry agglomeration on regional green economic efficiency was examined in terms of both local and spillover effects using a dynamic spatial Durbin model. The empirical findings show an inverted U-shaped relationship between sports industry agglomeration

Table 13
Mediating effect test of LT and HHC.

Variable	(3)	(8)	(9)	(10)	(11)
	GTFP	LT	GTFP	HHC	GTFP
L.GTFP	1.0319***		0.9282***		0.9260***
	(11.79)		(34.25)		(26.85)
L.LT		−0.1755			
		(−0.60)			
L.HHC				0.8527***	
				(11.55)	
ICA	3.0599**	1.2947***	1.7419***	−11.5174**	1.4937***
	(2.47)	(2.84)	(4.02)	(-1.96)	(2.86)
ICA^2	−13.0000***	−6.9570***	−8.9829***	56.6700	−7.4489***
	(−4.70)	(-2.77)	(-3.40)	(1.33)	(-2.88)
LT			0.3312**		
			(2.39)		
HHC					−0.0045**
					(-2.54)
_cons	−0.1313*	−0.0207**	−0.0211	1.2447**	0.0155
	(−1.78)	(-2.11)	(-0.97)	(0.029)	(0.50)
Control variable	YES	YES	YES	YES	YES
AR(1)	0.059	0.017	0.008	0.001	0.004
AR(2)	0.477	0.810	0.508	0.170	0.506
Sargan	0.896	0.507	0.496	0.302	0.573
Observed value	720	720	720	720	720

and local green economic efficiency from the perspective of local effects. When the scale of sports industry agglomeration is small, the agglomeration can generate effects of labor reservoirs, intermediate inputs, and knowledge spillovers and improve regional green economic efficiency. As the level of agglomeration rises, crowding and crowding-out effects dominate, detrimental to the regional green economy's efficiency. From the perspective of spillover effects, sports industry agglomeration has a demonstration and synergistic effect, which can drive the improvement of green economic efficiency in neighboring regions. In order to improve the reliability of the results mentioned previously, this paper adopts methods for replacing the spatial weight matrix, explanatory variables, explained variable measurement methods, and regression models to conduct robustness tests. The findings of this paper are thus confirmed. Based on the above conclusions, to investigate the agglomeration effect of the sports industry more thoroughly, this paper first investigates the heterogeneity effect of sports industry agglomeration on regional green economic efficiency based on the perspectives of regional distribution, environmental regulation level, and sports participation willingness. The regression results show that the green economy effect of sports industry agglomeration is more significant in the central and western regions, regions with high environmental regulation, and regions with high sports participation willingness than in other regions. Furthermore, the mediation mechanism test results indicate that technological innovation, natural resource dependence, industrial structure rationalization, labor force transfer, and healthy human capital can partially mediate between sports industry agglomeration and green economy efficiency.

5.2. Discussions

In recent years, China has vigorously advocated for optimizing the industrial layout and promoting the green transformation of its green industry-based economy. However, few studies have shown the relationship between industrial agglomeration and green development. Even rarer is the literature that examines their relationship from the green industry's perspective. As a sunrise and green industry cultivated by the state, the sports industry has the advantageous characteristics of low energy consumption, low pollution, and large prospective demand. Its comprehensive attributes across the secondary and tertiary industries can further magnify the green industry's development benefits through industrial correlation and industrial integration and promote the construction of the green industrial system and the intensive and highly efficient transformation of economic development. Consequently, this paper begins with the sports industry, a green comprehensive industry, and thoroughly examines the intrinsic relationship between the sports industry agglomeration and green economic efficiency. Compared with the existing literature, this paper makes the following marginal contribution: Firstly, it illustrates the efficiency improvement of the sports industry agglomeration to the traditional sports industry development mode and the theoretical mechanism of its impact on the regional green economy efficiency at three levels: single industry agglomeration, intra-industry synergistic agglomeration, and inter-industry correlation agglomeration, to provide a theoretical basis for the optimization of the related industrial layout in other economies. Secondly, based on the strategic background of China's dual-carbon target and the re-interpretation of the connotation of green economy, the Super-SBM model is used to re-measure the green economic efficiency of each region, which improves the objectivity and scientificity of the evaluation index of green economic efficiency. Thirdly, based on the dynamic spatial Durbin model, we examine the dynamic nonlinear impact of sports industry agglomeration on regional green economic efficiency and its spatial spillover effect. Furthermore, we use the dynamic panel system GMM model to test the mechanism of sports industry agglomeration on green economic efficiency from five aspects: technological innovation, natural resource dependence, rationalization of industrial structure, labor transfer, and healthy human capital. Which is an essential supplement to the study of green development influencing factors based on the meso-industrial perspective, the space perspective, and the mechanism variable perspective. Fourthly, the heterogeneous relationship between sports industry agglomeration and green economy efficiency is analyzed and evaluated in terms of regional distribution, the degree of environmental regulation, and the willingness of residents to participate in sports; this will provide inspiration for other economies to optimize the layout of the sports industry according to local conditions.

5.3. Accordingly, this paper provides the following suggestions for improvement

Firstly, local governments should clarify the logic of local industrial development by formulating reasonable sports industry policies in conjunction with regional resource endowment, economic development level, and consumption characteristics and by taking measures such as guiding the regional sports industry to maintain a moderate scale to maximize the benefits of sports industry agglomeration. On this basis, further, break down government barriers, take the local government as the hub, assist in establishing a sports market operation rule of collaborative innovation and benign competition, and promote the joint construction, sharing, and complete cooperation of sports projects and event resources, helping the sports industry agglomeration play a positive role.

Secondly, for the eastern region, the relevant departments should carry out in-depth inter-industry cooperation with the central and western regions via business outsourcing, collaborative management, and other means to amplify industrial agglomeration spatial advantages while weakening the local industrial crowding effect. For regions with low environmental regulation, local governments should formulate appropriate policies based on local conditions, guiding the sports industry to gradually form a scale and layout of agglomeration that matches environmental regulation and maximizing the "icing on the cake" effect of environmental regulation. For regions with a low willingness to participate in sports, local sports bureaus should guide the development of green sports and leisure programs with high participation, high fun, and high health value through the active development of industrial development plans for special sports programs to stimulate the enthusiasm of local residents to participate in sports.

Thirdly, we should precisely locate the combining point of sports industrial agglomeration to promote regional green economic efficiency and maximize the promotion of regional green economy efficiency of industrial agglomeration by strengthening and guiding the crucial role of sports industrial agglomeration in promoting technological innovation, rationalization of industrial structure, labor transfer, accumulation of healthy human capital, and reduction of natural resource dependence.

Data availability statement

The data cannot be published because of the copyright policy of original data. Data will be made available on request.

CRediT authorship contribution statement

Hao Hu: Writing – review & editing, Writing – original draft, Data curation, Conceptualization. **Yalin Chen:** Writing – review & editing, Writing – original draft, Data curation, Conceptualization. **Wenjie Li:** Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Funding statement

This work was supported by the Ministry of Education of the Humanities and Social Sciences Project [Grant Number 23YJAZH051], and the Major Program of the National Social Science Foundation of China [Grant Number 20&ZD124].

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