Article

Not peer-reviewed version

Analysis of the Spatiotemporal Evolution Characteristics of Green Total Factor Productivity Measurement of China's Sports Industry

Dan Ding and DONG Yanmei *

Posted Date: 5 December 2024

doi: 10.20944/preprints202412.0439.v1

Keywords: sports industry; green total factor productivity; HMB index; Theil Index; kernel density estimation; Markov chain

Article

Analysis of the Spatiotemporal Evolution Characteristics of Green Total Factor Productivity Measurement of China's Sports Industry

DING Dan [1] and DONG Yanmei [2]

[1] Adam Smith Business School, University of Glasgow, G12 8QQ;
[2] Sports Industry and Leisure College, Nanjing Sport Institute, Nanjing 210014, China
* Correspondence: 9120180032@nsi.edu.cn

Abstract: The HMB index method is used to measure the green total factor productivity of the sports industry in 31 provinces (municipalities and autonomous regions) in China from 2013 to 2022, and on this basis, the convergence and kernel density estimation of regional differences are carried out, and the Markov state transition analysis is further carried out. The results show that: (1) the green total factor productivity of China's sports industry shows a wave-like upward trend as a whole; The sports manufacturing industry has increased the control of pollution process, but the investment in pollution control in the sports service industry is low; The $GTFP_{HM}$ index in the eastern region is the highest, with an average annual growth rate of 3.3%, and most of the provinces (cities) in the region are environment-friendly, but the $GTFP_{HM}$ index in the central and western regions is less than 1, and there are few environment-friendly provinces (cities). (2) The highest contribution to the improvement of green total factor productivity of China's sports industry is pure technical efficiency, followed by range productivity and scale efficiency, and the technological progress index does not mention but decreases. However, unlike other regions, the eastern region has an average annual growth rate of 4.1% in the index of technological progress. (3) The differences in green total factor productivity of the sports industry in the four major regions of China generally showed a wave-like upward trend, and the differences mainly came from within the group, and the contribution between the groups was small. From the perspective of the contribution of each region to the total difference, the western and eastern regions contributed more to the total difference, but the contribution of the eastern region showed a wave-like downward trend, while the western region had a gradual upward trend, which was the main source of regional differences in the future. (4) There is a club effect in the transfer of green total factor productivity in the sports industry, and it is relatively difficult to transfer across levels. The higher the productivity level of the neighbors, the more conducive to the improvement of the productivity level of the low-level area. However, when neighboring with high-level areas, the phenomenon of good-neighboring and beggar-thy-neighbor coexists.

Keywords: sports industry; green total factor productivity; HMB index; Theil Index; kernel density estimation; Markov chain

1. Introduction

In the report of the 20th National Party Congress, China clearly put forward "accelerating the green transformation of development patterns" and "promoting the formation of green and low-carbon production and lifestyle." [1] Green development is the background color of high-quality development, one of the important contents for realizing Chinese path to modernization, and a long-term plan related to people's livelihood. As a sunrise industry in China, the sports industry will continue to rise to a pillar industry of our country in the next 10 years or even longer. [2] Its green development will be of great value to the country and the people. In fact, the green development of the sports industry has become a new direction for the development of the world's sports industry. For example, after the 26th conference of the United Nations Framework Convention on Climate Change in 2021, sports organizations such as FIFA and ATP and more than 280 sports federations such as the IOC and Formula E have announced that they will follow the provisions of the convention

 doi:10.20944/preprints202412.0439.v1

and join the zero-carbon emission competition campaign advocated by the United Nations. [3] The 2022 Winter Olympics held by our country is guided by the concept of green development. Mainly through the cultural thoughts including values contained in the Olympic movement, it indirectly guides the sports industry to transform into a green, low-carbon and circular economy and reconstructs the unsustainable development concept of high ecological investment in the sports industry.[4] However, at present, in the fields of sports manufacturing, sports venues, competitive sports and mass sports in China, extensive development with high input and low output still generally exists. For example, according to iiMedia Research data, in 2018, China produced 1.09 billion pairs of sports shoes, with carbon emissions of 14 million tons, equivalent to about 400 million yuan. [5] Facing the high-carbon emission manufacturing industry, the "Action Plan for Carbon Peaking Before 2030" clearly proposes to accelerate the optimization of industrial structure and the green and low-carbon transformation of traditional industries. The carbon emissions of the sports service industry mainly come from transportation, venue services and infrastructure. According to the data of the Olympic Organizing Committee, in 2018, it was estimated that during the Beijing Winter Olympics, carbon emissions from transportation and venue facilities were 1.637 million tons (actual emissions were 1.02 million tons), accounting for 87.2% of the total emissions. [4] Facing large carbon emitters, in 2019, the Ministry of Ecology and Environment of China released the "Trial Scheme for Carbon Neutrality of Large-Scale Activities." [6] Incorporating the carbon emissions of large-scale sports events into the macro management system, the green transformation of the sports industry is imperative. It is a necessary condition for promoting the sports industry to become a pillar industry of the national economy and practicing China's "dual carbon" goals of "peaking carbon dioxide emissions by 2030 and achieving carbon neutrality by 2060" and the "14th Five-Year Plan" and long-term goals for 2035 with remarkable results in the green transformation of production and lifestyle.

As a new social transformation strategy, green development was first officially proposed by British environmental economists Pearce et al. in their report "Blueprint for a Green Economy" (1989). [7] As a new social development strategy, green development is a process of transitioning to a low-carbon and resource-saving society. It reduces environmental pressure while promoting economic growth and enhances human well-being and social equality. [8] As a pillar industry of future economic development, although the proportion of the service industry in the sports industry is increasing year by year, problems such as extensive development, small scale, and low structural efficiency of the sports industry have not changed. [9] Contradictions such as "having business forms but no system", "having chains but not being unobstructed", "having elements but not being coordinated", and "high input and low efficiency" are prominent. [10] However, current research on the transformation and upgrading of the sports industry mostly focuses on the linear growth of the sports industry. [11,12] It does not link the development of the sports industry with carbon emissions. Even with the increase in the proportion of the tertiary industry in the sports industry, some scholars even inaccurately call it a green industry. In fact, as the marginal effect of emission reduction in the primary and secondary industries is decreasing day by day, there is huge potential space for fully tapping the emission reduction potential of the tertiary industry. [13] At present, research on the green transformation of the sports industry has just emerged. Relevant research is mostly qualitative description without systematic economic theory and empirical research. [14] To promote the green transformation of the sports industry, it is necessary to draw on the green transformation methods of other industries to study it.

At present, research on green transformation mainly includes three aspects: First, research on measuring green transformation. The measurement of green transformation is mainly divided into parametric and non-parametric methods, represented by stochastic frontier analysis (SFA) and data envelopment analysis (DEA) respectively. The SFA method mainly measures factor allocation efficiency based on a specific production function model. [15] Many studies have applied it to the measurement of green transformation. [16,17] Compared with SFA, the DEA method does not need to assume the form of a production function and can avoid estimation bias caused by inappropriate distribution of assumed error terms. The most common DEA method is the non-radial SBM-DSE model proposed by Tone (2001), [18] which is widely used in green transformation evaluation. [19–21] Second, the characteristics of green transformation changes. Green transformation is dynamic and its characteristics must be captured from dimensions such as time and space [22]. Some scholars study the spatial characteristics of industrial green transformation and find that there are significant heterogeneities, including regional differences [23] and industrial differences [24]. Some scholars also study the time-varying trend of industrial green transformation within a region and find that it shows a certain convergent or divergent trend. [25] Third, analysis of factors influencing green transformation. Existing research mainly focuses on the impact of industrial green transformation from perspectives such as environmental regulation [26], technological progress [27], import and export trade [28], etc.

In general, domestic and foreign scholars have sufficient research on green total factor productivity, especially total factor productivity, but research on green total factor productivity of the sports industry is still in its infancy, lacking quantitative analysis of its spatiotemporal evolution and state transition. Based on this, this paper uses the super-efficiency HMB index method to measure the green total factor productivity of China's sports industry, and combines methods such as Theil index, kernel density estimation, and Markov transition probability matrix to explore the evolution process, regional differences and transfer states of green development of the sports industry, providing a scientific basis for promoting the green development of the sports industry.

2. Research Design

2.1. Research Object

This study takes the sports industries of 31 provinces (municipalities directly under the Central Government) in China as the research object. Regarding the category of the sports industry, the "Statistical Classification of Sports Industry" of the National Bureau of Statistics divides the sports industry into 11 major categories such as sports management activities. Since 2018, the announcements of the total output and added value data of the sports industry of the National Bureau of Statistics have always merged the 11 major categories of sports industries in China into three major categories, namely sports service industry, sports goods and related product manufacturing industry, and sports venue facility construction. According to the relevant statistical data of the National Bureau of Statistics in recent years, the sum of the proportions of the sports service industry and sports goods and related product manufacturing industry in the sports industry exceeds 96%. However, the proportion of sports venue facility construction is relatively low and relevant data is difficult to obtain. Therefore, referring to existing research, this paper selects the relevant data of the sports service industry and sports goods and related product manufacturing industry to represent the sports industry.

2.2. Index selection

The core variable of this study is the green total factor productivity of the sports industry. Referring to the research of Li Haijie et al. [28–30], the index system for measuring the green total factor productivity of the sports industry is determined (Table 1). Input factors include asset and labor variables. According to the traditional three-factor input theory of economics, capital, labor, and land are the basic input factors. However, considering that the total output of sports venue facility construction accounts for a relatively small proportion in the total industrial output and the data is difficult to obtain, only labor and capital are selected as input variables. In order to eliminate the influence of asset price factors, referring to the practice of Zeng Xinfeng and Huang Haiyan (2022) [31], using 2013 as the base period, the fixed asset investment index is used for deflation. Finally, the international general perpetual inventory method is used to estimate the total capital input of the sports industry from 2013 to 2022. Expected output is represented by operating income. In order to eliminate the influence of price factors, taking 2013 as the base period, the operating income of the

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 5 December 2024 doi:10.20944/preprints202412.0439.v1

sports manufacturing industry is deflated by the producer price index (PPI), and the operating income of the sports service industry is deflated by the consumer price index (CPI). Considering that "three wastes" are usually relatively comprehensive variables for measuring pollution emissions, the main controlled pollutants of China's environmental regulations include chemical oxygen demand and sulfur dioxide [32]. Drawing on the practices of Pang Ruizhi and Deng Zhongqi (2014), Wang Bing (2010) and others [33,34], chemical oxygen demand (COD) and sulfur dioxide (SO2), the main pollutants in water and air, are taken as the "undesired" output of the sports industry.

Table 1. Index system for measuring the green total factor productivity of the sports industry.

Indicator type	Indicator name	Indicator representation
Input indicators	Asset input of sports manufacturing industry	Input indicators Asset input of sports manufacturing industry Total assets of cultural, artistic, sports and entertainment products manufacturing industry grouped by region × corresponding stripping coefficient (i.e., total assets of national sports goods manufacturing industry / total assets of national cultural, artistic, sports and entertainment products manufacturing industry)
	Asset input of sports service industry	Total assets of enterprise legal person units in culture, sports and entertainment industry grouped by region × corresponding stripping coefficient (i.e., total assets of national sports service industry enterprise legal person units / total assets of national culture, sports and entertainment industry enterprise legal person units)
	Labor input of sports manufacturing industry	Average number of employees in cultural, artistic, sports and entertainment products manufacturing industry grouped by region × corresponding stripping coefficient (i.e., average number of employees in national sports goods manufacturing industry / average number of employees in national cultural, artistic, sports and entertainment products manufacturing industry)
	Labor input of sports service industry	Number of employees of enterprise legal person units in culture, sports and entertainment industry grouped by region × corresponding stripping coefficient (i.e., number of employees of national sports service industry enterprise legal person units / number of employees of national culture, sports and entertainment industry enterprise legal person units)
	Asset input of sports industry	Total assets of sports manufacturing industry + total assets of sports service industry
	Labor input of sports industry	Number of employees in sports manufacturing industry + number of employees in sports service industry

 doi:10.20944/preprints202412.0439.v1

Expected output	Operating income of sports manufacturing industry	Operating income of cultural, artistic, sports and entertainment products manufacturing industry grouped by region × corresponding stripping coefficient (i.e., operating income of national sports goods manufacturing industry / operating income of national cultural, artistic, sports and entertainment products manufacturing industry)
	Operating income of sports service industry	Operating income of enterprise legal person units in culture, sports and entertainment industry grouped by region × corresponding stripping coefficient (i.e., operating income of national sports service industry enterprise legal person units / operating income of national culture, sports and entertainment industry enterprise legal person units)
	Operating income of sports industry	Operating income of sports manufacturing industry + operating income of sports service industry
Undesired output	Sulfur dioxide (SO2) of sports manufacturing industry	Industrial sulfur dioxide (SO2) × (total output value of national sports industry / total output value of national industry)
	Chemical oxygen demand (COD) of sports service industry	Total discharge of domestic chemical oxygen demand (COD) × (number of employees in urban units of sports service industry / urban permanent population at the end of the region)
	Sulfur dioxide (SO2) of sports service industry	Total discharge of domestic sulfur dioxide (SO2) × (number of employees in urban units of sports service industry / urban permanent population at the end of the region)
	Chemical oxygen demand (COD) of sports industry	Chemical oxygen demand (COD) of sports manufacturing industry + chemical oxygen demand (COD) of sports service industry
	Sulfur dioxide (SO2) of sports industry	Sulfur dioxide (SO2) of sports manufacturing industry + sulfur dioxide (SO2) of sports service industry

2.3. Theoretical Framework and Method Selection

2.3.1. Construction of Production Possibility Set

In this paper, each province is regarded as a production decision-making unit to construct the best practice boundary of China's sports industry production in each period. In order to incorporate environmental factors into the productivity analysis framework, the paper first constructs a production possibility set (i.e., environmental technology) that contains both "desired" output and "undesired" output according to Fare et al (2007) [35]. Suppose each province k (k = 1,..., K) uses N kinds of inputs $x=(x_1,\dots,x_N)\in R_N^+$ to produce M kinds of "desired" outputs $y=(y_1,\dots,y_M)\in R_M^+$ and I kinds of "undesired" outputs $b=(b_1,\dots,b_I)\in R_I^+$ in each period t (t = 1,..., T). Under the assumptions that the production feasibility set satisfies closed set bounded set, "desired" output and input are freely disposable, zero-combination axiom and weak disposability axiom of output [36], the current data envelopment analysis (DEA) production possibility set is modeled as:

 doi:10.20944/preprints202412.0439.v1

$$P^t(x^t) = \left\{ \begin{array}{l} (y^t, b^t): \sum_{k=1}^{K} z_k^t y_{km}^t \geq y_{km}^t, m = 1, \cdots, M; \sum_{k=1}^{K} z_k^t b_{ki}^t = b_{ki}^t, i = 1, \cdots, I; \\ \sum_{k=1}^{K} z_k^t x_{kn}^t \leq x_{kn}^t, n = 1, \cdots, N; \sum_{k=1}^{K} z_k^t = 1, z_k^t \geq 0, k = 1, \cdots, K \end{array} \right\}$$

z_k^trepresents the weight of each cross-sectional observation value. The two constraint conditions that the sum of weight variables is 1 and non-negative indicate that the production technology has constant returns to scale (CRS). If the constraint that the sum of weight variables is 1 is removed, it indicates variable returns to scale (VRS).

2.3.2. Super-Efficiency SBM-DEA

The DEA model is a scientific analysis method for non-parametric efficiency analysis from the perspective of relative comparison of evaluated objects and can realize multi-input and multi-output evaluation. However, ordinary DEA models are all radial angles, that is, inputs and outputs are enlarged or reduced in the same proportion. When there are non-zero slack inputs or outputs, radial DEA usually overestimates the efficiency value of DMU. To overcome the defects of ordinary DEA models, Tone (2001) [37] proposed a non-radial and non-angular SBM-DEA model based on slack, which solves the problem of low measurement accuracy caused by slack in input, expected output and undesired output indicators. However, there is still a problem that it is impossible to distinguish multiple effective decision-making units (DUM) with a relative efficiency of 1. To make up for this defect, Tone (2002) [38] proposed the SE-SBM (Super efficiency-Slack Based Measure) model. The formula is as follows:

$$\rho^* = min \frac{\frac{1}{m}\sum_{i=1}^{m}\frac{\overline{x}}{x_{ik}}}{\frac{1}{q_1+q_2}\left(\sum_{r=1}^{q_1}\frac{\overline{y}^d}{y_{rk}^d}+\sum_{q=1}^{q_1}\frac{\overline{y}^b}{y_{qk}^b}\right)}, s.t. \begin{cases} x \geq \sum_{j=1,\neq k}^{n} \gamma_j x_{ij}, i = 1,2,\cdots,m \\ \overline{y}^d \leq \sum_{j=1,\neq k}^{n} \gamma_j y_{rj}^d, r = 1,2,\cdots,q_1 \\ \overline{y}^b \leq \sum_{j=1,\neq k}^{n} \gamma_j y_{qj}^b, q = 1,2,\cdots,q_2 \\ \overline{x} \geq x_k, \overline{y}^d \leq y_k^b, \gamma_j \geq 0, j = 1,2,\cdots,n \end{cases} \tag{2}$$

In Equation (2), m represents the number of input indicators, q_1 represents the number of desired outputs, q_2 represents the number of undesired outputs, x, y^d and y^b are input, desired output and undesired output respectively; $\overline{y}^d$ represents the deficiency of desired output, $\overline{x}$ and $\overline{y}^b$ represent the redundancy of input and undesired output respectively; ρ^* represents efficiency and can be greater than 1.

2.3.3. HMB Index

With the super-efficiency SBM-DEA function, the total factor productivity index can be constructed. At present, the Malmquist index method is mostly used. However, the index constructed by this method is either from the input perspective or from the output perspective, and the selection is arbitrary. Moreover, there are great differences in technical results from different perspectives and they are incomparable. It cannot decompose the growth rate of scope efficiency and the growth rate of scale efficiency at the same time. In view of the inherent defects of the Malmquist productivity index such as incomplete decomposition and decomposition failure under variable returns to scale, O'Donnell (2008) based on the research results of Hicks (1961), Moorsteen (1961), Bjurek (1996), etc., defined a new productivity index by taking the ratio of the Malmquist output quantity index and the Malmquist input quantity index, and named it Hicks-Moorsteen productivity index method (TFPHM). It can not only be constructed by using the ratio of the Malmquist index from the output perspective and the input perspective, which fully conforms to the definition of total factor productivity, but also can accurately measure and completely decompose the total factor productivity growth rate under any returns to scale, which is superior to the Malmquist index method. Combined with O'Donnell (2008)'s definition of the TFPHM index, the TFPHM formula can be expressed as:

$$TFP_{HM}^{jt,j't'} = [\frac{d_o^{t'}\left(x_{j'}^{t'},y_{j'}^{t'}\right)d_o^t\left(x_{j'}^{t},y_{j'}^{t'}\right)}{d_o^{t'}\left(x_{j'}^{t'},y_j^t\right)d_o^t\left(x_j^t,y_j^t\right)} \Big/ \frac{d_I^{t'}\left(x_{j'}^{t'},y_{j'}^{t'}\right)d_I^t\left(x_{j'}^{t'},y_j^t\right)}{d_I^{t'}\left(x_j^t,y_{j'}^{t'}\right)d_o^t\left(x_j^t,y_j^t\right)} \tag{3}$$

TFPHM can be further decomposed into the growth rate of technical level ΔTL^* and the growth rate of efficiency ΔE. See formula (4):

$$TFP_{HM}^{jt,j't'} = \frac{TL^{t'^*}}{TL^{t^*}} \times \frac{E_{j'}^{t'}}{E_j^t} = \Delta TL^* \times \Delta E \tag{4}$$

In the formula (4), the efficiency growth rate ΔE can be further decomposed into ΔTE、ΔSE and ΔRE. See formula (5):

$$TFP_{HM}^{jt,j't'} = \frac{TL^{t'^*}}{TL^{t^*}} \times \frac{E_{j'}^{t'}}{E_j^t} = \frac{TL^{t'^*}}{TL^{t^*}} \times \left(\frac{TE_{j'}^{t'}}{TE_j^t} \times \frac{SE_{j'}^{t'}}{SE_j^t} \times \frac{RE_{j'}^{t'}}{RE_j^t}\right) = \Delta TL^* \times \Delta TE \times \Delta SE \times \Delta RE \tag{5}$$

In formula (5), ΔTL^* represents the maximum achievable growth in technical level from period t to period t', that is, the technical progress index of the movement of the production frontier; ΔTE represents the technical productivity index of the observation point moving towards the frontier surface from period t to period t'; ΔSE represents the scale productivity index of the observation point moving on the frontier surface from period t to period t' to achieve economies of scale; ΔRE represents the range productivity index of the observation point adjusting the output ratio from period t to period t' to obtain economies of scope.

$$HMB(x_{t+1},y_{t+1},x_t,y_t) = M_O(x_{t+1},y_{t+1},x_t,y_t) / \ M_I(x_{t+1},y_{t+1},x_t,y_t), \tag{6}$$

In formula (6), $M_O(x_{t+1},y_{t+1},x_t,y_t)$ and $M_I(x_{t+1},y_{t+1},x_t,y_t)$ respectively represent the Malmquist index from the output perspective and the input perspective. Referring to the practice of Guo Junhua (2011), the Hicks-Moorsteen TFP index is decomposed as follows:

$$lnHMB(x_{t+1},y_{t+1},x_t,y_t) = lnT_C + lnP_C + lnS_C + \ln M_E \ , \tag{7}$$

In formula (7), T_C represents the technological progress index, P_C represents the pure technical efficiency index, S_C represents the scale efficiency index, and M_E is the mixed effect index of input and output. M_E indicates that changes in input and output quantities will also have an impact on changes in the green total factor productivity of the sports industry. It reflects the part that is not reflected by technological progress, technical efficiency, and scale efficiency. In addition to having the properties of general indexes, the decomposition of HMB is also complete, avoiding the defect of the Malmquist index being decomposed only from one perspective. In view of this, this paper chooses the HMB index to calculate the changes in the green total factor productivity of China's sports industry and decompose it, and then explain the changing trends and reasons of each part.

2.4. Data Sources and Processing

All index data in this paper are from "China Statistical Yearbook on Tertiary Industry", "China Industrial Statistical Yearbook", "China Environmental Statistical Yearbook", "China Statistical Yearbook" and "China Economic Census Yearbook". Considering that some statistical data of the sports industry intersect with the cultural, educational, artistic and entertainment industries, in order to make the data accurately reflect the real situation of the sports industry, relevant data stripping processing is carried out with reference to the relevant data stripping idea [39]. This method has been used in related research on marine industry, aging industry, sports industry, etc. It is a relatively mature statistical method and has theoretical and practical significance for solving the industrial statistical approach with cross-industry characteristics. The data stripping process of relevant indicators in this study is as follows.

The stripping coefficients of total assets, average number of employees, and main business income of sports manufacturing industry are respectively obtained from the proportion of total assets of sports goods manufacturing industry in the total assets of cultural, educational, artistic, sports and entertainment products manufacturing industry, and the proportion of main business income of

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 5 December 2024 doi:10.20944/preprints202412.0439.v1

sports goods manufacturing industry in the main business income of cultural, educational, artistic, sports and entertainment products manufacturing industry in the industry-by-industry data of "China Industrial Statistical Yearbook"; The stripping coefficients of total assets, number of employees, and main business income of sports service industry are respectively obtained from the proportion of total assets of sports enterprises in the total assets of cultural, sports and entertainment enterprise legal person units, the proportion of employees of sports enterprises in the number of employees of cultural, sports and entertainment enterprise legal person units, and the proportion of main business income of sports enterprises in the main business income of cultural, sports and entertainment enterprise legal person units in the main indicators by industry of service enterprise legal person units in "Statistical Yearbook on Tertiary Industry". The relevant data of cultural, sports and entertainment enterprise legal person units here are obtained by merging the relevant data of enterprises in the press and publication industry, radio, television, film and audio-visual industry, cultural and artistic industry, sports and entertainment industry, etc. For specific stripping coefficients, see Table 2.

Table 2. Stripping coefficients.

Indicator \ Year	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Average employment in sports manufacturing	0.121	0.120	0.115	0.116	0.107	0.099	0.130	0.139	0.147	0.154
Employees in sports service industry	0.093	0.094	0.091	0.092	0.096	0.103	0.103	0.105	0.094	0.108
Total assets of sports manufacturing	0.105	0.098	0.096	0.097	0.100	0.103	0.111	0.117	0.123	0.131
Total assets of sports service industry	0.091	0.090	0.170	0.135	0.076	0.093	0.095	0.098	0.095	0.102
Operating income of sports manufacturing	0.089	0.087	0.088	0.087	0.088	0.090	0.095	0.108	0.112	0.110
Operating income of sports service industry	0.058	0.059	0.060	0.065	0.076	0.073	0.075	0.072	0.068	0.072
Total output value of sports industry	0.033	0.038	0.048	0.049	0.049	0.044	0.044	0.039	0.036	0.036

3. Empirical Analysis

3.1. Analysis of HMB Index of Sports Industry and Its Sub-Sectors

According to the HMB index method, the green total factor productivity of China's sports industry and its sub-sectors is calculated (see Table 3). As can be seen from Table 3, from 2013 to 2022, without considering the impact of environmental factors, the average value of China's sports industry HMB index is 1.016, which is higher than the average value of HMB index of 1.003 considering the impact of environmental factors. This indicates that the production and business activities of the sports industry generally have an adverse impact on the environment. This is consistent with the research results of Chen Jinghua (2020) [40]. Therefore, to truly measure the high-quality development of China's sports industry, it is necessary to calculate the HMB index of the sports industry under environmental constraints.

From the time trend perspective, from 2013 to 2022, China's sports industry HMB index generally shows a wavy upward trend, and the average annual growth rate of GTFPHM is 0.3%. Especially from 2014 to 2017, influenced by favorable national policies, the sports industry ushered in a spring of development. The sports industry HMB index increased year by year and was always

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 5 December 2024 doi:10.20944/preprints202412.0439.v1

greater than 1, indicating that the green total factor productivity of China's sports industry has been continuously improved in these years. However, after 2018, China's economy encountered a "capital winter". Coupled with the impact of the epidemic since 2019, China's sports industry HMB index has been declining all the way from 2018 to 2022. Although there was a short-term rebound from 2020 to 2021, the overall average value is less than 1, indicating that the high-quality development of China's sports industry is hindered by the general economic environment.

From the perspective of sub-sectors, China's sports service industry is similar to the sports industry as a whole. The average value of HMB index without considering the impact of environmental factors is 1.062, which is higher than the average value of HMB index of 0.999 considering the impact of environmental factors. On the contrary, for sports manufacturing, the average value of HMB index without considering the impact of environmental factors is 1.037, which is lower than the average value of HMB index of 1.059 considering the impact of environmental factors. This indicates that during the research period, sports manufacturing has increased its investment in pollution control in the production process, but the investment in pollution control in sports service industry is relatively small, resulting in the fact that the productivity is falsely high when environmental factors are not considered.

Table 3. HMB index of China's sports industry and its sub-sectors from 2013 to 2022.

Time interval	HMB index without considering environmental factors			HMB index considering environmental factors		
	Sports industry	Sports manufacturing	Sports service industry	Sports industry	Sports manufacturing	Sports service industry
2013-2014	0.780	1.137	0.609	0.722	1.014	0.573
2014-2015	1.106	1.082	1.118	1.024	0.983	1.039
2015-2016	1.098	1.061	1.209	1.161	1.130	1.292
2016-2017	1.225	1.020	1.652	1.255	1.140	1.538
2017-2018	1.061	1.089	1.129	0.932	1.243	0.850
2018-2019	1.010	0.895	0.989	0.985	0.898	0.949
2019-2020	0.870	0.961	0.728	0.968	1.057	0.790
2020-2021	1.129	1.200	1.062	1.076	1.124	1.055
2021-2022	0.868	0.887	1.062	0.906	0.943	0.909
mean	1.016	1.037	1.062	1.003	1.059	0.999

From a regional perspective, from 2013 to 2022, without considering the impact of environmental factors, the HMB productivity index (TFP_{HM}) of China's sports industry is greater than 1 in all three major regions except for the central region (with an average annual decrease of 0.7%). Among them, the TFP_{HM} in the western region is the highest (with an average annual growth of 3.8%), followed by the eastern region (with an average annual growth of 0.8%) and the northeastern region (with an average annual growth of 0.2%). However, considering the impact of environmental factors, the $GTFP_{HM}$ index in China's eastern and northeastern regions is greater than 1. Among them, the $GTFP_{HM}$ in the eastern region is the highest (with an average annual growth of 3.3%), followed by the northeastern region (with an average annual growth of 0.3%). However, the $GTFP_{HM}$ index in the central and western regions is less than 1. Among them, the central region has an average annual decrease of 2.3%, and the western region has an average annual decrease of 0.9% (see Table 4). This result shows that in recent years, the development of the sports industry in central and western China, especially in the western region, is still in a relatively extensive development stage. While the northeastern region, especially the eastern region, belongs to an environmentally friendly

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 5 December 2024 doi:10.20944/preprints202412.0439.v1

development area for the sports industry. The $GTFP_{HM}$ considering environmental impacts is higher than the TFP_{HM} without considering environmental impacts.

From within the region, most provinces (municipalities directly under the Central Government) in China's eastern region belong to environmentally friendly provinces (municipalities directly under the Central Government), but there are relatively few in other regions. That is, within the same region, there are also certain differences in $GTFP_{HM}$ of the sports industry in different provinces (municipalities directly under the Central Government). For example, in the eastern region, except for Tianjin and Hainan, the other eight are all environmentally friendly provinces (municipalities directly under the Central Government), accounting for 80% of the eastern region. However, in the central region, only Anhui and Henan are environmentally friendly provinces (accounting for 33% of the central region). In the northeastern region, only Liaoning is an environmentally friendly province (accounting for 33% of the northeastern region). In the western region, only Guangxi and Qinghai are environmentally friendly provinces (accounting for 17% of the western region) (see Table 4).

Table 4. HMB productivity index and its decomposition index of sports industry in various provinces and municipalities from 2013 to 2022.

Region	TFP_{HM}	$GTFP_{HM}$	ΔTL^*	ΔTE	ΔSE	ΔRE	Region	TFP_{HM}	$GTFP_{HM}$	ΔTL^*	ΔTE	ΔSE	ΔRE
Beijing✱	1.046	1.090	1.107	1.084	1.054	0.981	Inner Mongolia	0.968	0.962	0.944	1.017	0.987	1.031
Tianjin	1.036	1.033	1.063	1.008	0.997	0.972	Guangxi✱	0.963	0.964	0.950	1.001	0.992	1.036
Hebei✱	0.929	0.963	0.986	0.975	0.994	1.006	Chongqing	1.012	0.989	0.956	1.028	0.999	1.002
Shanghai✱	1.056	1.126	1.074	1.037	1.000	1.007	Sichuan	1.029	1.005	0.961	1.037	0.999	1.002
Jiangsu✱	0.990	1.000	1.009	1.011	1.015	0.999	Guizhou	1.048	0.981	0.936	1.049	1.008	1.002
Zhejiang✱	0.994	1.012	1.054	1.014	1.003	0.968	Yunnan	0.997	0.972	0.947	1.020	0.996	1.009
Fujian✱	1.037	1.066	1.037	1.015	1.000	1.001	Tibet	1.100	0.978	0.957	1.000	1.045	1.558
Shandong✱	0.916	0.949	1.008	0.945	1.002	1.011	Shaanxi	0.980	0.953	0.959	1.001	0.996	1.005
Guangdong✱	0.993	1.041	1.047	0.999	1.003	1.014	Gansu	0.976	0.970	0.937	1.021	0.991	1.043
Hainan	1.089	1.048	1.025	1.091	1.017	1.008	Qinghai✱	0.881	0.950	0.985	1.149	1.007	1.096

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 5 December 2024 doi:10.20944/preprints202412.0439.v1

Eastern	1.008	1.033	1.041	1.018	1.008	0.997	Ningxia	1.051	1.014	1.026	1.235	1.065	1.137
Shanxi	1.004	0.990	0.947	1.045	0.995	1.024	Xinjiang	1.457	1.156	0.932	1.200	0.998	1.050
Anhui✱	0.944	0.946	0.961	0.987	0.998	1.000	**Western**	1.038	0.991	0.957	1.063	1.007	1.081
Jiangxi	0.977	0.941	0.942	1.002	0.999	1.000	Liaoning✱	0.905	0.949	0.989	0.963	0.989	1.020
Henan✱	0.942	1.000	1.009	0.990	0.998	0.997	Jilin	1.068	1.045	0.953	1.060	0.993	1.036
Hubei	1.037	0.977	0.940	1.041	1.001	0.997	Heilongjiang	1.032	1.016	0.951	1.064	1.000	1.037
Hunan	1.050	1.007	0.956	1.053	1.000	0.999	**Northeastern**	1.002	1.003	0.965	1.029	0.994	1.031
Central	0.993	0.977	0.959	1.020	0.999	1.003							

Note: The provinces (municipalities directly under the Central Government) with "⁎" are environmentally friendly provinces (municipalities directly under the Central Government) for the sports industry. The TFP_{HM} value of the sports industry in this type of province (municipality directly under the Central Government) is less than the $GTFP_{HM}$, and the value of GTFPHM in this province (municipality directly under the Central Government) is greater than 1.

3.2. Contribution Analysis of Decomposition Index of Sports Industry HMB Index

From the time trend perspective, the improvement of China's sports industry's green total factor productivity from 2013 to 2014 was mainly due to economies of scope, but from 2021 to 2022, it was mainly due to scale efficiency and pure technical efficiency (see Figure 1). From the average value perspective, the improvement of China's sports industry's green total factor productivity from 2013 to 2022 was mainly due to the improvement of pure technical efficiency, followed by the improvement of the range productivity index obtained by the change of input and output ratio, and the third was due to the improvement of scale efficiency. However, the contribution of the technological progress index not only did not increase, but decreased instead (see Table 5). The research results show that since 2013, under the influence of favorable national policies, on the supply side, both the macroscopic national level and the microscopic enterprise level have carried out relevant institutional reforms and adjustments to sports, continuously improving the management level of the sports industry. As a result, the pure technical efficiency has increased by an average of 3.7% per year, with remarkable results. Secondly, under the influence and incentive of favorable national policies, on the demand side, personalized and diversified sports demands have become an important development trend in the market. In order to meet the growing demands of consumers, sports enterprises also continuously increase and innovate the categories of sports products. As a result, the range productivity index has increased by an average of 3.4% per year, which largely meets the constantly changing sports demands of the masses. Of course, under the influence of favorable national policies, the investment of all parties in the sports industry has also begun to increase, and the scale efficiency has increased by an average of 0.5% per year. But unfortunately, in the process of the rapid development of the sports industry, less attention has been paid to the investment in pure technological progress. As a result, this index has decreased by an average of 1.5% per year, bringing a negative impact on the growth of the green total factor productivity of the sports industry.

Table 5. China's sports industry's green total factor productivity ($GTFP_{HM}$) and its decomposition index from 2013 to 2022.

Index / Year	$GTFP_{HM}$	ΔTL^*	ΔTE	ΔSE	ΔRE
2013-2014	0.722	0.718	0.966	0.963	1.094
2014-2015	1.024	1.046	0.984	1.004	0.993
2015-2016	1.161	0.987	1.293	0.849	1.340
2016-2017	1.255	1.188	1.100	1.083	0.916
2017-2018	0.932	0.966	0.966	1.028	0.993
2018-2019	0.985	0.994	1.018	0.998	1.019
2019-2020	0.968	1.033	0.962	0.992	1.026
2020-2021	1.076	1.081	0.983	1.062	0.976
2021-2022	0.906	0.855	1.060	1.063	0.948
mean	1.003	0.985	1.037	1.005	1.034

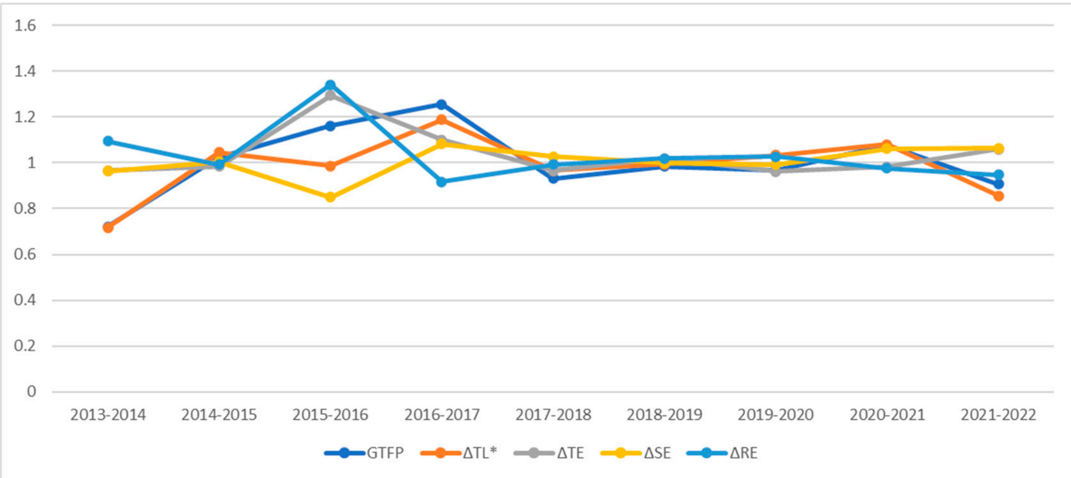


Figure 1. Green total factor productivity of China's sports industry ($GTFP_{HM}$) and its decomposition indexes from 2013 to 2022.

From the perspective of the contribution of different decomposition indexes to the growth and change of regional sports industry $GTFP_{HM}$, the highest contributor in the eastern region is the technological progress index (with an average annual growth of 4.1%). In the central region, the highest contributor is pure technical efficiency (with an average annual growth of 2%). In the western and northeastern regions, the highest contributor is the scope productivity index (with an average annual growth of 8.1% and 3.1% respectively). However, the scope productivity index in the eastern region (with an average annual decrease of 0.3%), the technological progress index in the central, western, and northeastern regions (with an average annual decrease of 4.1%, 4.3%, and 3.5% respectively), and the scale efficiency index in the central and northeastern regions (with an average annual decrease of 4.1% and 4.3% respectively) all show significant declines. This result indicates that in recent years, with the strong support of the state for the development of the sports industry, the eastern region has mainly increased its technological investment in the sports industry. The central region has mainly strengthened the reform and innovation of its management and institutions. The northeastern region, especially the western region, has made relatively large adjustments and optimizations to the input and output of sports industry products, with obvious economies of scope. However, the central and western regions and the northeastern region still urgently need to further increase technological investment to improve the technological level of their sports industries. The scale efficiency of the sports industries in the central and northeastern regions has not been fully released and needs to be improved. The scope economic benefits of the eastern region still need to be further strengthened.

3.3. Regional Difference Analysis

3.3.1. Convergence Analysis of Regional Differences

Using Stata16 software technology to calculate the Theil index for the green total factor productivity of the sports industry in China's four major economic regions from 2014 to 2022, and measure the inter-group and intra-group differences (see Figures 2 and 3). Judging from the overall Theil index, the inter-regional differences showed a "zigzag" fluctuation from 2014 to 2018. It decreased rapidly from 2018 to 2019. After that, the fluctuation amplitude was significantly reduced, but there was still a spontaneous divergence trend. From 2014 to 2022, the intra-group Theil index was basically consistent with the change trend of the overall Theil index. The inter-group Theil index was relatively small, but overall it also showed a wave-like upward trend. This result indicates that during the research period, regional differences mainly came from intra-group differences, and the inter-group differences were small.

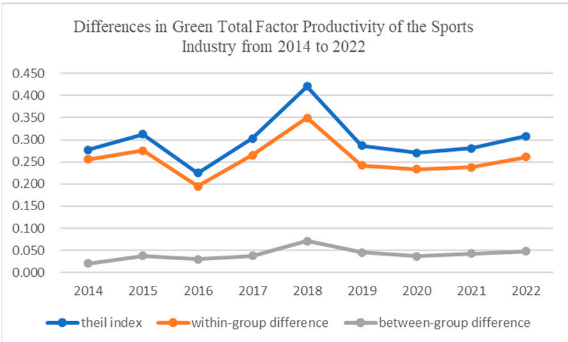


Figure 2. Regional differences in green total factor productivity of the sports industry.

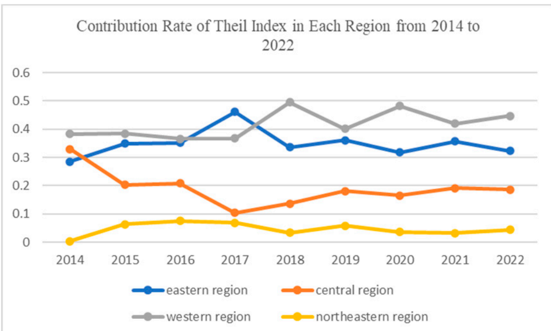


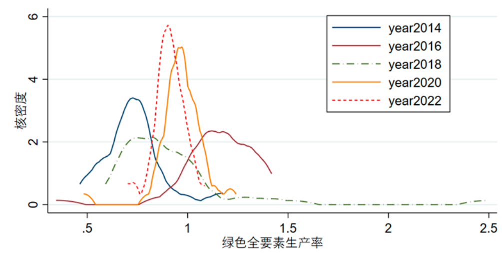
Figure 3. Contribution rate of Theil index in each economic region.

From the perspective of the contribution rate of each economic region to the overall Theil index in Figure 3, from 2014 to 2022, the contribution rates of the western region and the eastern region to the total regional difference are in a complementary fluctuating state and are the main sources of the total difference. Among them, the eastern region shows a wave-like downward trend, but the western region has a gradually rising trend and is the main source of future regional differences. The central region ranks third. In this region, there was a sharp decline from 2014 to 2017, and after 2017, there was a small wave-like upward trend. The overall contribution degree is relatively stable. The northeastern region has the smallest overall contribution.

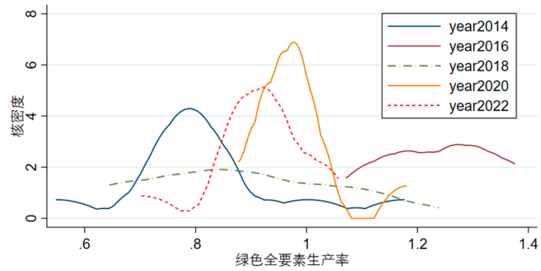
3.3.2. Kernel Density Estimation Analysis of Regional Differences

There are obvious regional differences in GTFP$_{HM}$ of the sports industry. In order to clearly explore the evolution process of its regional differences as time goes by, this article uses the Gaussian kernel density function to analyze its evolution law. Figure 3 depicts the Gaussian kernel density distribution in representative years 2014, 2016, 2019, 2020, and 2022. The horizontal axis represents the efficiency value of green total factor productivity, and the vertical axis represents the kernel density value.

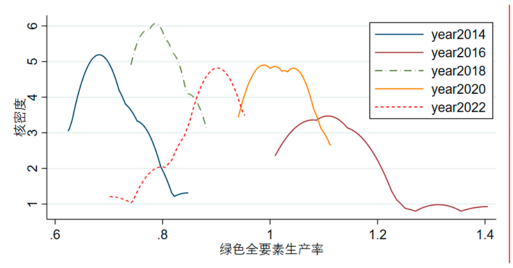
At the national level (see Figure 4a), in terms of displacement, the Gaussian kernel density curve generally shows a trend of moving from left to right from 2014 to 2022, indicating that the efficiency value of green total factor productivity of China's sports industry shows a gradually increasing trend. In terms of basic form, all generally show a unimodal form, indicating that the efficiency values of most regions are relatively concentrated and there is no serious polarization phenomenon. In terms of kurtosis strength, the peak value of the kernel density curve shows a gradually increasing trend from 2014 to 2022, indicating that the distribution concentration of GTFP$_{HM}$ in the sports industry is gradually increasing and the regional differences are becoming smaller.



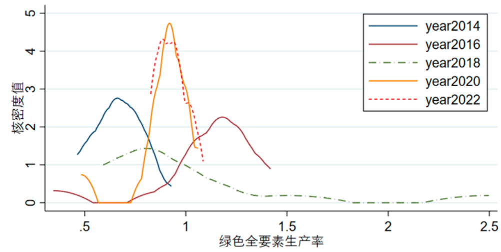
(a) Nationwide



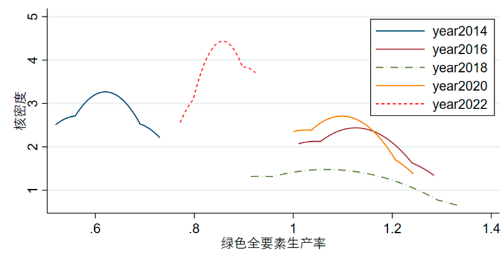
(b) Eastern region



(c) Central region



(d) Western region



(e) Northeastern region

Figure 4. Kernel density distribution and evolution trend chart of GTFP$_{HM}$ in representative years from 2014 to 2022.

At the regional level (see Figure 4b–e), the centers of the kernel density curves of the four major regions all move to the right during the sample period, indicating that the GTFPHM of the four major regions generally shows a growth trend. The peak value of the eastern region generally increases, indicating that the gap in GTFP$_{HM}$ of the sports industry in the eastern region shows a trend of narrowing; but in 2022, the left tail is significantly longer than in other years, indicating that the decline trend in some provinces and cities in the eastern region is relatively obvious. The peak value

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 5 December 2024 doi:10.20944/preprints202412.0439.v1

of the kernel density curve in the central region generally shows a downward trend, indicating that the concentration of $GTFP_{HM}$ in the central region has decreased and the interval gap is widening; but in 2022, the left tail is significantly longer than in other years, indicating that there is also an obvious decline trend in some provinces and cities in the central region. The peak value of the kernel density curve in the western region generally shows an upward trend, indicating that the concentration of $GTFP_{HM}$ in the western region has increased and the interval gap is narrowing; in addition, the long right tail indicates that the upward trend in some provinces and cities in this region is relatively obvious. In 2022, the peak value in the northeastern region is significantly higher than in other years, indicating that the concentration of $GTFP_{HM}$ in the northeastern region has increased and the interval gap is narrowing; but the long left tail indicates that the decline trend in some provinces and cities in this region is relatively obvious.

3.4. State Transition Analysis of Green Total Factor Productivity

According to the cumulative distribution of green total factor productivity of the sports industry, green total factor productivity is divided into four level grades, namely low (I), medium-low (II), medium-high (III), and high (IV). Then, according to the range of different grades of efficiency values of 31 provinces (municipalities directly under the Central Government and autonomous regions) from 2014 to 2022, the state classification is carried out to obtain the individual frequencies at each grade, calculate the state transition probability, and finally determine the traditional and spatial Markov transition matrices. Among them, the elements on the main diagonal represent the probability of maintaining the original state, that is, there is no state transition; the elements off the main diagonal represent the probability of transitioning from one state to another. (Table 4).

3.4.1. Traditional Markov Transition Analysis

Analyzing the traditional Markov transition probability matrix, the results show that (Table 6): (1) Judging from the elements on the main diagonal of the matrix, the probability values on the main diagonal of the Markov transition probability matrix are all higher than the probability values off the main diagonal. The probabilities of low (I), medium-low (II), medium-high (III), and high (IV) maintaining their initial states are 72.73%, 38.30%, 38.30%, and 59.52% respectively, all of which are greater than the probability of transitioning to other states. Among them, the probabilities of maintaining the initial state at low and high levels are both greater than 50%. This result indicates that the probability of green total factor productivity of the sports industry at the provincial level retaining its initial state is relatively high. There is a club effect in the transfer of green total factor productivity of the sports industry, and there is a relatively obvious path dependence in its spatial distribution. (2) Judging from the transition direction of the elements off the main diagonal of the matrix, the probability of upward transfer of green total factor productivity of the sports industry in the Markov transition probability matrix is higher than the probability of downward transfer. For example, the proportion of medium-low (II) type in the matrix transferring to medium-high (III) and high (IV) types is 40.43%, which is significantly higher than the probability of transferring to low (I) type of 21.28%. Other types also have similar transfer laws, indicating that green total factor productivity of the sports industry has a trend of positive development, and China's sports industry tends to develop towards a higher efficiency level. (3) Judging from the probability of the difference in distance from the elements on the main diagonal, the probability value adjacent to the main diagonal is generally higher than the probability value not adjacent. For example, the probability of low (I) type transferring to medium-low (II) type in the matrix is 15.91%, which is greater than the probability of transferring to medium-high (III) type of 6.82%, and this value is greater than the probability of transferring to high (IV) type of 4.55%; the probability of medium-high (III) type in the matrix transferring to medium-low (II) type is 23.40%, which is greater than the probability of transferring to low (I) type of 6.38. This result indicates that the transfer of green total factor productivity of the sports industry has a certain dependence on the initial state type, and cross-level transfer is relatively difficult.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 5 December 2024 doi:10.20944/preprints202412.0439.v1

3.4.2. Spatial lag Markov transition analysis

Considering the efficiency state of adjacent regions in the calculation of the state transition probability of green total factor productivity of the sports industry, and constructing a spatial Markov transition probability matrix. The results show that: (1) When adjacent to low-level regions, generally it will not cause the efficiency value of below medium-high level in this region to decline, and its own productivity level is at least maintained at the original level, because the possibility of technological regression in actual production is relatively small. (2) The higher the productivity level of neighbors, the more conducive it is to the improvement of the productivity level of low-level regions. For example, when taking medium-low level as neighbors, the probability of low-level regions transferring to medium-low level is 11.76% respectively. However, when taking medium-high level as neighbors, the probability of low-level regions transferring to medium-low level increases to 28.57% respectively, an increase of 16.81 percentage points. (3) Medium-low level regions are more inclined to transfer upward, and the probability of upward transfer is greater when taking high-level regions as neighbors. For example, when taking low-level, medium-low level, medium-high level and high-level regions as neighbors, the probability of upward transfer of a medium-low level region is 100%, 33.33%, 33.33% and 100% respectively, while the probability of downward transfer is 0%, 25%, 22.22% and 0% respectively. Obviously, the probability of upward transfer is greater than the probability of downward transfer, and the probability of upward transfer is greater when taking high-level regions as neighbors. For example, although the probability of low-level and high-level neighbors promoting its transfer to high-level regions is 100%, the probability of low-level neighbors promoting its transfer to high-level regions is 33.33%, while the probability of high-level neighbors promoting its transfer to high-level regions increases to 50%, an increase of 16.67 percentage points. (4) Medium-high level regions are more inclined to move downward, but when adjacent to high-level regions, they are more inclined to transfer upward. For example, when the neighbor levels are medium-low and medium-high levels respectively, the probability of its own upward transfer is 33.33% and 28.57% respectively, and the probability of downward transfer is 38.89% and 35.71% respectively. However, when the neighbor level is high level, the probability of its own upward transfer is 33.33%, and the probability of downward transfer is 22.22%. (5) When adjacent to high-level regions, the phenomena of being friendly with neighbors and being hostile to neighbors coexist. For example, when taking high-level regions as neighbors, the probability of low-level regions maintaining their initial state increases to 87.50%. This may be because at this time, the sports production factor resources in low-level regions are more likely to flow to high-level regions, thus hindering the transfer of low-level regions to medium-low and high-level regions. However, the medium-low and medium-high level regions are obviously affected by the positive spatial spillover effect of high-level regions and are more inclined to transfer upward.

Table 6. Traditional and spatial Markov transition probability matrices of green total factor productivity of the sports industry (%)。.

Spatial lag classification	Status type in period T	L	ML	MH	H
Without lag	L	72.73	15.91	6.82	4.55
	ML	21.28	38.30	27.66	12.77
	MH	6.38	23.40	38.30	31.91
	H	7.14	7.14	26.19	59.52
Neighbors at low level	L	60.00	20.00	0.00	20.00
	ML	0.00	0.00	66.67	33.33
	MH	0.00	0.00	66.67	33.33
	H	0.00	0.00	25.00	75.00

Neighbors at medium-low level	L	76.47	11.76	11.76	0.00
	ML	25.00	41.67	25.00	8.33
	MH	11.11	27.78	27.78	33.33
	H	28.57	0.00	42.86	28.57
Neighbors at medium-high level	L	64.29	28.57	0.00	7.14
	ML	22.22	44.44	22.22	11.11
	MH	7.14	28.57	35.71	28.57
	H	0.00	13.33	20.00	66.67
Neighbors at high level	L	87.50	0.00	12.50	0.00
	ML	0.00	0.00	50.00	50.00
	MH	0.00	22.22	44.44	33.33
	H	8.33	8.33	25.00	58.33

4. Conclusions and Suggestions

4.1. Conclusions

The HBM index model is used to measure the green total factor productivity of the sports industry in 31 provinces (municipalities directly under the Central Government and autonomous regions) in China from 2013 to 2022. On this basis, the spatiotemporal evolution and state transition analysis are carried out. The following research conclusions are drawn:

(1) Calculating the sports industry HMB index, the results show that: From the time trend perspective, the green total factor productivity of China's sports industry as a whole showed a wave-like upward trend from 2013 to 2022. However, after 2018, due to the influence of the general environment such as the "capital winter" and the epidemic, the high-quality development of the sports industry was hindered. From the perspective of segmented industries, the sports manufacturing industry has increased investment in pollution process treatment, but the sports service industry has relatively less investment in pollution treatment, resulting in a false high productivity when environmental factors are not considered. By region, the GTFPHM index of the eastern region is the highest, with an average annual growth of 3.3%. Followed by the northeastern region with an average annual growth of 0.3%. However, the GTFPHM indexes of the central and western regions are both less than 1. From the intra-region perspective, most provinces (cities) in the eastern part of China belong to environment-friendly provinces (cities), but relatively few in other regions.

(2) Decomposing and calculating the sports industry HMB index for analysis, the results show that: From the time trend perspective, the improvement of the green total factor productivity of China's sports industry from 2013 to 2022 has shifted from mainly benefiting from economies of scope to scale efficiency and pure technical efficiency. From the average value perspective, from 2013 to 2022, the factor with the highest contribution to the improvement of the green total factor productivity of China's sports industry is pure technical efficiency, followed by scope productivity and scale efficiency. However, the technological progress index has not increased but decreased. From the regional perspective, the highest contributors in the eastern, central, western, and northeastern regions are the technological progress index (with an average annual growth of 4.1%), pure technical efficiency (with an average annual growth of 2%), and scope productivity index (with an average annual growth of 8.1% and 3.1% respectively). However, the scope productivity index in the eastern region, the technological progress index in the central, western, and northeastern regions, and the scale efficiency index in the central and northeastern regions have all decreased significantly.

(3) Using the Theil index and kernel density estimation for regional difference analysis, the results show that: From the perspective of regional difference convergence, the overall difference in

 doi:10.20944/preprints202412.0439.v1

the green total factor productivity of the sports industry in China's four major regions from 2014 to 2022 shows a wave-like upward trend. This difference mainly comes from intra-group differences, and the inter-group differences are relatively small. From the perspective of the contribution of each region to the total difference, the western and eastern regions contribute relatively more to the total difference, while the other two regions contribute relatively less. Moreover, the contribution of the eastern region to the total difference shows a wave-like downward trend, but the western region has a gradually rising trend and is the main source of future regional differences. From the perspective of the evolving process of continuous regional differences, the green total factor productivity of China's sports industry shows a gradually increasing trend. The efficiency values of most regions are relatively concentrated, and the concentration is gradually increasing, and the regional differences are becoming smaller. At the regional level, the eastern, western, and northeastern regions show a trend of narrowing gaps, while the gap in the central region is widening.

(4) Using traditional and spatial Markov transition matrices to calculate the state transition of green total factor productivity of the sports industry, the results show that: There is a club effect in the transfer of green total factor productivity of the sports industry, and the path dependence is obvious. The probability of upward transfer of green total factor productivity of the sports industry is higher than the probability of downward transfer. The transfer of green total factor productivity of the sports industry has a certain dependence on the initial state type, and cross-level transfer is relatively difficult. When adjacent to low-level regions, generally it will not cause the efficiency value of below medium-high level in this region to decline, and its own productivity level is at least maintained at the original level. The higher the productivity level of neighbors, the more conducive it is to the improvement of the productivity level of low-level regions. Medium-low level regions are more inclined to transfer upward, and the probability of upward transfer is greater when taking high-level regions as neighbors. Medium-high level regions are more inclined to move downward. When adjacent to high-level regions, the phenomena of being friendly with neighbors and being hostile to neighbors coexist.

4.2. Suggestions

(1) Strengthen publicity and guidance to deeply embed the concept of "ecological priority and green development" into the entire process of the development of the sports industry, especially the sports service industry. For a long time, the sports industry, especially the sports service industry, has been widely labeled as a green industry by the public, and it is considered a green and pollution-free industry. However, in fact, sports service industries such as sports events and sports tourism still have environmental pollution problems such as exhaust gas, wastewater, and solid waste emissions during the development process. The empirical results also prove that the sports service industry has relatively less investment in pollution treatment, resulting in false high productivity when environmental factors are not considered. Therefore, at the macro level, the government should further strengthen the publicity of the concept of green development, especially strengthening the publicity in the central and western regions, so that the whole society realizes that the sports industry is also a polluting industry and should also carry out pollution treatment and protection. And mobilize the masses to carry out mass supervision of related issues. At the same time, at the micro level, sports enterprises should carry out green development planning strategically and widely publicize and convey relevant development concepts to every enterprise employee. At the meso level, relevant government regulatory agencies should be set up for third-party supervision to ensure that pollution treatment is implemented in place.

(2) Further increase investment in science and technology, especially in the central, western, and northeastern regions. Since the release of the national "Document No. 46" in 2014, policy dividends have successively released the institutional management dividends, market demand dividends, and capital investment dividends of the sports industry, ultimately bringing about the improvement and greater contribution of pure technical efficiency, scope productivity, and scale productivity of the sports industry. However, there is relatively less investment in science and technology. Specifically

 doi:10.20944/preprints202412.0439.v1

by region, mainly the investment in science and technology in the central, western, and northeastern regions shows a downward trend, but the investment in the eastern region shows an upward trend. Therefore, the central, western, and northeastern regions should take the eastern region as a benchmark to further increase investment in science and technology and drive industrial scale growth and improvement in management efficiency with science and technology. The eastern region can further strengthen investment in technological advantages and maintain a leading level in science and technology to drive the improvement of product scope productivity with science and technology.

(3) Further improve and implement regional, especially intra-regional coordinated development mechanisms, and actively serve the national regional coordinated development strategy. Since the regional differences in the green total factor productivity of the sports industry mainly come from intra-group differences, and this difference mainly comes from the east and the west. However, the eastern difference shows a downward trend, and the western difference shows an upward trend, which is the main source of future differences. However, some provinces and cities in this region have an obvious upward trend. Considering that the transfer of green total factor productivity of the sports industry has a certain dependence on the initial state type, and cross-level transfer is relatively difficult. At the same time, there is a phenomenon where being friendly with neighbors and being hostile to neighbors coexist when adjacent to high-level regions. Therefore, we should follow the development law of the spatial transfer state of green total factor productivity of the sports industry. First, formulate relevant preferential policies to encourage high-level regions to lead and promote the sequential transfer of medium-high, medium-low, and low-level regions, promote the occurrence of the phenomenon of "being friendly with neighbors", and try to avoid the occurrence of the phenomenon of being hostile to neighbors.

Acknowledgements: The author is grateful for the financial support provided by the Jiangsu Excellent Project of Social Science Application Research (Project No:22SYB-118) and the university level training program of Nanjing Sport Institute (Project No:PY202103). Nanjing.

Conflict of Interest: The author declares no conflict of interest.

References

1. Xi Jinping. Hold high the great banner of socialism with Chinese characteristics and strive in unity to build a modern socialist country in all respects: Report at the 20th National Party Congress [M]. Beijing: People's Publishing House, 2022: 45.
2. Jiang Xiaojuan. China's sports industry: development trends and pillar status [J]. Journal of Management World, 2018, 34(05): 1-9.
3. Sports Pro. Beyond Cop26: Five Core Climate Challenges for the Sports Industry [EB/OL]. https://www.sportspromedia.com/from-the-magazine/cop26-climate-change-sport-sustainability-david-goldblatt-roger-mcclendonocean-race/,2021-11-10/2022-12-09.
4. National Energy Administration. How is the carbon emitted by the Beijing Winter Olympics "neutralized"? [EB/OL]. http://www.nea.gov.cn/2022-02/18/c_1310478262.html, 2022-02-19/2022-12-09.
5. IiMedia Research. Data analysis of China's sports shoe industry: In 2018, China's sports shoe production reached 1.09 billion pairs [EB/OL]. https://www.iimedia.cn/c1061/66136.html, 2019-09-23/2022-12-09.
6. The State Council. Notice of the State Council on Issuing the Action Plan for Carbon Peaking Before 2030 [EB/OL]. http://www.gov.cn/zhengce/content/2021-10/26/content_5644984.htm, 2021-10-26/2022-12-09.
7. Pearce D., Markandya A., Barbier E.B. Blueprint for a Green Economy[M]. UK, London, Earthscan Publications Ltd.,1989:211.
8. Pushpam K.The Economics of Ecosystems and Biodiversity: Ecological and Economic Foundations [R]. Nairobi: UNEP/Earth print, 2012.
9. Liu Fumin. Implement the "Opinions of the General Office of the State Council on Promoting National Fitness and Sports Consumption and Promoting the High-Quality Development of the Sports Industry" and Promote the Sports Industry to Become a Pillar Industry of the National Economy [J]. Journal of Sports Science, 2019, 39(10): 3-10. DOI: 10.16469/j.css.201910001.
10. Huang Haiyan. Deepen the integration of sports and technology and promote the high-quality development of the sports industry [J]. Journal of Sports Research, 2020, 41(05): 1.

11. Duan Yanling, Fu Zhihua, Chen Xi. Research on the impact of the servitization of China's sporting goods manufacturing industry on industrial transformation and upgrading [J]. Journal of Wuhan Institute of Physical Education, 2019, 53(11): 23-28.
12. Zhang Zhenfeng. The transformation and development path of the sports industry from the perspective of upgrading sports consumption demand [J]. Journal of Xi'an Institute of Physical Education, 2017, 34(04): 453-458.
13. Wang Kai, Tang Xiaohui, Gan Chang, Liu Haolong. Spatiotemporal pattern and influencing factors of carbon emission intensity of China's service industry [J]. China Population, Resources and Environment, 2021, 31(08): 23-31.
14. Wang Meng, Liu Dongfeng. Theoretical logic, practical dilemmas and implementation paths of digital technology empowering the low-carbon development of the sports industry [J]. Journal of Sports Research, 2022, 36(01): 71-80.
15. Lampe H W , Hilgers D . Trajectories of efficiency measurement: A bibliometric analysis of DEA and SFA[J]. European Journal of Operational Research, 2015, 240(1):1-21.
16. Liu H , Yang R , Wu J , et al. Total-factor energy efficiency change of the road transportation industry in China: A stochastic frontier approach[J]. Energy, 2020, 219(3):119612.
17. Sun Chuanwang, Lin Boqiang. Research on the allocation efficiency of energy elements and energy-saving potential of China's industrial sector [J]. The Journal of Quantitative & Technical Economics, 2014, 31(5): 14.
18. Tone K . A slacks-based measure of efficiency in data envelopment analysis[J]. European Journal of Operational Research, 2001, 130(3):498-509.
19. Chen Shiyi. China's green industrial revolution: An explanation from the perspective of total factor productivity of environment (1980-2008) [J]. Economic Research Journal, 2010(11): 15.
20. Shi Dan, Li Shaolin. Measurement and convergence research on green total factor productivity of patent-intensive industries in China [J]. Science & Technology Progress and Policy, 2020, 37(14): 76-85.
21. Mohsin M, Hanif I, Taghizadeh-Hesary F, et al. Nexus between energy efficiency and electricity reforms: A DEA-Based way forward for clean power development [J]. Energy Policy, 2021, 149: 112052.
22. Yuan Qian, Wu Lihua, Zhang Ping. Measurement and convergence research on green total factor productivity of patent-intensive industries in China [J]. Science & Technology Progress and Policy, 2020, 37(14): 76-85.
23. Yu J , Zhou K , Yang S . Regional heterogeneity of China's energy efficiency in 'new normal': A meta-frontier Super-SBM analysis[J]. Energy Policy, 2019, 134(Nov.):110941.1-110941.13.
24. Chen Y , Wang M , Feng C , et al. Total factor energy efficiency in Chinese manufacturing industry under industry and regional heterogeneities[J]. Resources Conservation and Recycling, 2020, 168(1):105255.
25. Stergiou E , Kounetas K E . Eco-efficiency convergence and technology spillovers of European industries[J]. Journal of Environmental Management, 2021, 283(4):111972.
26. Chen Lin, Xiao Qianbing, Lan Shujing. Evaluation of pollution control benefits of environmental policies based on the industrial structure threshold effect model: Taking the "Action Plan for Air Pollution Prevention and Control" as an example [J]. Resources Science, 2021, 43(02): 341-356.
27. Xie Xuemei, Zhu Qiwei. How can enterprises' green innovation practices solve the problem of "harmonious coexistence"? [J]. Journal of Management World, 2021, 37(01): 128-149 + 9.
28. Amoako S, Insaidoo M. Symmetric impact of FDI on energy consumption: Evidence from Ghana[J]. Energy, 2021(2009):120005.
29. Li Haijie, Shao Guihua, Wang Yi. Research on the impact of China's sports industry agglomeration on industrial efficiency [J]. Journal of Tianjin University of Sport, 2019, 34(6): 9.
30. Zhong Jingqiu, Cui Ruihua, Zhao Wenzhen, Wang Zeyu. Research on the spatial differentiation and coupling relationship of input-output-efficiency of China's sports industry [J]. Journal of Shenyang Sport University, 2018, 37(01): 41-50.
31. Zeng Xinfeng, Huang Haiyan. Sports industry agglomeration and total factor productivity: From the perspective of the sports industry in the Yangtze River Delta region [J]. China Sport Science and Technology, 2022, 58(7): 9.
32. Yu Yongze, Yang Xiaozhang, Zhang Shaohui. Research on the temporal and spatial transformation characteristics of China's economy from high-speed growth to high-quality development [J]. The Journal of Quantitative & Technical Economics, 2019, 36(6): 19.
33. Pang Ruizhi, Deng Zhongqi. Is the productivity of the service industry really low? [J]. Economic Research Journal, 2014(12): 86-99.
34. Chen Jinghua, Wang Susu. Research on the spatial differences and influencing factors of green total factor productivity growth in China's service industry [J]. Journal of Nanjing University of Finance and Economics, 2020(2): 12.

 doi:10.20944/preprints202412.0439.v1

36. Wang Bing, Wu Yanrui, Yan Pengfei. Regional environmental efficiency and environmental total factor productivity growth in China [J]. Economic Research Journal, 2010, 45(05): 95-109.
37. Tone K.A slacks-based measure of efficiency in data envelopment analysis[J].European Journal of Operational Research,2001,130(3):498-509.
38. Tone K.A slacks-based measure of super-efficiency in data envelopment analysis [J].European Journal of Operational Research,2002,143(1):32-41.
39. Han Yuanjun, Wu Pu, Lin Tan. Measurement and comparative analysis of tourism industry efficiency in representative provinces based on carbon emissions [J]. Geographical Research, 2015, 34(10): 1957-1970.
40. Chen Jinghua. Convergence analysis of green total factor productivity growth in China's service industry: A test from the perspective of industry heterogeneity [J]. Soft Science, 2020, 34(4): 7.