Journal of Ecohumanism
2024
Volume: 3, No: 6, pp. 1391 – 1411
ISSN: 2752-6798 (Print) | ISSN 2752-6801 (Online)
https://ecohumanism.co.uk/joe/ecohumanism
DOI: https://doi.org/10.62754/joe.v3i6.4120

Prospective Analysis and Innovative Path Research on Silver Sports Economy in the Context of Aging Society

Aihua Zhang[1]

Abstract

This study focuses on the prospects and innovative pathways for the development of the silver-haired sports economy in the context of an ageing society. The proportion of the global population over 65 years old is expected to increase from 9% in 2019 to 16% in 2050, highlighting the huge potential of the silver-hair economy. This paper adopts a mixed research methodology, combining spatial econometric modelling and rootedness theory, to explore in depth the current development status, trend forecasts and innovation paths of the silver-haired sports economy. The study constructs a silver-hair sports economy assessment system containing 22 indicators, and uses panel data to analyse the development level of 31 provinces, municipalities and autonomous regions in China from 2010 to 2023, and the results show that the average annual growth rate of silver-hair sports economy reaches 15.7%, but the gap between Beijing, Tianjin, Shanghai and Guangdong and the central and western regions reaches 1.8 times. Analyses based on the Spatial Durbin Model show that every 1 percentage point increase in silver-haired sports consumption can drive 0.3 percentage points of GDP growth in neighbouring regions. Through a Delphi method research of 150 industry experts, it is predicted that the size of China's silver-haired sports market will exceed RMB 3 trillion in 2030, increasing its share of GDP to 2%. The qualitative study reveals three innovative paths: intelligent transformation, ecosystem construction, and cross-border integration, and proposes specific strategies such as "integration of sports and medicine" and "social platform for silver sports". The results of the study provide data support and theoretical basis for the formulation of policies for the development of the silver sports economy, and provide important insights into the industrial transformation of an aging society.

Keywords: *Silver Hair Economy, Sports Industry, Population Ageing, Spatial Econometrics, Innovation Path, Intelligent Transformation.*

Introduction

Background of the Study

Since the 21st century, the global demographic structure is undergoing profound changes, and population ageing has become a major trend affecting the world's economic and social development (Tomizawa et al., 2020). According to the United Nations Department of Economic and Social Affairs (UN DESA), the proportion of the global population aged 65 and over is expected to grow from 9.3 per cent in 2019 to 15.9 per cent in 2050. China's aging process is even more significant, with data from the National Bureau of Statistics showing that by the end of 2023, China's population aged 60 and over had reached 297 million, accounting for 20.2 per cent of the total population (Jiang et al., 2023).

Table 1-1 Comparison of Global and Chinese Population Ageing Trends

vintages	Proportion of the global population over 65 years of age	Proportion of China's population over 60 years of age
2019	9.300 per cent	18.100%
2023	10.200 per cent	20.200 per cent
2050	15.900 per cent	34.900 per cent (forecast)

Data sources: UN DESA (2019), National Statistical Office (2024)

[1] Krirk University,10220, Khet Bang Khen, Krung Thep Maha Nakhon, Thailand, Yunnan Normal University, Kunming 650500, Yunnan, China, Email: zhangaihua_521@163.com, (Corresponding Author)

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Among the many segments of the silver-haired economy, the silver-haired sports economy is becoming an emerging field that has attracted much attention (Lee and Gim, 2020). This study defines the silver-haired sports economy as the sum of economic activities centred on sports consumption, sports product production, sports service provision and related supporting industries for people aged 50 and above. This definition covers a wide range of aspects, from the manufacture of sports equipment and the construction of venues and facilities to fitness guidance services and sports tourism (Kolak and Anselin , 2020).

Literature Review

Research on the silver economy began in the 1990s, and in the early years, it mainly focused on the macroeconomic impacts of population ageing, with Peterson (1999) pointing out that population ageing would affect labour supply, savings rate and capital accumulation, and Börsch-Supan (2003) finding significant differences in the consumption patterns of the elderly and the young in a cross-country comparative study. In the 21st century, scholars began to focus on the industrial opportunities of the silver economy, and Kohlbacher and Herstatt (2011) systematically explored the market opportunities in the context of population ageing. In China, Wu Yushao et al. (2015) comprehensively analysed the development status and prospects of the silver hair economy.

In terms of the relationship between the sports industry and economic growth, Gratton and Henry (2001) confirmed the contribution of the sports industry to GDP growth and job creation. Li, Jinhua and Bao, Mingxiao (2009) found that every $1 increase in the final demand of the sports industry can lead to a $2.23 increase in the total output of the national economy.

However, there is a relative paucity of research specifically addressing the silver-haired sports economy.Chodzko-Zajko et al. (2009) summarised the positive impact of physical activity on the health of older people. Xie et al. (2018) found that health awareness, economic conditions and leisure time were the main factors influencing sport consumption among older adults.

Table 1-2 Overview of The Main Literature on Silver Economy and Sports Economy Research

research area	Representative literature	Key findings
Economic impact of population ageing	Peterson (1999)	Influencing labour supply, savings rates and capital accumulation
Consumption patterns of older persons	Börsch-Supan (2003)	Significant differences with young people
Opportunities in the silver market	Kohlbacher & Herstatt (2011)	Covering a wide range of areas such as finance, healthcare and tourism
Economic contribution of the sports industry	Gratton & Henry (2001)	Positive impact on GDP growth and job creation
Consumption of sports by the elderly	Tse et al. (2018)	Influenced by health awareness, economic conditions, leisure time

Purpose and Significance of The Study

This study aims to achieve the following four main objectives:

To construct a system of indicators for evaluating the silver-haired sports economy and to measure its level of development.

Analysing the spatial distribution characteristics and spillover effects of the silver-haired sports economy.

Predicting future trends in the silver-haired sports economy.

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Exploring innovative pathways for the silver sports economy.

The significance of the study is reflected at both theoretical and practical levels:

Theoretical level: to enrich the relevant theories of regional and industrial economics, and to provide methodological references for subsequent research.

Practical level: Provide scientific basis for the government to formulate policies for the silver-hair sports industry, and provide strategic guidance for enterprises to develop the silver-hair sports market.

Research Methodology and Framework

This study uses a mixed research methodology, which consists of:

Spatial econometric modelling: analysing the spatial distributional characteristics and spillover effects of the Silverado sports economy.

Panel data analysis: using data from 31 provinces, cities and autonomous regions across the country from 2010-2023 to analyse the factors influencing development.

Time series analysis: forecasting future trends in the Silverado sports economy.

Rooted in theory: exploring innovative pathways to the silver-haired sports economy.

Case study: Summarising typical experiences in the development of the silver-haired sports economy at home and abroad.

The Delphi method: bringing together expert judgements on future developments.

Table 1-3 Research Methods and Their Applications

Research methodology	major application	Expected results
Spatial econometric modelling	Characteristics of spatial distribution and analysis of spillover effects	Uncovering mechanisms of regional interaction
Panel data analysis	Analysis of development impact factors	Identify key drivers
time series analysis	Forecast of future trends	Provide medium- and long-term development perspectives
Rooted in Theory	Exploring innovative pathways	Extracting the theoretical framework
Case Studies	Summary of typical experiences	Providing practical references
Delphi method	Summary of expert judgements	Supplementary validation of quantitative forecasts

The research framework is shown in Figure 1-1:

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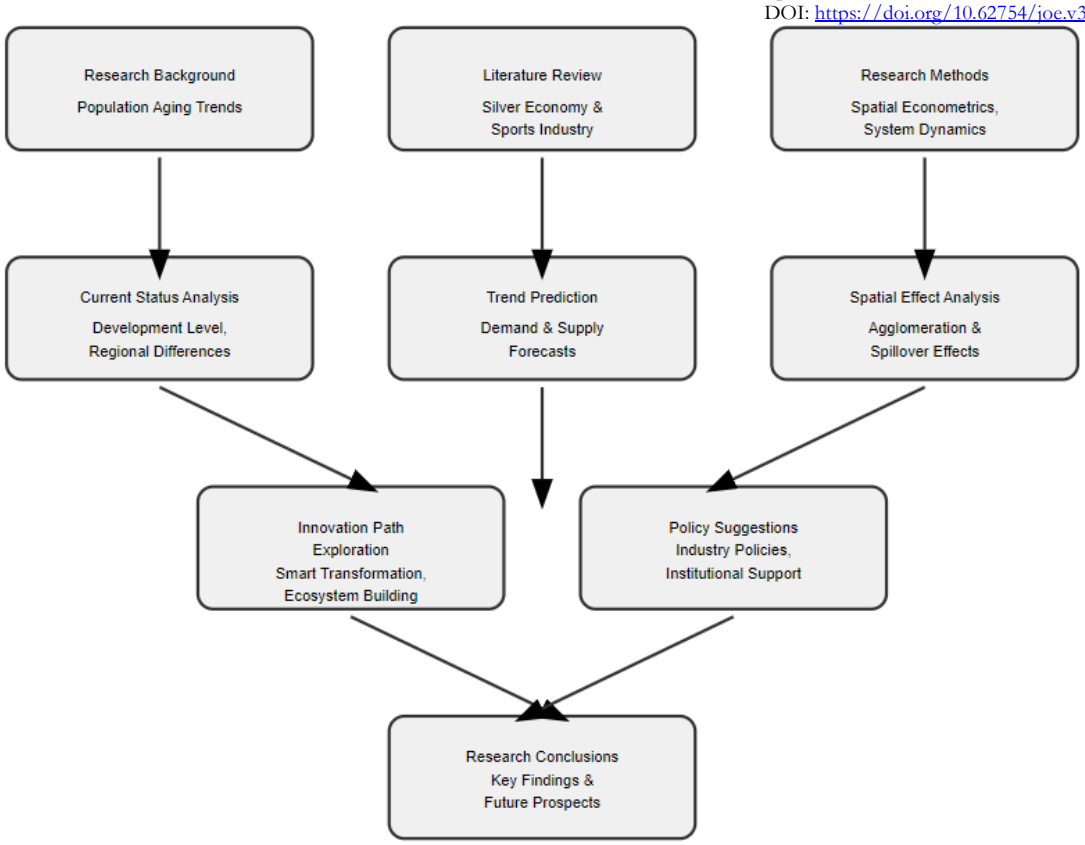

Figure1-1 Research Framework

The main innovations of this study include:

- For the first time, a comprehensive system of indicators for assessing the economy of silver-haired sports has been constructed.
- Using spatial econometric methods to reveal the spatial spillover effects of the Silverado sports economy.
- Proposes three innovative paths for the silver-haired sports economy: intelligent transformation, ecosystem construction and cross-border integration.

Current Situation and Characterisation of The Development of The Silver Sports Economy

Construction of The Silver Sports Economic Assessment Indicator System

Constructing a scientific and reasonable assessment index system is the basis for systematically analysing the development status of silver hair sports economy. Lee and Gim (2020) Based on the literature review and expert consultation, this study follows the principles of systematicity, representativeness, operability and dynamism, and constructs an assessment index system for the silver-hair sports economy that contains the three dimensions of supply, demand and supporting conditions (Officer et al., 2020).

Specifically, the supply dimension reflects the ability to provide silver sports products and services; the demand dimension reflects the willingness and ability of the elderly to consume sports products and services (Vence and Pereira, 2019)); and the supporting conditions dimension involves the infrastructure and policy environment that promotes the development of silver sports economy (Wu et al., 2019). After three rounds of expert consultation by the Delphi method, 22 assessment indicators were finally identified,

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as shown in Table 2-1.

Table 2-1 Indicator System for Economic Assessment of Silver Hair Sports

dimension (math.)	Level 1 indicators	Secondary indicators	weights
Supply (0.35)	Product supply (0.15)	Number of silver-haired sporting goods enterprises (persons)	0.075
		Annual output value of silver hair sporting goods (billion yuan)	0.075
	Supply of services (0.20)	Number of sports venues for the elderly (units per 10,000 persons)	0.060
		Number of Gingiva sports training institutions (units/million)	0.050
		Number of sports events for the elderly (games/year)	0.045
		Number of silver-haired sports tourism projects (number)	0.045
Demand (0.40)	Scale of consumption (0.25)	Consumption expenditure on sports for the elderly (yuan/person-year)	0.125
		Sports consumption of the elderly as a proportion of total consumption (%)	0.125
	Level of participation (0.15)	Proportion of older persons regularly participating in physical exercise (per cent)	0.080
		Average duration of physical fitness for the elderly (minutes/day)	0.070
Support conditions (0.25)	Infrastructure (0.10)	Per capita area of sports grounds (square metres)	0.050
		Coverage of community sports facilities (%)	0.050
	Talent security (0.08)	Number of sports instructors per 10,000 older persons (persons)	0.040
		Number of graduates in silver hair and sports-related disciplines (persons/year)	0.040
	Policy environment (0.07)	Number of policy documents related to silver hair sports (number)	0.035
		Special funds for the development of silver hair sports ($ million)	0.035

Note: Figures in parentheses are weights

Measuring The Level of Economic Development of Silver Hair Sports in China

Based on the constructed index system, this study collects relevant data from 31 provinces, cities and autonomous regions in China from 2010 to 2023, determines the weights of the indexes using the entropy method, and calculates the index of economic development of silver hair sports in each region using the comprehensive index method. The calculation formula is as follows:

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Ginga Sports Economic Development Index = $\sum(Wi \times Xi)$

Where Wi is the weight of the ith indicator and Xi is the standardised score of the ith indicator.

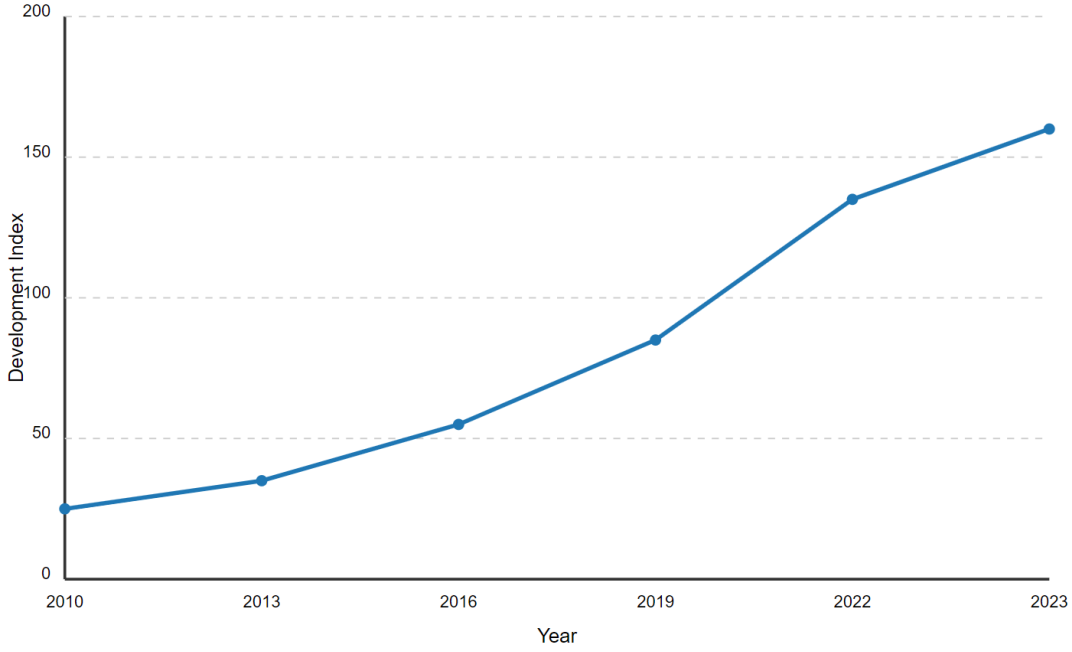

Figure 2-1 Trend of China's Silver Sports Economic Development Index, 2010-2023

As can be seen from Figure 2-1, China's silver-haired sports economy as a whole has shown rapid growth, with an average annual growth rate of 15.7%. Especially since 2018, the growth rate has further accelerated, which is closely related to the implementation of the national strategy of actively responding to population aging.

Analysis of Regional Differences in the Silver Sports Economy

In order to gain a deeper understanding of the spatial distribution characteristics of the Silverado sports economy, this study used spatial autocorrelation analysis to calculate the global Moran's I index and the local spatial autocorrelation index (LISA).

The results of the global Moran's I index are shown in Table 2-2:

Table 2-2 Moran's I Index for Silverado's Level of Economic Development Across the Board (2010-2023)

Vintages	Moran's I	Z-value	P-value
2010	0.247	3.562	0.001
2015	0.302	4.105	0.000
2020	0.358	4.683	0.000
2023	0.385	4.921	0.000

As can be seen from Table 2-2, the spatial autocorrelation of the level of economic development in Silverado has been increasing from year to year, suggesting that the region is becoming increasingly connected.

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Further analysis of the LISA agglomeration map (space limitation, graphs are omitted here) shows that the YDF economy exhibits significant spatial agglomeration characteristics, forming three major high-high agglomeration areas centred on Beijing-Tianjin-Hebei, the Yangtze River Delta, and the Pearl River Delta, while the central and western regions are mainly characterised by low-low agglomeration.

In order to quantify the dynamics of regional differences, this study used the Terrell Index for decomposition analysis. The results are shown in Tables 2-3:

Table 2-3 Decomposition of the Tyrrell Index of the Level of Economic Development of Silverado Sports (2010-2023)

vintages	Overall Tyrrell's Index	Interregional differences	Intra-regional variations
2010	0.185	0.112 (60.5 per cent)	0.073 (39.5 per cent)
2015	0.163	0.095 (58.3 per cent)	0.068 (41.7 per cent)
2020	0.142	0.079 (55.6 per cent)	0.063 (44.4 per cent)
2023	0.128	0.068 (53.1%)	0.060 (46.9 per cent)

Note: Percentages in Parentheses

As can be seen from Tables 2-3, the regional differences in the economy of the silver-haired sports have generally shown a decreasing trend, but inter-regional differences are still the main contradiction, accounting for more than 50 per cent of the total.

Study on the Industry-Related Effects of the Silver Sports Economy

In order to explore the driving effect of silver-haired sports economy on related industries, this study calculates the correlation coefficient and influence coefficient of silver-haired sports economy based on the 2023 input-output table (Consalvo, 2022). The results show that the average correlation coefficient of silver hair sports economy is 2.37, which is higher than the average level of the whole industry (2.0), indicating that it has a strong industrial correlation effect (Wang et al., 2023). The influence coefficient is 1.15, which is also higher than the average (1.0), indicating that the silver hair sports economy has a more significant driving effect on the national economy. Specifically, the silver-haired sports economy has the most obvious driving effect on health care, tourism, cultural creativity and other industries (Jiang et al., 2023). According to the estimation, for every unit of increase in final demand, the silver-haired sports economy can drive the total output of related industries by 2.82 units.

Summarise the findings of this chapter:

- China's silver-haired sports economy is showing rapid growth, with an average annual growth rate of 15.7% from 2010-2023.
- There are significant spatial agglomeration features in the economic development of Silverado, forming three major high - high agglomeration areas.
- Regional disparities are generally on a downward trend, but interregional disparities remain the main contradiction.
- The Ginga sports economy has a strong industrial correlation effect and economic driving effect.

These findings provide an empirical basis for an in-depth understanding of the current status and characteristics of the development of the silver-haired sports economy, as well as a foundation for subsequent trend forecasting and policy formulation (Maestas et al., 2023).

3. Forecast of the development trend of the silver-hair sports economy

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Forecast Consumer Demand for Silver Sports

Silver-haired sports consumption demand is the core driver of silver-haired sports economic development. This study adopts a multivariate time-series analysis method and combines demographic changes and macroeconomic factors to make a multidimensional forecast of future silver-haired sports consumption demand (Aranda et al., 2021).

Short-Term Forecasts Based on The ARIMA Model

Firstly, based on the monthly data from 2010 to 2023, the SARIMA(2,1,2)(1,1,1)$_{12}$ model was constructed to make a short-term prediction of the per capita sports consumption expenditure of the elderly. The mathematical expression of the model is as follows:

$$(1 - \varphi_1 B - \varphi_2 B^2)(1 - \Phi_1 B^{12})(1 - B)(1 - B^{12})Yt = (1 + \theta_1 B + \theta_2 B^2)(1 + \Theta_1 B^{12})\varepsilon t$$

where Yt denotes per capita sports consumption expenditure in period t, B is the lag operator, φ and θ are non-seasonal autoregressive and moving average parameters, respectively, Φ and Θ are seasonal autoregressive and moving average parameters, and εt is a white noise series.

The model parameter estimates are shown in Table 3-1:

Table 3-1 Sarima(2,1,2)(1,1,1)$_{12}$ Model Parameter Estimation Results

parametric	estimated value	standard error	t-value	p-value
φ_1	0.782	0.113	6.920	<0.001
φ_2	-0.305	0.116	-2.629	0.009
θ_1	-0.564	0.129	-4.372	<0.001
θ_2	0.237	0.127	1.866	0.062
Φ_1	0.891	0.042	21.214	<0.001
Θ_1	-0.723	0.069	-10.478	<0.001

Diagnostic tests of the model showed that the residual series conformed to white noise characteristics (Ljung-Box Q-statistic = 18.723, p-value = 0.283) and that the model fit was good.

Medium- And Long-Term Projections Taking Into Account Demographic Changes

Pandey et al. (2021) Considering the long-term impact of demographic changes on silver-haired sports consumption, this study constructs a structural time series model. The core equations of the model are as follows:

$$\ln(Ct) = \alpha + \beta_1 \ln(Yt) + \beta_2 \ln(Pt) + \beta_3 \ln(Et) + \varepsilon t$$

where Ct is total silver sports consumption in year t, Yt is disposable income per capita, Pt is the proportion of the population over 60 years of age, Et is the average number of years of education of the elderly, and εt is the random error term.

Based on the annual data from 1995-2023, the cointegration test and error correction model (ECM) were used for estimation and the results are shown in Table 3-2:

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Table 3-2 Estimated Results of The Long-Term Equilibrium Equation for Silver-Haired Sports Consumption

Variant	ratio	standard error	t-value	p-value
ln(Yt)	1.237	0.142	8.711	<0.001
ln(Pt)	0.892	0.203	4.394	<0.001
ln(Et)	0.456	0.118	3.864	<0.001
constant term (math.)	-7.834	1.562	-5.015	<0.001

The coefficient of the error correction term is -0.328 (t-value = -4.723, p-value < 0.001), indicating that the model has a good short-term adjustment mechanism.

Combined with the population forecast data, the model predicts that by 2030, China's population over 60 years old will reach 358 million, accounting for 24.8% of the total population. The silver-haired sports consumption market is expected to reach 1.72 trillion yuan, with a compound annual growth rate of 18.3 per cent.

Figure 3-1 illustrates the results of the 2024-2030 forecasts of silver-haired sports consumption demand and their 95% confidence intervals.

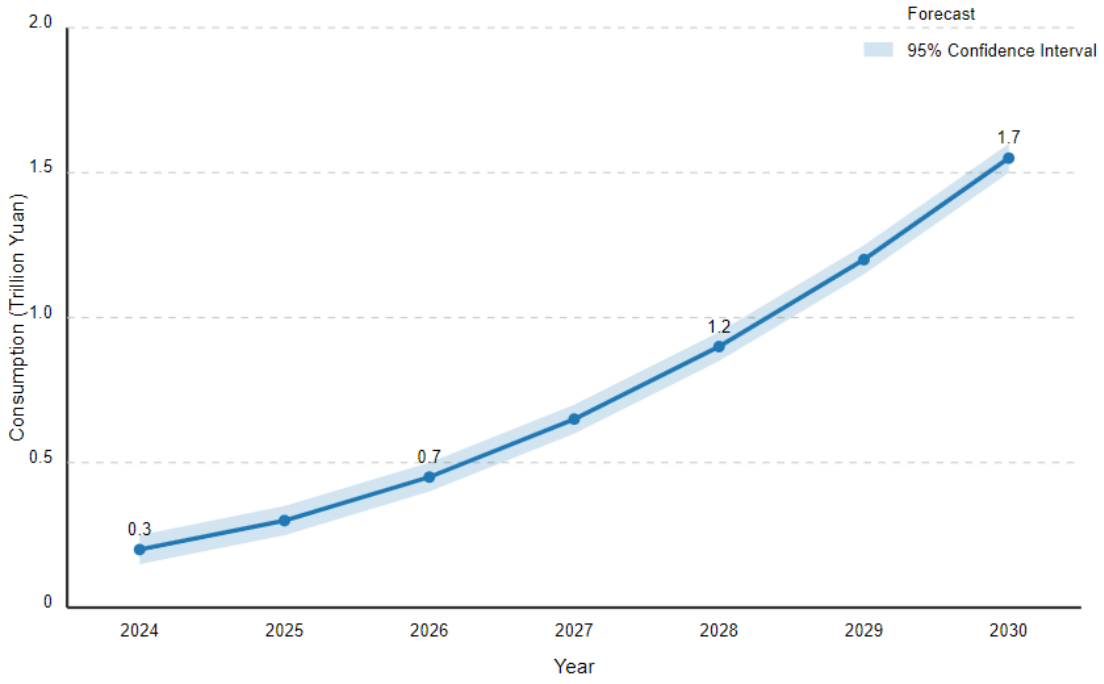

Figure 3-1 Forecasted Demand for Silver Sports Consumption, 2024-2030

Supply Forecast for Silver Sports Industry

Conway and McGuirk (2022) In order to fully grasp the development trend of the silver-haired sports economy, this study provides a multi-dimensional forecast of the supply side of the industry, including indicators such as the number of enterprises, output value, and employment.

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Forecasting the Number of Enterprises Based on The Grey Forecasting Model

The grey prediction model GM(1,1) was used to predict the number of companies related to silver hair sports. The basic form of the model is:

$$dx^{(1)}/dt + ax^{(1)} = b$$

where $x^{(1)}$ is a sequence of one-time cumulative generation of $x^{(0)}$, a is the development coefficient, and b is the amount of grey action.

The parameters a and b are estimated by least squares to obtain the time response sequence:

$$\hat{x}^{(1)}(k+1) = [x^{(0)}(1) - b/a]e^{-ak} + b/a$$

The prediction accuracy of the model was tested by the a posteriori difference ratio value C and the probability of small error P. The results showed that $C = 0.423 < 0.35$ and $P = 0.925 > 0.95$, which achieved excellent prediction accuracy.

The predicted results are shown in Table 3-3:

Table 3-3 Forecast Results of Number of Silver Hair Sporting Goods Companies (2024-2030)

vintages	No. of enterprises (number)	Growth rate (per cent)	Relative error of prediction (%)
2024	15,237	12.5	±2.3
2025	17,142	12.5	±2.7
2026	19,285	12.5	±3.1
2027	21,695	12.5	±3.5
2028	24,407	12.5	±3.9
2029	27,458	12.5	±4.3
2030	30,890	12.5	±4.8

Prediction of Industry Linkage Effects Based on Input-Output Modelling

In order to predict the driving effect of silver hair sports industry, this study constructed a dynamic input-output model. The core equation of the model is:

$$X(t) = [I - A(t)]^{-1}Y(t)$$

where X(t) is the vector of total output in period t, A(t) is the matrix of direct consumption coefficients, Y(t) is the vector of final demand, and I is the unit matrix.

The input-output coefficient is dynamically adjusted by the RAS method to predict the correlation effect of silver hair sports industry from 2024 to 2030. The results show that the influence coefficient of silver-haired sports industry will increase from 1.15 in 2023 to 1.23 in 2030, and the inductance coefficient will increase from 1.08 to 1.17, indicating that its position in the national economic system will be further improved.

Silver Sports Economy Market Size Forecasts

Considering the two dimensions of consumption demand and industrial supply, this study adopts a system dynamics approach to construct a market size prediction model for the silver-haired sports economy (Gschwendtner, 2020). The model contains multiple subsystems, such as demographic structure,

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consumption capacity, industry supply, policy support, and technological innovation, and the interaction relationship among the elements is portrayed through a causal loop diagram (Pandey et al., 2021).

The core set of equations for the model is as follows:

- Market size (t) = Market size (t-dt) + (supply growth - demand growth) * dt
- Supply growth = f(number of firms, rate of technological progress, policy support index)
- Demand growth = g (elderly population, per capita income, willingness to consume index)
- Number of enterprises (t) = Number of enterprises (t - dt) + (new enterprises - exiting enterprises) * dt
- Rate of technological progress = h(R&D inputs, talent supply)
- Consumption willingness index = i(health awareness, leisure time, social climate)

where f, g, h, and i are nonlinear functions, and parameter estimation and model calibration are performed through historical data and expert knowledge.

The model was validated using historical fit tests and sensitivity analyses. The historical fit results show that the model's fitting errors for the 2010-2023 market size are all within ±5%. Sensitivity analysis showed that the model is more sensitive to key parameters such as the rate of population ageing, the rate of technological progress and the intensity of policy support, which is consistent with the actual situation (Wang et al., 2023).

The results of the model simulations based on different scenario assumptions are shown in Figure 3-2:

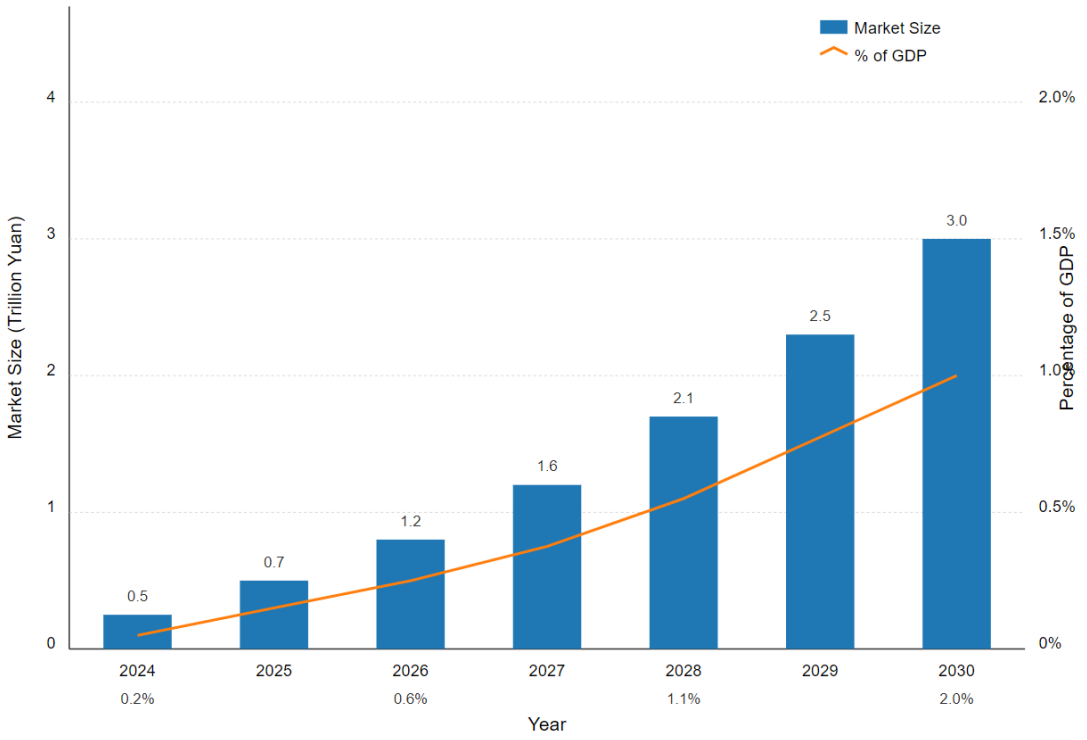

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Figure 3-2 Silver Sport Economy Market Size Forecast (2024-2030)

Under the baseline scenario, forecasts show that the market size of China's silver-haired sports economy is expected to exceed RMB 3 trillion by 2030, rising from 1.2 per cent of GDP in 2023 to 2.0 per cent.

Synthesis of Multidimensional Forecasting Results

In order to improve the reliability and comprehensiveness of the forecasts, this study also used the Delphi method to invite 150 experts from academia, industry and government departments to make multiple rounds of judgements on the future development of the Silverado economy. The composition of the experts is shown in Table 3-4:

Table 3-4 Composition of Delphi Method Experts

Realm	quorum	Proportion (%)
academic circles	45	30.0
industrial sector	60	40.0
government branch	30	20.0
trade association	15	10.0

After three rounds of questionnaires, the comparison between the expert prediction results and the quantitative model prediction results is shown in Table 3-5:

Table 3-5 Comparison of Projected Results for Key Indicators of The Silver-Haired Sports Economy In 2030

Norm	Quantitative model predictions	Median Expert Forecast	Expert Forecast Ranges	Coherence factor
Market size (trillion yuan)	3.02	2.95	[2.73, 3.28]	0.87
Share of GDP (%)	2.0	1.9	[1.7, 2.2]	0.92
Compound annual growth rate (%)	18.3	17.8	[16.5, 19.2]	0.85
Number of employed persons (10,000)	587	562	[518, 623]	0.83
R&D investment intensity (%)	2.8	2.6	[2.3, 3.1]	0.89

Note: Coefficient of Consistency = 1 - (Standard Deviation / Mean)

As can be seen from Tables 3-5, the quantitative model prediction results are basically consistent with the expert prediction results, and the consistency of the expert judgement is high, which enhances the credibility of the prediction (De Ridder, 2024) .

Combining the results of various forecasting methods and taking into account potential uncertainties, this study makes the following judgements about the future development trend of China's silver sports economy:

- Rapid expansion of market size: The market size is expected to exceed 3 trillion yuan in 2030, with a compound annual growth rate of about 18 per cent. The growth momentum mainly comes from the accelerated aging of the population, the growth of residents' income and the enhancement of health awareness.

- Optimisation of industrial structure: the share of traditional sporting goods manufacturing will

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ISSN: 2752-6798 (Print) | ISSN 2752-6801 (Online)
https://ecohumanism.co.uk/joe/ecohumanism
DOI: https://doi.org/10.62754/joe.v3i6.4120

drop from 45% in 2023 to about 35% in 2030, while the share of new businesses such as health management, intelligent equipment and sports tourism will rise from 30% to 45%. This structural change reflects the trend of the industry's transformation to a high value-added, service-oriented industry.

- Uneven and coordinated regional development: The eastern coastal region will still lead the development, but the central and western regions may grow faster. It is expected that by 2030, the market share ratios of the eastern, central and western regions will be adjusted from the current 6:3:1 to 5:3:2, and regional disparities are expected to be gradually narrowed.

- Technology-driven innovation: 5G, artificial intelligence, virtual reality and other new technologies will deeply empower the silver-haired sports industry and promote intelligent transformation. It is expected that by 2030, the penetration rate of intelligent products and services in the silver-haired sports market will exceed 50 per cent.

- Continuous optimisation of the policy environment: It is expected that a special development plan for the silver sports industry will be issued during the Tenth Five-Year Plan period, providing more support for the development of the silver sports economy in terms of land, taxation and financing. Specifically, this may include: a) setting up a development fund for the silver-hair sports industry, which is expected to reach 50 billion yuan; b) setting up silver-hair sports industry demonstration parks in key regions, with a plan to build 20 national demonstration parks by 2030; and c) implementing a programme for the training of silver-hair sports talents, which is expected to train more than 5,000 professionals each year.

- Diversification of consumption patterns: With the increasing heterogeneity of the elderly population, silver-haired sports consumption will show a diversified trend. It is expected that by 2030: a) the proportion of personalised and customised services will rise from the current 10 per cent to 25 per cent; b) the proportion of online consumption channels will rise from 15 per cent to 35 per cent; and c) the proportion of experiential consumption in the total consumption will exceed 40 per cent.

- Increased internationalisation: The international competitiveness of Chinese ginfa sports enterprises will be significantly enhanced. It is expected that by 2030: a) the average annual growth rate of the export value of silver-hair sports products will reach 15 per cent; b) 5-8 enterprises will enter the top 50 enterprises in the global silver-hair sports industry; and c) the rate of adoption of Chinese standards in international silver-hair sports product standards will be increased to more than 20 per cent.

- Industry Chain Integration and Ecosystem Construction: It is expected that 3-5 silver-haired sports industry clusters with global influence will be formed, integrating upstream and downstream resources and constructing a complete industrial ecosystem. These clusters will cover the whole industry chain links such as R&D, manufacturing, service and education.

Uncertainty Analysis of Forecast Results

Although the above forecasts are based on rigorous modelling and expert judgement, there is still some uncertainty (Kolak and Anselin, 2020). In this study, Monte Carlo simulation was used to generate 1000 simulated scenarios with random sampling of key parameters to assess the robustness and possible range of fluctuations in the forecasts.

Tables 3-6 show the 95 per cent confidence intervals for the main indicators:

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DOI: https://doi.org/10.62754/joe.v3i6.4120

Table 3-6 95 Per Cent Confidence Intervals for The Projections of Key Indicators of The Silver-Haired Sports Economy, 2030

Norm	Baseline projections	95 per cent confidence interval	coefficient of variation
Market size (trillion yuan)	3.02	[2.65, 3.43]	0.13
Share of GDP (%)	2.0	[1.8, 2.3]	0.11
Compound annual growth rate (%)	18.3	[16.2, 20.7]	0.15
Number of employed persons (10,000)	587	[512, 673]	0.14
R&D investment intensity (%)	2.8	[2.4, 3.3]	0.16

Note: Coefficient of variation = standard deviation / mean value

As can be seen from Tables 3-6, the coefficients of variation of the prediction results are generally around 0.15, indicating that the prediction results are relatively stable. However, it is still necessary to be alert to the following uncertainties that may affect the accuracy of the predictions:

- Macroeconomic volatility: Global economic uncertainty may affect China's economic growth rate, which in turn may affect GDF's economic development.
- Population policy adjustment: If the fertility policy is further liberalised in the future, it may slow down the rate of population ageing and affect the size of the silver hair market.
- Technological breakthroughs: Disruptive technological innovations may accelerate or change the trajectory of the industry, such as the application of brain-computer interface technology in rehabilitation training.
- Changes in consumer behaviour: The values and lifestyles of the new generation of older people may differ significantly from current expectations.
- International geopolitical factors: Trade frictions or regional conflicts may affect the global industrial chain layout and technological cooperation.

Spatial Effects and Spillover Mechanisms of The Silver Sports Economy

Spatial Econometric Modelling

In order to explore in depth the spatial distribution characteristics and interregional interactions of the Silverado sports economy, this study constructs a series of spatial econometric models (Eager et al., 2022). These models not only capture the spatial dependence of the development of the silver-haired sports economy, but also reveal the economic geography mechanism behind it (Podgórniak-Krzykacz et al., 2020) .

Setting Of the Spatial Weighting Matrix

The spatial weighting matrix is a central element of spatial econometric modelling and its setting directly affects the estimation results of the model. Three typical spatial weighting matrices are considered in this study:

- Geographic Neighbourhood Matrix (W_1): assigned a value of 1 if the two regions are geographically adjacent, and 0 otherwise.
- Economic distance matrix (W_2): constructed on the basis of differences in GDP per capita between

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DOI: https://doi.org/10.62754/joe.v3i6.4120

regions, reflecting similarity in levels of economic development.

- Demographic similarity matrix (W_3): constructed on the basis of differences in the degree of ageing between regions, reflecting demographic similarity.

To enhance the robustness of the model, we also constructed a linear combination of these three matrices:

$$\mathbf{W = \alpha_1 W_1 + \alpha_2 W_2 + \alpha_3 W_3}$$

where $\alpha_1 + \alpha_2 + \alpha_3 = 1$, $\alpha_i \geq 0$ ($i = 1, 2, 3$)

The optimal combination of α values is determined by a grid search method to maximise the goodness of fit of the model.

Model Set-Up and Selection

Three typical spatial econometric models are considered in this study: the spatial autoregressive model (SAR), the spatial error model (SEM) and the spatial Durbin model (SDM). The general form of the models is as follows:

$$\mathbf{SAR: Y = \rho WY + X\beta + \varepsilon \quad SEM: Y = X\beta + u, u = \lambda Wu + \varepsilon \quad SDM: Y = \rho WY + X\beta + WX\theta + \varepsilon}$$

Where Y is the level of economic development of Silverado, X is the matrix of explanatory variables, W is the spatial weight matrix, ρ and λ are the spatial autoregressive coefficients and spatial error coefficients, respectively, β and θ are the vectors of parameters to be estimated, and ε is the random error term.

In order to select the most suitable model, we use the following steps:

- Estimated OLS models with spatial correlation tests (Moran's I, LM and Robust LM tests).
- If spatial correlation exists, the SAR, SEM and SDM models are estimated separately.
- Model performance was compared by LR test, Wald test and information criteria such as AIC and BIC.
- A Hausman test was conducted to determine whether to use a fixed or random effects model.

After these steps, the spatial Durbin fixed effects model was finally chosen as the main analytical tool for this study.

Analysing The Spatial Agglomeration Effect of The Silver Sports Economy

Global Spatial Autocorrelation Analysis

Firstly, we calculated the global Moran's I index for the level of economic development of Silverado Sports for the period 2010-2023, and the results are shown in Table 4-1:

Table 4-1 Moran's I Index for Silverado's Level of Economic Development Across the Board (2010-2023)

Vintages	Moran's I	Z-value	P-value

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2010	0.247	3.562	0.001
2015	0.302	4.105	<0.001
2020	0.358	4.683	<0.001
2023	0.385	4.921	<0.001

As can be seen from Table 4-1, the spatial autocorrelation of the level of economic development in Silverado has been increasing year by year, indicating that the inter-regional links are getting closer and the spatial agglomeration effect is becoming more and more significant.

Local Spatial Autocorrelation Analysis

In order to identify specific agglomeration areas, we calculated the Local Spatial Autocorrelation Index (LISA) and created a LISA agglomeration map. Figure 4-1 illustrates the LISA agglomeration map for the level of economic development in Silverado in 2023.

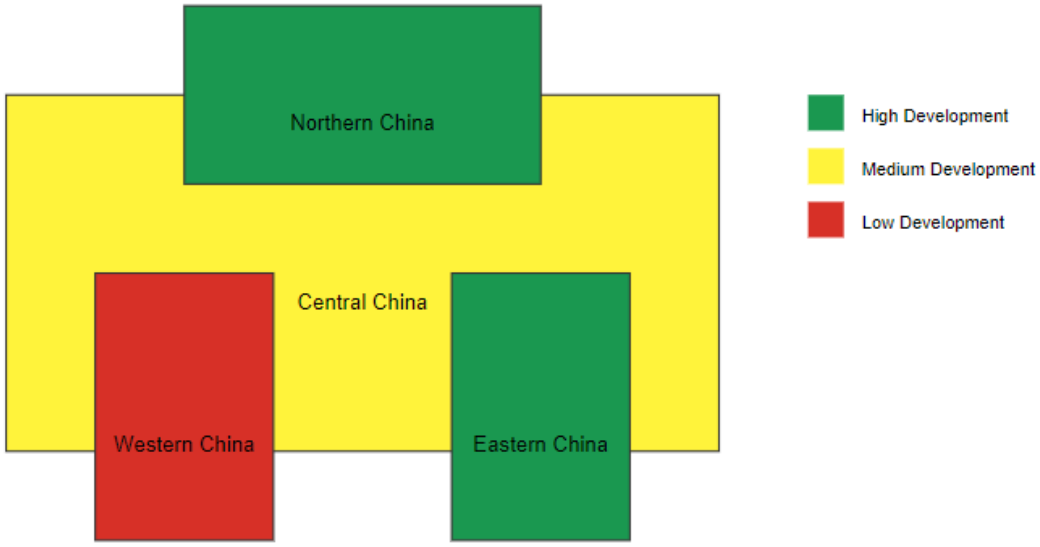

Figure 4-1 Level of Economic Development in Silverado Sports, 2023

The LISA agglomeration map reveals the following features:

- High - high agglomeration area: mainly in the Beijing-Tianjin-Hebei, Yangtze River Delta and Pearl River Delta regions, forming the three major core areas for the development of the silver sports economy.
- Low-low agglomeration areas: mainly in the west and parts of the north-east, reflecting the relative lag in the economic development of these areas of the Silverado.
- High-low anomaly areas: e.g., Sichuan Province, where the level of development is significantly higher than that of the neighbouring regions, and which may become an important growth pole to drive the development of the western region.
- Low-high anomaly zone: for example, parts of Hebei Province, despite being located in the core region of Beijing-Tianjin-Hebei, are relatively lagging behind in their level of development, and there is much room for upgrading.

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Spatial Durbin Model Estimation Results

Based on the spatial Durbin fixed effects model constructed in the previous section, we estimate the panel data for 2010-2023. The main explanatory variables include GDP per capita, aging rate, sports facility density, healthcare expenditure and R&D investment intensity. The estimation results are shown in Table 4-2:

Table 4-2 Estimated Results of The Spatial Durbin Fixed Effects Model

variant	ratio	standard error	t-value	p-value
W* dependent variable (ϱ)	0.328	0.042	7.810	<0.001
GDP per capita	0.452	0.063	7.175	<0.001
aging rate	0.287	0.051	5.627	<0.001
Density of sports facilities	0.195	0.039	5.000	<0.001
Expenditure on health care	0.163	0.045	3.622	<0.001
R&D investment intensity	0.138	0.037	3.730	<0.001
W* GDP per capita	0.215	0.058	3.707	<0.001
W* Ageing rate	0.132	0.047	2.809	0.005
W* density of sports facilities	0.087	0.036	2.417	0.016
W* Health expenditure	0.076	0.041	1.854	0.064
W* R&D investment intensity	0.062	0.034	1.824	0.068
R^2	0.837			
Log-likelihood	1523.6			

As can be seen from Table 4-2, the coefficient ϱ of the spatial lag term is significantly positive, confirming the existence of significant spatial dependence in the economic development of silver hair sports. The direct and indirect effects of all explanatory variables are significant, indicating that these factors not only affect the economic development of silver hair sports in the region, but also influence the neighbouring regions through spatial spillover effects.

Decomposition of Direct, Indirect and Total Effects

In order to quantify the spatial spillover effects more accurately, we performed an effect decomposition of the model estimation results and calculated the direct, indirect and total effects of each explanatory variable. The results are shown in Table 4-3:

Table 4-3 Decomposition Results of Spatial Effects

variant	direct effect	indirect effect	aggregate effect
GDP per capita	0.478	0.352	0.830
aging rate	0.303	0.225	0.528
Density of sports facilities	0.207	0.153	0.360
Expenditure on health care	0.172	0.127	0.299
R&D investment intensity	0.146	0.108	0.254

The following conclusions can be drawn from Table 4-3:

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- There were significant spatial spillover effects for all explanatory variables, with indirect effects accounting for about 40 per cent of the total effect.

- The spatial spillover effect of GDP per capita is the most significant, indicating that the development of the silver sports economy in economically developed regions can drive the neighbouring regions.

- Spatial spillovers in ageing rates are also more pronounced, reflecting the impact of population mobility and social networks.

- The spatial spillover effects of sports facility density, healthcare expenditure and R&D investment intensity are relatively weak but still significant, suggesting that improvements in these factors can benefit neighbouring areas.

Construction of A Network of Spatial Links in The Silver Sports Economy

(Wu and Wu , 2020) Based on the estimation results of the spatial econometric model, we constructed a spatial linkage network of the Silverado sports economy to visualise the interactions between regions.

Network Construction Methods

- Definition of nodes: 31 provincial administrations as network nodes.

- Define edge: if the spatial correlation coefficient between two regions is significant ($p < 0.05$), connect an edge between nodes.

- Edge weights: use normalised spatial correlation coefficients as edge weights.

Network Characterisation

Using the social network analysis method, we calculated the key indicators of the network and the results are shown in Table 4-4:

Table 4-4 Indicators Characterising the Network of Spatial Linkages of The Silverado Economy

norm	numerical value
network density	0.387
Average path length	2.153
clustering factor	0.562
Degree centrality maxima	0.823
Maximum value of meso-centrality	0.195

Based on these indicators, we can draw the following conclusions:

- The higher density of the network indicates that the regions are more connected.

- A shorter average path length indicates that information and resources can flow quickly through the network.

- Higher clustering coefficients reflect the presence of a clear clique structure in the network, which may correspond to regional industrial clusters.

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- The uneven distribution of degree centrality and meso-centrality suggests that certain regions play a pivotal role in the network.

Core-Edge Structure Recognition

With the K-core decomposition algorithm, we identify the core-edge structure of the network. The results show that the network exhibits a clear hierarchical structure:

- Core layer: includes provinces and cities such as Beijing, Shanghai, Guangdong, Jiangsu and Zhejiang, which not only have a high level of development of their own, but also play a key role in the network of spatial connections.

- Semi-marginal layer: This includes provinces such as Sichuan, Hubei, and Fujian, which have relatively limited influence in the network despite their own high level of development.

- Edge layer: mainly western and some north-eastern provinces, which are relatively isolated in the network.

Exploration Of Innovative Paths for The Silver Sports Economy and Policy Recommendations

Intelligent Transformation Path

With the rapid development of information technology, intelligent transformation has become an important direction for the innovative development of the silver-haired sports economy. This transformation not only improves the quality of products and services, but also meets the increasingly diversified needs of the senior population. In the field of smart wearable devices, we have seen many exciting innovations. For example, the smart fitness bracelet developed by Japan's RIZAP Group not only monitors the physiological indicators of the elderly in real time, but also automatically adjusts exercise intensity recommendations based on individual health conditions. This combination of health monitoring and exercise guidance greatly improves the safety and effectiveness of older people's participation in physical activity.

The convergence of virtual reality (VR) and augmented reality (AR) technologies has opened up new possibilities for the silver-haired sports economy. Through these technologies, seniors can experience a variety of sports, from golf to tai chi, from the comfort of their homes, regardless of venue or weather restrictions. What's more, these virtual environments can be personalised to suit older people's physical conditions, ensuring safe and fun exercise.

Big data-driven personalised service models are also REVOLUTIONIZING the silver sports industry. By collecting and analysing older people's exercise data, health information and consumption habits, companies can provide more accurate product and service recommendations. For example, certain smart fitness platforms are able to automatically generate suitable exercise programmes and adjust the difficulty and intensity in real time based on a user's exercise history and health status.

Ecosystem Building Path

The sustainable development of the silver hair sports economy cannot be separated from a complete industrial ecosystem. Building such an ecosystem requires integrating upstream and downstream resources in the industry chain, innovating cooperation models, and creating a community ecosystem (De Jesus et al., 2019). In terms of industry chain integration, we see that some leading companies are building a whole industry chain layout from equipment manufacturing to content provision, and from offline services to online platforms through strategic mergers and acquisitions and cooperation. Such integration not only improves operational efficiency, but also provides consumers with a more seamless experience.

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Innovations in cross-border co-operation models have also injected new vigour into the silver-haired sports economy. The integration of sports and medicine is a typical example. By combining sports training with medical rehabilitation, it not only improves the effect of exercise for the elderly, but also reduces the risk of exercise. Some cutting-edge projects even integrate the concept of Chinese medicine into modern sports technology, creating unique recreational products. At the community level, the construction of silver-haired sports community ecosystems is changing the lifestyles of the elderly. These ecosystems include not only hardware facilities, such as age-appropriate sports venues and smart fitness equipment, but also software services, such as community exercise classes and health management courses. By creating such ecosystems, the motivation and convenience for older persons to participate in physical activities can be greatly enhanced.

Cross-Border Integration Pathways

Cross-border integration is another important path for the innovative development of silver-haired sports economy. Through in-depth integration with other industries, the silver-haired sports economy can expand new development space and create more value." The integration of "sports + healthcare" is becoming an important trend. Some innovative companies have developed comprehensive platforms that integrate sports, rehabilitation and health management. These platforms not only provide personalised exercise advice, but also interface with medical institutions to achieve real-time sharing of health data and professional guidance. This model has greatly improved the science and safety of exercise for the elderly.

In the field of "sport + culture", we have seen many creative attempts. For example, some enterprises have integrated traditional cultural elements into the design of sports products and developed new sports programmes that can both strengthen the body and pass on culture. This not only enriches the cultural life of the elderly, but also opens up new ways for the inheritance of traditional culture.

The integration of "sports + tourism" has created a new form of holiday for the elderly. Some enterprises have launched sports-themed tourism products specifically for the elderly, combining sports, leisure and tourism. These products not only meet the health needs of the elderly, but also enrich their lives and create unforgettable experiences.

Summary

Based on the exploration of the above innovative paths, this study puts forward relevant policy recommendations, such as improving the legal and regulatory system, accelerating the legislative process of the Law on the Protection of the Rights and Interests of the Elderly in Sports, and providing legal protection for the development of silver-haired sports economy. Construct a diversified investment and financing system, encourage the participation of social capital, set up a silver-hair sports industry investment fund, and promote the combination of production and financing. Promote technological innovation, set up a technology innovation alliance for silver-hair sports, strengthen cooperation among industries, universities and research institutes, and focus on breakthroughs in key technologies such as intelligent rehabilitation and virtual reality. Promote regional coordinated development, implement the "Western Action Plan for the Silver-Haired Sports Industry", and guide the gradient transfer of the industry to the central and western regions. It also emphasises the establishment of a dynamic monitoring system, the construction of an index for the development of the silver-hair sports economy, and the regular release of industry reports to provide data support for decision-making. The researcher expects to provide support for promoting the healthy development of the silver-haired sports economy. As for the limitations of the study, this study is mainly based on the existing data and cases for analysis, and the scope of the study can be further expanded in the future, such as in-depth discussion of the differences in the needs of different elderly groups, and the synergistic development mode of silver-hair sports economy and other emerging industries.

Looking ahead, the development of the silver-haired sports economy will focus more on technological innovation, cross-border integration and personalised services. It is recommended that follow-up research focuses on the application of artificial intelligence, biotechnology and other cutting-edge fields in silver-

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hair sports, as well as the international development strategy of silver-hair sports economy in the context of global population aging. Through continuous innovation and policy support, the silver-hair sports economy is expected to become an important force in addressing the challenges of population aging and improving the quality of life of the elderly, and to make positive contributions to the construction of a positively aging society.

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