“Cointegration among technological innovation, structural transformation, and development of China’s sports industry: An autoregressive distributed lag (ARDL) approach”

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COINTEGRATION AMONG TECHNOLOGICAL INNOVATION, STRUCTURAL TRANSFORMATION, AND DEVELOPMENT OF CHINA'S SPORTS INDUSTRY: AN AUTOREGRESSIVE DISTRIBUTED LAG (ARDL) APPROACH

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Abstract

In the context of China's push for high-quality economic growth, analyzing the dynamic relationships between technological innovation and structural transformation in the sports industry is crucial. This study aims to empirically examine the long-term equilibrium and short-term dynamic relationships among technological innovation, industrial structure optimization, and the development of China's sports industry. Using provincial panel data from 2008 to 2023, this study employs the autoregressive distributed lag–error correction model (ARDL-ECM) and Granger Causality tests to analyze these interactions. Results indicate that a 1% increase in technological innovation input leads to a 0.223% rise in sports industry output, while a unit increase in the growth rate of the sports service sector boosts gross output by 0.357%. However, innovation output shows a weaker impact (0.066%), and no long-run equilibrium exists between the industrial structure ratio and economic scale. These findings underscore the need for targeted innovation policies and structural reforms. This study provides empirical support for enhancing the quality and efficiency of China's sports industry development.

Keywords China, sports industry, technological innovation, structural transformation, sports economy, autoregressive distributed lag (ARDL) model

JEL Classification L83, O31, O14, C32

INTRODUCTION

Technological innovation is a critical endogenous driver for industrial restructuring and high-quality economic development (Romer, 1990). In an era characterized by rapid technological advancement and interdisciplinary integration, leveraging science and technology to optimize industrial structures has become pivotal for accelerating modernization (Han, 2021). The synergy between technological progress and human needs catalyzes the emergence of new industries. The sports industry is a quintessential example of such an emerging sector. As a burgeoning sector of this century, China's sports industry has exhibited substantial growth within this innovation-driven ecosystem, benefiting from sustained technological momentum.

However, a significant disparity persists. While China's sports industry has reached a comparable scale to that of developed nations like

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Japan, South Korea, and the United States in the long term, its contribution to GDP remains strikingly low. The value-added shares in GDP for 2017, 2018, and 2019 were merely 0.90%, 0.94%, and 1.10%, respectively. By contrast, the sports industry in Western developed countries typically contributes over 2.50% to GDP. This disparity stems primarily from two factors: first, sports technology innovation in China remains at an embryonic stage, lagging behind global leaders; second, structural challenges persist, including a truncated industrial chain, irrational organization, content homogenization, and operational rigidity (Liu & Wang, 2024). Consequently, China's sports industry predominantly occupies the low-value-added base of the Smiling Curve, hindered by underdeveloped new business models and imbalanced development.

To address these challenges, a concerted effort should leverage scientific and technological elements. Enhancing the capacity for technological services and advancing innovation in the sports sector are not only inherent requirements for its development but also the core drivers of its sustainable and high-quality growth. Technological innovation is crucial for advancing the development philosophy centered on "innovation, coordination, greening, openness, and sharing," and for propelling the sports industry to internationally advanced levels in terms of production methods, industrial structure, management, workforce, and techno-economic indicators.

Therefore, investigating the interaction mechanisms between technological innovation and structural adjustment within the sports industry, as well as their combined impact on industrial development, holds significant theoretical and practical value. Through a detailed analysis of these mechanisms, this study proposes targeted optimization strategies. These strategies are intended to enhance the quality and efficiency of China's sports industry development and provide empirical insights for meeting the population's evolving sports consumption demands.

1. LITERATURE REVIEW

In modern societal development, technological innovation has become an important force supporting the transformation of industrial structures and development models. A substantial body of research has been conducted on the relationship between technological innovation, industrial restructuring, and economic development.

Economists have proposed numerous scientific theories in research areas such as technological innovation and industrial development. Schumpeter (1934) pioneered the study of technological innovation, proposing that technological innovation serves as the primary source of capitalist economic growth. Subsequent scholars have explored the relationships between technological innovation, industrial scale, and market competition (Kamien & Schwartz, 1974, 1976), as well as new technology diffusion (Mansfield, 1988), positing that technological innovation constituted an endogenous driver of industrial growth. Freeman (1997) regards technological innovation as the primary driving factor for the emergence, development, and diffusion of emerging industries, as well as for latecomer countries to achieve catch-up development. Christensen (2013) argues that technological innovation, often characterized as disruptive innovation due to its transformative nature, serves as the foundation for future products, services, and industries. The co-evolution of technological innovation and its embedded ecosystem significantly influences industrial growth (Christensen et al., 2018), constituting a key strategic driver for enterprise and industrial advancement.

By examining the respective advantages and limitations of evolutionary economics, the Neo-Schumpeter School, and the complex system dynamics approach, Aghion et al. (2009) explored the applicability of the "system theory" approach when dealing with the policy issues of the interdependence of the dynamics of technological innovation and its relationship with economic growth. By integrating elements from multiple fields, including innovation system theory, evolutionary economics, and export-oriented growth theory, Krammer (2017) constructed a conceptual framework aimed at clarifying the mechanism through which competitive advantages in science, technology, and innovation are transformed into economic growth. From the perspective of research scope, Nelson and Winter (1982) established an evolutionary economics framework for industrial evolution, analyzing the role of technological path dependence and organizational routines. Bilbao-Osorio and Rodríguez-Pose (2004) found that the socio-economic characteristics of various regions in Europe would affect the ability of each region to convert R&D investment into innovation, and thereby influence the ability of technological innovation to transform into economic growth.

Wu (2011) found no evidence of a long-term stable equilibrium relationship between technological innovation conversion efficiency and economic growth in Guangdong Province. Zhou (2016) identified a long-term cointegration relationship between technological innovation and industrial structure in Hunan Province, though the impact of technological innovation exhibits time lag effects. Wu and Deng (2019) affirmed that technological innovation in the Yangtze River Economic Belt effectively promotes the enhancement of green total factor productivity (GTFP) in cities along its corridor, with the relationships among technological innovation, openness, and high-quality economic development showing significant spatial heterogeneity.

From a methodological perspective, scholars have empirically investigated the relationship between government fiscal allocations for science and technology and economic growth through unit root tests, cointegration tests, Granger Causality tests, VAR models, and impulse response analysis (Li & Dang, 2010; Tie & Wang, 2012). Romer (1990) transcended the limitations of exogenous technology in traditional neoclassical growth models (e.g., the Solow model) by proposing an endogenous growth model, which utilizes Hamiltonian functions and equilibrium analysis to elucidate the intrinsic linkages among knowledge accumulation, R&D incentives, and economic growth. Liu et al. (2014) proposed employing factor analysis, cointegration tests, and vector autoregression (VAR) models to analyze and determine whether a long-run equilibrium relationship exists between China's Gross Domestic Product (GDP) and technological innovation outcomes, and whether they exhibit mutual causality. Gu et al. (2017) employed the C-D production function to demonstrate an increasing contribution rate of technological innovation investment to economic development. They applied a coupling coordination degree model to examine the evolution of the relationship between technological innovation and economic development.

Regarding research on the impact of technological innovation on sports industry development, empirical studies have employed descriptive statistics (Marques Miragaia et al., 2015; Yoshida et al., 2013) and regression analysis (Balmer et al., 2012), among other methods, to examine sports industry fields such as sports events, social responsibility of sports enterprises, and sports consumption from the perspective of technological innovation. Dašić (2023) analyzed the global sports industry trends and the process of economic transformation from the perspective of digital transformation. Hyysalo (2009) emphasized the mechanisms of user participation, adaptation, and technological innovation in sports-related industries. Fredberg and Piller (2011) examined the case of adidas, with conclusions underscoring the critical role of technological innovation in the development of sports enterprises. Overall, in recent years, alongside the robust expansion of the sports industry, theoretical research on innovating operational mechanisms, adjusting industrial structures, and transforming development models within this sector has proliferated. However, a significant research gap persists: rigorous econometric analysis of the quantitative impact of technological innovation on the structural transformation of the sports industry remains notably scarce.

Prior research has provided valuable perspectives, conceptual frameworks, and methodological approaches, laying a solid foundation for this study. Therefore, adopting a multi-method and multi-angle approach to investigate the quantitative interactions between technological innovation and sports industry development, and conducting in-depth analyses of how technological innovation drives structural transformation in the sports industry – thereby stimulating sports economic growth – holds significant practical value for strengthening China's sports economy and accelerating the process of building China into a

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leading sporting nation. Guided by these objectives, this study integrates technological innovation, structural transformation and upgrading of the sports industry, and sports industry development. Utilizing the autoregressive distributed lag (ARDL) error correction model (ECM), we explore the long-run equilibrium relationships among these three dimensions to provide empirical support and strategic insights for the sustainable development of China's sports economy.

2. METHODOLOGY

2.1. Variable specification and data sources

Balancing data availability and temporal relevance, this study employs provincial-level panel data from China's sports industry (excluding Hong Kong, Macao, and Taiwan) covering the period 2008 to 2023 to examine the interrelationships among technological innovation, industrial structure, and economic development within the sector. Technological innovation is operationalized through two distinct variables: input and output. Consistent with the methodology outlined in the China National Innovation Index Report 2020, innovation input (INP) is measured by a composite index of R&D expenditure intensity and R&D personnel intensity. Innovation output (ONP) is constructed as a composite index comprising the number of invention patents granted and scientific papers published, normalized per 10,000 R&D personnel (Liu et al., 2014).

Various methods are used internationally to measure industrial structure. This study adopts two prevalent approaches. Sports industry structural transformation (RAT) is proxied by the ratio of output value from the sports service sector to that of sporting goods manufacturing. This metric captures the intra-sectoral shift from manufacturing (secondary industry) toward service-oriented (tertiary industry) activities. Sports industry upgrading (GRT) is measured by the growth rate of output value in the sports service sector, which serves as an indicator of the expansion of high-value-added, knowledge-intensive activities. Finally, overall sports industry development (GOP) is measured by the gross output value of the sports industry. All variable specifications are detailed in Table 1. The provincial data were primarily obtained from the China Statistical Yearbook on Science and Technology, historical editions of the China Statistical Yearbook, other relevant scientific and technological statistical reports, and the official websites of provincial statistical bureaus and sports administrations.

2.2. Model specification

This study employs the autoregressive distributed lag–error correction model (ARDL-ECM) framework to investigate both long-run equilibrium and short-term dynamic relationships among three variable sets of variables:(a) technological innovation and sports industry development, (b) structural transformation/upgrading of the sports industry, and (c) sports economic scale. The ARDL approach is particularly suitable for this analysis, given its robustness and flexibility in handling variables with different orders of integration – it does not require all series to be integrated of the same order [i.e., exclusively I(0) or I(1)]. Moreover, this method yields reliable long-run parameter estimates even in the presence of endogenous explanatory variables. The empirical procedure consists of three steps.

Step 1 is unit root testing. Unit root tests are conducted on all time series variables to assess stationarity and determine their order of integration. The ARDL modeling procedure proceeds only if all variables are confirmed to be integrated of order I(0) or I(1), and none are I(2).

Table 1. Variables and definitions

Subsystem	Variables
Sports Technological Innovation	Technological Innovation Input (INP)
	Technological Innovation Output (ONP)
Sports Industrial Structure	Ratio of Sports Service Sector to Sporting Goods Manufacturing Output Value (RAT)
	Growth Rate of Sports Service Sector Output Value (GRT)
Sports Economic Scale	Gross Output Value of Sports Industry (GOP)

$$\Delta y_t = a_0 + \sum_{i=1}^{m} a_{1i}\Delta y_{t-1} + \sum_{j=1}^{m} a_{2i}\Delta x_{t-i} \qquad (1)$$
$$+a_3\Delta y_{t-1} + a_0 x_{t-1} + \mu_t,$$

where a_0 denotes the constant term, a_1 and a_2 capture short-term dynamic relationships, while a_3 and a_4 represent long-run dynamics or cointegration relationships; *t* indicates the trend term; μ_t follows a white noise process; *m* and *n* denote the lag orders of the dependent and explanatory variables respectively, determined by the Schwarz Information Criterion (SIC).

Step 2 is ARDL model construction and bounds test. The general form of the ARDL model is specified as follows:

$$y_t = a_0 + \sum_{i=1}^{m} a_{1i}\Delta y_{t-1} + \sum_{j=1}^{m} a_{2i}\Delta x_{t-i} + \mu_t, \qquad (2)$$

The null hypothesis (H_0) of bounds test for cointegration test posits "no long-run equilibrium relationship exists between the two variables," specifically $H_0\!: a_3 = a_4 = 0,$ the alternative hypothesis (H1) is $H_1\!: a_3 \neq a_4 \neq 0.$ The test involves comparing the *F*-statistic against the critical values. If the *F*-statistic falls below the lower critical value, the null hypothesis cannot be rejected, indicating no long-run cointegration. If it exceeds the upper critical value, the null hypothesis is rejected, confirming long-run cointegration. If the *F*-statistic falls within the inconclusive range, determination requires comparing the test statistic to Pesaran et al. (2001) critical values based on the order of integration of the series.

Step 3 is long-run and error correction estimation. If cointegration is confirmed, the long-run equilibrium relationship is estimated. The short-term dynamics are then captured through ECM:

$$\Delta y_t = a_0 + \sum_{i=1}^{m} a_{1i}\Delta y_{t-1} + \sum_{j=1}^{m} a_{2i}\Delta x_{t-i} \qquad (3)$$
$$-\delta ECM_{t-1} + \mu_t,$$

where ECM_{t-1} is the lagged error correction term and δ represents the speed of adjustment, generally satisfying $0 < \delta < 1$. If no cointegration is detected, the specification of an ECM is not warranted.

3. RESULTS

3.1. Stationarity tests

Prior to cointegration testing, stationarity tests were conducted. This study employs the Augmented Dickey-Fuller (ADF) test, a standard unit root testing procedure, with the lag order determined as 3 according to the Schwarz Information Criterion (SIC). The test results, presented in Tables 2 and 3, indicate that all five variable series are integrated of order I(1) or I(0), thereby satisfying the prerequisite for applying the ARDL modeling approach. This result provides a statistical foundation for the applicability of the subsequent ARDL modeling, ensuring that model specification is not biased due to inconsistent orders of integration of the variables.

Visual inspection of the comovement trends among the five variables (Figure 1) provides preliminary evidence of potential cointegration relationships.

Table 2. Variable stationarity test results (Part 1)

Variable	Logarithmic Series	First-Differenced Logarithmic Series
Technological Innovation Input (INP)	Non-stationary	Stationary**
Technological Innovation Output (ONP)	Non-stationary	Stationary*
Gross Output of Sports Industry (GOP)	Stationary**	

Note: ** and * denote rejection of the null hypothesis of a unit root at the 1% and 5% significance levels, respectively.

Table 3. Variable stationarity test results (Part 2)

Variable	Logarithmic Series	First-Differenced Logarithmic Series
Ratio of Sports Service Sector to Sporting Goods Manufacturing Output Value (RAT)	Non-stationary	Stationary**
Growth Rate of Sports Service Sector Output Value (GRT)	Stationary*	

Note: ** and * denote rejection of the null hypothesis of a unit root at the 1% and 5% significance levels, respectively.

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Notably, the most pronounced comovement is observed between technological innovation input/output and the gross output of the sports industry (GOP), suggesting a potential positive long-run equilibrium relationship. Comovement is also observed between the growth rate of the sports service sector (GRT) and gross output of the sports industry, as well as between technological innovation input/output and growth rate of the sports service sector. However, due to substantial fluctuations, visual assessment remains inconclusive for determining cointegration between technological innovation and sports industry transformation (RAT), as well as between industrial transformation (RAT) and sports industry development (GOP).

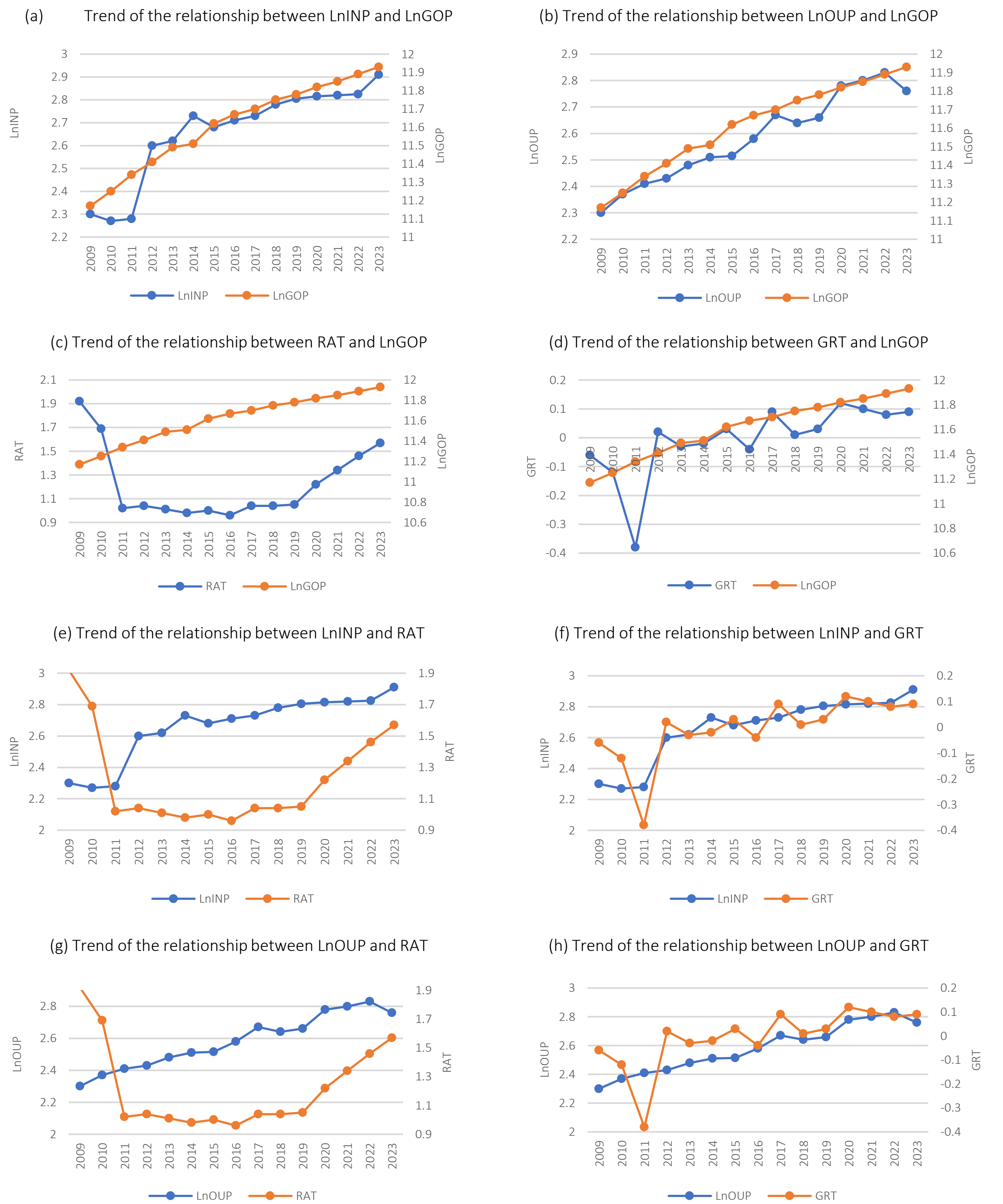

Figure 1. Comovement trends between key variables

3.2. Cointegration tests

An ARDL model was established to examine the relationship between technological innovation input (lnINP) and gross sports industry output (lnGOP). The optimal lag structure, ARDL(1,2), was selected based on the Schwarz Information Criterion (SIC). The regression yielded an R-squared value of 0.989, suggesting that the model explains a high proportion of the variance in the dependent variable. The high R-squared value indicates that the model has strong explanatory power for the gross output of the sports industry, enhancing the credibility of the empirical results. The estimated long-run equilibrium relationship (Table 4) shows a positive and statistically significant coefficient for lnINP, suggesting that a 1% increase in innovation input (INP) induces a 0.223% long-run increase in sports industry output (GOP), statistically significant at the 1% level. This result indicates that technological innovation input is a sustained driver for the expansion of the sports industry scale, confirming its core role in the high-quality development of the industry. Based on the confirmed cointegration relationship, the short-term ECM was derived. The ECM reveals that approximately 2.7% of any short-run deviation from the long-run equilibrium is corrected in the subsequent period. The relatively slow short-term adjustment speed indicates a certain lag in the sports industry's response to changes in innovation input, suggesting that policy implementation needs to be forward-looking. Both the first and second lags of the differenced technological innovation input (ΔlnINP) contribute positively to short-term GOP growth. For technological innovation output (lnONP) and gross output (lnGOP), the optimal ARDL(3,1) model demonstrates that a 1% increase in ONP induces a 0.066% long-term GOP increase. The elasticity of innovation output on total output is much lower than that of input, highlighting the chronic inefficiency in transforming scientific and technological achievements in China's sports sector. The error correction term is significant and negative (–0.334), indicating a relatively rapid adjustment speed where about 33.4% of any disequilibrium is corrected within one period. The relatively fast error correction mechanism indicates a strong internal linkage between innovation output and industrial scale, suggesting that short-term fluctuations are not easily sustained.

Table 4. Long-run coefficients and error correction terms for innovation input/output and sports industry output

lnINP and lnGOP		lnOUP and lnGOP	
Variable	**Coefficient**	**Variable**	**Coefficient**
lnINP	0.223	lnOUP	0.066
lnGOP(–1)	1.026	C	2.776
D(lnINP)	0.221	D(lnOUP)	0.065
D(lnINP(–1))	0.142	D(lnOUP(–1))	–0.484
ECM(–1)*	0.027	ECM(–1)*	–0.334

Note: C denotes the constant term.

Table 4 clearly demonstrates a stronger long-run impact of innovation input (0.223) on sports industry output compared to innovation output (0.066). The significant error correction terms for both relationships confirm that short-term deviations consistently adjust back towards the long-run equilibrium, with the adjustment being notably faster for the innovation output model.

The optimal ARDL(3,0) model for cointegration analysis between sports service sector growth rate (GRT) and gross sports industry output (lnGOP) yields an R-squared of 0.999, indicating excellent model fit (Table 5). A one-unit increase in GRT is associated with a 0.357% increase in gross output in the long run, reflecting a positive association between the optimization of the sports industrial structure and its economic development. The significant pulling effect of service sector growth on total output highlights the contribution of the sports industry's structural transformation toward servitization to overall economic development. When short-term fluctuations exceed the long-run equilibrium level, reversion occurs at a 0.110% adjustment speed. The time series relationship between the sports service-to-manufacturing ratio (RAT) and lnGOP fails to meet significance testing criteria, indicating no long-run equilibrium relationship exists – structural adjustment shows no necessary linkage to gross output growth. This finding challenges the traditional perception that 'an increase in structural proportion necessarily drives scale growth,' suggesting that policies solely pursuing proportional adjustment while neglecting quality and efficiency improvements may have limited effects.

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Table 5. Long-run equilibrium and short-term dynamics of sports service sector growth rate and gross sports industry output in China (2008–2023)

Variable	Coefficient	Probability
GRT	0.357	0.002
lnGOP(–1)	0.763	0.001
C	1.299	0.006
ECM(–1)*	–0.110	0

Note: C denotes the constant term.

The optimal cointegration model between technological innovation input (lnINP) and the sports service-to-manufacturing ratio (RAT) is ARDL(2,1), yielding a regression R-squared of 0.931 and confirming their long-run equilibrium relationship. For technological innovation output (lnONP) and sports service sector growth rate (GRT), the optimal ARDL(2,3) specification achieves an R-squared of 0.900 (results in Table 6). The estimated error correction term (ECM) coefficients for the short-run dynamics between technological innovation and the sports service sector growth (GRT) are –1.296 and –1.302 (Table 6), exceeding the standard theoretical range of (–1, 0). Such deviation typically indicates potential model misspecification or significant external shocks. It is postulated that the COVID-19 pandemic, which occurred during the sample period (2008–2023), constituted such a shock, inflicting extreme structural disruption on the offline-dependent sports service industry. Lockdowns and cancellations precipitated a sharp contraction, while the subsequent post-pandemic recovery fueled a volatile rebound. This sequence of exogenous shocks likely induced the observed instability in short-term dynamics. Nevertheless, the identified long-run cointegration between lnINP, lnONP, and GRT remains valid. Isolating the pandemic's effect through dummy variables or segmented regression represents a productive avenue for future research.

Long-term analysis reveals that technological innovation output positively promotes sports service sector growth. Specifically, a 1% increase in technological innovation input elevates the sports service-to-manufacturing ratio by 0.446%, suggesting that investment in R&D capital and human resources may be a primary driver of industrial scale expansion. The high elasticity of innovation input on the structural ratio indicates its leverage effect in promoting the industry's transition from manufacturing to services. Long-term analysis further shows that every 1% rise in innovation input boosts the sports service sector growth rate by 0.397% – a marginal effect approaching its impact on industrial restructuring (0.446%). The promoting effect of innovation input on service sector growth is close to its impact on the structural ratio, indicating its dual function of both 'quantitative increase' and 'qualitative improvement'. Conversely, a 1% increase in technological innovation output (papers/patents) only enhances industrial growth by 0.180%, which suggests insufficient efficiency in converting scientific outputs into economic value and points to bottlenecks in industry-academia-research collaboration. The low elasticity of innovation output reveals the disconnection in the 'paper-patent-industry' chain, highlighting the urgency of improving the efficiency of scientific and technological achievement transformation.

Overall, the impact of technological innovation output on the transformation and upgrading of the sports industry structure is significantly weaker than that of innovation input. Therefore, upgrading the sports industrial structure and developing the sports economy should prioritize

Table 6. Long-run equilibrium and short-term dynamics of technological innovation input, innovation output, and sports industrial structure transformation/upgrading in China (2008–2023)

lnINP & RAT		lnINP & GRT		lnOUP & GRT	
Variable	Coefficient	Variable	Coefficient	Variable	Coefficient
lnINP	0.446	lnINP	0.397	lnOUP	0.180
C	–3.261	C	–2.467	C	–1.322
ECM(–1)*	–0.120	ECM(–1)*	–1.296	ECM(–1)*	–1.302

Note: ECM coefficient exceeding 1 violates theoretical bounds, suggesting potential model misspecification. Robustness checks with alternative lag structures are recommended. C denotes the constant term.

the allocation of R&D resources (e.g., fiscal subsidies, talent acquisition for R&D). Concurrently, enhancing the conversion efficiency of scientific outputs, bridging the gap from "research outcomes to commercialization," and establishing technology transfer offices with performance-based funding mechanisms to accelerate patent commercialization are imperative.

Granger Causality tests were employed to examine the intrinsic Granger-causal relationships among the three dimensions (Table 7).

First, growth in sports economic scale (GOP) significantly Granger-causes increased technological innovation input (INP) (rejecting "GOP does not Granger-cause INP"), while technological innovation input enhancement also effectively Granger-causes sports economic scale expansion (rejecting "INP does not Granger-cause GOP"). This bidirectional causal relationship reveals a positive feedback mechanism, providing empirical evidence that market expansion pulls innovation, while innovation, in turn, drives further market growth. This confirms a bidirectional Granger-causal relationship between sports economic scale and innovation input, establishing a virtuous cycle.

Second, sports economic scale (GOP) unilaterally Granger-causes technological innovation output (ONP) (rejecting 'GOP does not Granger-cause ONP'), while technological innovation output exhibits no significant driving effect on sports economic scale (failing to reject 'ONP does not Granger-cause GOP'). Sports economic scale significantly elevates both the sports service-to-manufacturing ratio (RAT) and sports service growth rate (GRT) (rejecting "GOP does not Granger-cause RAT/GRT" for both), yet neither service-to-manufacturing ratio nor sports service growth rate demonstrates feedback effects on sports economic scale. These results collectively indicate that sports economic scale unilaterally drives technological innovation output and industrial structure upgrading.

Third, an increase in the sports service-to-manufacturing ratio (RAT) Granger-causes higher technological innovation input (INP) (rejecting "RAT does not Granger-cause INP"), while technological innovation input fails to significantly drive service-to-manufacturing ratio improvement (failing to reject "INP does not Granger-cause RAT"), indicating that industrial structure optimization (RAT) unilaterally stimulates innovation investment. The guiding effect of structural optimization on innovation input is stronger than the reverse influence, indicating that an increase in the service sector's proportion can better stimulate enterprises' emphasis on R&D.

Fourth, key missing links emerge: technological innovation output (ONP) exhibits no significant causal impact on sports economic scale, service-to-manufacturing ratio, or nor sports service growth rate, indicating insufficient conversion of scientific outputs. Both technological innovation input and technological innovation output fail to Granger-cause sports service growth rate, implying sports service sector growth lacks innovation-driven momentum. The failure of service sector growth to be significantly caused by innovation variables indicates that its development still relies on traditional factor inputs rather than technological penetration, and an innovation-driven model has not yet been formed. The absence of cointegration relationships between sports economic scale and service-to-manufacturing ratio, as well as service-to-manufacturing ratio and technological innovation output, suggests their causal interactions may exist only in the short-term dynamics.

In summary, increased technological innovation input (INP) and growth in tertiary sector output of the sports industry (GRT) both Granger-cause expansion in gross sports industry output (GOP). Technological innovation input further Granger-drives sports industrial structure upgrading (RAT), while technological innovation collectively stimulates sports service sector growth (GRT). Overall, the Granger Causality test results align with the long-run cointegration relationships established by ARDL analysis, demonstrating mutual validation. This consistency underscores the scientific rigor and reliability of integrating cointegration relationships with Granger Causality in empirical research.

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Table 7. Granger Causality results

Cointegration Verification Results			Granger Causality Test Results			
Dependent Variable	**Independent Variable**	**Cointegration**	**Null Hypothesis**	**Reject/Fail to Reject**	**Null Hypothesis**	**Reject/Fail to Reject**
lnGOP	lnINP	Yes	LNGOP does not Granger-cause LNINP	Reject	LNINP does not Granger-cause LNGOP	Reject
	lnOUP	Yes	LNGOP does not Granger-cause LNOUP	Reject	LNOUP does not Granger-cause LNGOP	Fail to Reject
lnGOP	RAT	No	LNGOP does not Granger-cause RAT	Reject	RAT does not Granger-cause LNGOP	Fail to Reject
	GRT	Yes	LNGOP does not Granger-cause GRT	Reject	GRT does not Granger-cause LNGOP	Fail to Reject
RAT	lnINP	Yes	RAT does not Granger-cause LNINP	Reject	LNINP does not Granger-cause RAT	Fail to Reject
	lnOUP	No	RAT does not Granger-cause LNOUP	Fail to Reject	LNOUP does not Granger-cause RAT	Fail to Reject
GRT	lnINP	Yes	GRT does not Granger-cause LNINP	Fail to Reject	LNGOP does not Granger-cause GRT	Fail to Reject
	lnOUP	Yes	GRT does not Granger-cause LNOUP	Fail to Reject	LNOUP does not Granger-cause GRT	Fail to Reject

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4. DISCUSSION

The findings demonstrate that a 1% increase in technological innovation input (INP) exerts a long-term 0.223% growth in gross sports industry output (GOP) (Table 4), empirically validating that the continuous penetration of technology brings new development opportunities to the sports industry. This suggests that innovations are transforming every aspect of the sports industry – from event organization and sporting goods manufacturing to sports media. For instance, in sports event management, advanced broadcasting technologies enable a larger audience to watch games live, enhancing the commercial value of events; in sporting goods manufacturing, the application of new materials and processes improves product performance, attracting more consumers. The bidirectional Granger Causality between technological innovation input and gross sports industry output (Table 7) suggests a mutually reinforcing relationship: innovation stimulates output growth, while economic expansion facilitates further investment in innovation. This reciprocal relationship forms a virtuous cycle, making technological innovation a core engine of sports industry development.

Technological innovation output (ONP) maintains a long-run equilibrium with gross sports industry output (coefficient 0.066), indicating its measurable, albeit relatively modest, contribution to aggregate sports output. However, the absence of a significant causal impact on industrial structure (RAT) (Table 7) reveals systemic inefficiencies in translating scientific achievements into structural transformation within China. In the sports industry, structural upgrading entails shifting from traditional manufacturing toward higher value-added services. While innovation output enhances overall industry output, it faces substantial barriers in elevating the service sector's proportion. For instance, sports technology innovations predominantly apply to traditional domains like sporting goods manufacturing, with relatively limited penetration into service sectors such as fitness, training, and sports tourism. This disparity likely stems from the service sector's distinctive characteristics – its development depends not merely on technology but equally on market demand and policy environments. Transforming technological achievements in sports services requires enhanced support mechanisms and market guidance; otherwise, achieving effective industrial upgrading remains challenging.

A one-unit increase in the growth rate of the sports service sector (GRT) is associated with a 0.357% increase in gross sports output (GOP) in the long run (Table 5), demonstrating its significant driving effect on overall industry expansion. Rising living standards have fueled growing demand for fitness, training, and sports tourism services, creating accelerated development opportunities for sports services. However, the sector faces pronounced volatility – reflected in an error correction term (ECT) coefficient below –1 (–1.296, Table 6) – indicating substantial adjustment lags in structural adaptation. This manifests as slow responsiveness to market fluctuations and weak risk resilience. For example, disruptions like pandemics, seasonal variations, and economic downturns significantly impact sports service consumption, creating development instability.

The pronounced volatility of the sports service sector, as evidenced by the abnormally high short-term adjustment speed (ECM > |1|) in its relationship with technological innovation, points to a fundamental vulnerability in its development model. The COVID-19 pandemic served as a stress test, revealing how reliant the sector is on stable external conditions and how easily the transmission of innovation can be disrupted. This structural fragility underscores that technological advancement, while crucial for long-term growth, is insufficient on its own. Therefore, building a resilient industrial ecosystem through digital transformation and robust crisis-response frameworks is not merely complementary but a necessary strategy to safeguard the sector's stability and ensure its sustainable contribution to the national economy.

China's sports industry exhibits a pronounced structural imbalance between manufacturing and services. The absence of a long-run equilibrium between industrial structure upgrading and gross sports industry output – coupled with the finding that the influence of technological innovation input on industrial structure upgrading (coefficient 0.446), though positive, is insufficient to catalyze a macro-level structural shift – reflects a

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critical lack of industrial synergy that constrains scale economies. Traditional sports manufacturing dominates the industrial composition while services remain underdeveloped, impeding comprehensive upgrading. For instance, manufacturing focuses primarily on product production and sales, whereas services emphasize experience delivery. Without effective coordination, product-service mismatches occur. Moreover, this synergy deficit hinders optimal allocation of innovation resources between sectors, undermining their collective upgrading potential.

As technological investment increases, its marginal returns on the sports service sector exhibit diminishing trends. The long-term elasticity of technological innovation input to growth rate of the sports service sector (0.397) is lower than its effect on industrial structure upgrading (0.446) (Table 6), suggesting that merely increasing innovation input cannot sustainably accelerate service growth. In the early stages of sports service development, technological investment yields significant efficiency gains – for example, advanced information management systems enhance operational efficiency and customer satisfaction. However, beyond certain investment thresholds, marginal benefits progressively decline. This diminishing return likely stems from multifaceted constraints, including human capital shortages, market saturation, and institutional barriers. Unless accompanied by corresponding workforce upskilling and market expansion, continued innovation investment faces decreasing marginal utility despite increasing absolute inputs.

The model results of this study reveal a noteworthy phenomenon: the short-term error correction mechanism between technological innovation and the growth rate of the sports service sector (GRT) exhibits a statistically anomalous adjustment speed, with the absolute value of the ECM coefficient exceeding 1. This finding may precisely reflect the inherent vulnerability and volatile recovery pattern of China's sports service sector when confronted with major external shocks. The COVID-19 pandemic, as a typical "black swan" event, almost entirely disrupted the conventional transmission mechanism through which technological innovation drives service sector growth – such as by enhancing service experiences or optimizing operational efficiency – in the short term. As a result, the output growth rate of the service sector (GRT) plummeted due to non-economic factors, significantly deviating from its long-term trend. Subsequently, once external constraints were lifted, the strong resurgence of market forces drove the system to correct at a pace far exceeding normal levels. Therefore, from a practical perspective, this "anomalous" ECM coefficient may serve as indirect evidence of the insufficient risk resilience and unstable developmental foundation of China's sports service sector. This insight alerts policymakers that, while relying on innovation to drive long-term growth, it is equally imperative to build a more resilient industrial ecosystem – for instance, by developing online sports services and establishing crisis response mechanisms – to buffer the disruptive impact of similar shocks on the short-term equilibrium of the industry.

CONCLUSION

This study aimed to empirically examine the long-term equilibrium and short-term dynamic relationships among technological innovation, structural transformation, and the development of China's sports industry. The key findings reveal that technological innovation input exerts a substantially stronger influence on the industry's gross output than innovation output, and while the growth of the sports service sector drives overall economic scale, the industrial structure ratio itself shows no long-run equilibrium with it. Furthermore, the short-term adjustment mechanisms, particularly for the sports service sector, were significantly disrupted by the COVID-19 pandemic.

Based on these results, it is concluded that the development of China's sports industry is currently characterized by scale-driven growth, hampered by inefficient conversion of scientific outputs and a lack of deep structural synergy. Accordingly, we propose the following recommendations. First, it is vital to establish an "R&D-Application-Feedback" closed-loop mechanism to enhance the conversion efficiency of technological innovation outputs. Second, it is worth prioritizing the servitization of sporting goods manufacturing to address structural imbalances and foster "Technology-Manufacturing-Service" synergy. Finally, there is a need for resilient policy tools, such as piloting Sports Industry Innovation Zones, to help the sector withstand external shocks and align structural adjustment with economic scale expansion.

AUTHOR CONTRIBUTIONS

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Methodology: Bingxu Zhao.
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REFERENCES

1. Aghion, P., David, P. A., & Foray, D. (2009). Science, technology and innovation for economic growth: Linking policy research and practice in 'STIG Systems'. *Research Policy, 38*(4), 681-693. https://doi.org/10.1016/j.respol.2009.01.016
2. Balmer, N., Pleasence, P., & Nevill, A. (2012). Evolution and revolution: Gauging the impact of technological and technical innovation on Olympic performance. *Journal of Sports Sciences, 30*(11), 1075-1083. https://doi.org/10.1080/02640414.2011.587018
3. Bilbao-Osorio, B., & Rodríguez-Pose, A. (2004). From R&D to innovation and economic growth in the EU. *Growth and Change, 35*(4), 434-455. https://doi.org/10.1111/j.1468-2257.2004.00256.x
4. Christensen, C. M. (2013). *The innovator's dilemma: When new technologies cause great firms to fail.* Harvard Business Review Press. Retrieved from https://books.google.com/books?id=lURBCgAAQBAJ
5. Christensen, C. M., McDonald, R., Altman, E. J., & Palmer, J. E. (2018). Disruptive innovation: An intellectual history and directions for future research. *Journal of Management Studies, 55*(7), 1043-1078. https://doi.org/10.1111/joms.12349
6. Dašić, G. (2023). Digital transformation in the sports industry. *First International Scientific Conference Sporticopedia-SMB2023.* Belgrade, Serbia. Retrieved from https://www.ceeol.com/search/article-detail?id=1215088
7. Freeman, C., & Soete, L. (1997). *The Economics of Industrial Innovation[M].* Routledge. https://doi.org/10.4324/9780203357637
8. Fredberg, T., & Piller, F. T. (2011). The paradox of tie strength in customer relationships for innovation: A longitudinal case study in the sports industry. *R&D Management, 41*(5), 470-484. https://doi.org/10.1111/j.1467-9310.2011.00659.x
9. Gu, W., Shen, Y., Wang, S., & Zeng, C. (2017). Spatial evolution of China's scientific and technological innovation ability and its relationship with economic development. *China Science and Technology Forum, 2017*(9), 1-7. (In Chinese). https://doi.org/10.13580/j.cnki.fstc.2017.09.003
10. Han, Y. (2021). Research on the impact of sports technological innovation on the optimization and upgrading of China's sports industry structure. *Contemporary Sports Technology, 11*(31), 1-3. (In Chinese). https://doi.org/10.16655/j.cnki.2095-2813.2105-1579-6828
11. Hyysalo, S. (2009). User innovation and everyday practices: Micro-innovation in sports industry development. *R&D Management, 39*(3), 247-258. https://doi.org/10.1111/j.1467-9310.2009.00558.x
12. Kamien, M. I., & Schwartz, N. L. (1974). Product durability under monopoly and competition. *Econometrica, 42*(2), 289-301. https://doi.org/10.2307/1911979
13. Kamien, M. I., & Schwartz, N. L. (1976). On the degree of rivalry for maximum innovative activity. *The Quarterly Journal of Economics, 90*(2), 245-260. Retrieved from https://ideas.repec.org/a/oup/qjecon/v90y1976i2p245-260..html
14. Krammer, S. M. S. (2017). Science, technology, and innovation for economic competitiveness: The role of smart specialization in less-developed countries. *Technological Forecasting and Social Change, 123,* 95-107. https://doi.org/10.1016/j.techfore.2017.06.028
15. Li, X. J., & Dang, J. (2010). An empirical analysis of fiscal science and technology appropriation on economic growth: Model test based on data from Gansu Province. *Gansu Social Sciences, 15,* 174-178. https://doi.org/10.15891/j.cnki.cn62-1093/c.2010.05.062

16. Liu, F., Lu, Y., & Yu, J. (2014). On relationship between innovation achievements of science and technology and economic growth in China. *Science and Technology Management Research, 2014*(17), 1-8. https://doi.org/10.3969/j.issn.1000-7695.2014.17.002

17. Liu, J., & Wang, H. (2024). The mechanism and implementation path of accelerating the development of new quality productive forces in the sports industry. *Journal of Chengdu Sport University, 50*(5), 1-7. (In Chinese). https://doi.org/10.15942/j.jcsu.2024.06.20

18. Mansfield, E. (1988). Industrial innovation in Japan and the United States. *Science, 241*(4874), 1767-1772. https://doi.org/10.1126/science.241.4874.1769

19. Marques Miragaia, D. A., Nunes Martins, C. I., Kluka, D. A., & Havens, A. (2015). Corporate social responsibility, social entrepreneurship and sport programs to develop social capital at community level. *International Review on Public and Nonprofit Marketing, 12*(2), 141-154. https://doi.org/10.1007/s12208-015-0131-x

20. Nelson, R. R., & Winter, S. G. (1982). *An evolutionary theory of economic change*. Harvard University Press. Retrieved from https://books.google.com/books?id=6Kx7s_HXxrkC&pg=PA1

21. Pesaran, M. H., Shin, Y., & Smith, R. J. (2001). Bounds testing approaches to the analysis of level relationships. *Journal of applied econometrics, 16*(3), 289-326. https://doi.org/10.1002/jae.616

22. Romer, P. M. (1990). Are nonconvexities important for understanding growth? *American Economic Review, 80*(2), 97-103. Retrieved from https://papers.ssrn.com/sol3/papers.cfm?abstract_id=319587

23. Schumpeter, J. A. (1934). *The theory of economic development*. Harvard University Press. https://doi.org/10.4324/9781003146766

24. Tie, W., & Wang, T. (2012). The empirical analysis of Shaanxi Province investment for science performance in a perspective of economic growth. *Statistics & Information Forum, 27*(2), 73-78. Retrieved from https://kns.cnki.net/kcms2/article/abstract?v=4qE7rfs4XRGTkBCVuzDWPrv5s8thAr1TEiKDfbRhs1HAuybj9qlShqByHye0grakJI8rRv2wnlCaM0yTyEhqvj4bgePX6kpcKEixCSSdZfh-x3xWqL8cKCqQgTlBfpa3p3nWvekptv2lh05RPRF1Rf2wVNtMvBEvnVY9IDy19UYle3zbXqu9Q==&uniplatform=NZKPT&language=CHS

25. Wu, C., & Deng, M. (2019). Technological innovation, opening to the outside world and high-quality development of the Yangtze River Economic Belt. *Science & Technology Progress Policy, 36*(3), 1-9.

26. Wu, E. (2011). Cointegration analysis of influence of scientific and technological innovation on economic growth: A case of Guangdong Province. *Journal of Shenyang University of Technology (Social Science Edition), 4*(1), 1-5. Retrieved from https://kns.cnki.net/nzkhtml/xmlRead/trialRead.html?dbCode=CJFD&tableName=CJFDTOTAL&fileName=SHES201101013&fileSourceType=1&appId=KNS_BASIC_PSMC&invoice=wapqY+keeFiWz9DZZDQLUMlTYNHXbJa+sd6PvHpF+M7EHcc6EXKp6BXrUOBm52RBT3JV7E/hKnj3hq1IlLLppPjF1g8DTmNaXVgyiNASBG5nPT1cZssaS8jPFYH9CV2QpEpcPgR7vOMFWeV+PDVIziIMXbb7cX1QkoRu203f5nA=

27. Yoshida, M., James, J. D., & Cronin, J. J. (2013). Sport event innovativeness: Conceptualization, measurement and its impact on consumer behavior. *Sport Management Review, 16*(1), 68-84. https://doi.org/10.1016/j.smr.2012.03.003

28. Zhou, Z. (2016). The impact of sci-tech innovation on industrial upgrading in Hunan Province. *Economic Geography, 36*(5), 1-6. (In Chinese). https://doi.org/10.15957/j.cnki.jjdl.2016.05.016