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Dynamic mechanism and evolutionary game analysis of sports industry service transformation

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Service transformation plays a pivotal role in achieving the sustainable development of the sports industry. This study originates from the interactive relationships among sports enterprises, consumers, and regulatory authorities, proposing a logical framework for the service transformation of the sports industry. Furthermore, a three-party evolutionary game model is constructed to explore the strategic evolution and stability conditions under both single-agent and multi-agent scenarios. The primary findings are as follows: (1) Interactive relationships among sports enterprises, consumers, and regulatory authorities exhibit a game dilemma resembling the "prisoner's dilemma." (2) A positive promotion relationship conducive to the transformation of the sports industry towards a service model is triggered only when at least two stakeholders' strategic choices surpass a certain threshold. (3) Fiscal subsidies play a facilitating role in encouraging service transformation for sports enterprises but have limited incentives for consumers. Finally, this paper suggests the introduction of competition mechanisms and the establishment of reward and penalty systems, offering decision-making guidance for the service transformation of the sports industry.

Keywords Service transformation, Sports industry, Evolutionary game, Strategic stability

With the popularization of the concept of healthy living, people's demand for physical exercise is increasing day by day, and the sports industry has also begun to enter a stage of rapid development[1]. Especially after the COVID-19 epidemic, participating in sports activities has become an important means for people to pursue a healthy life. With the support of Internet of Things, big data, cloud computing and other digital technologies, consumers' demand for sports activities has also begun to change from simple sports events and entertainment activities to more diversified and personalized service needs[2]. According to the statistics of American Sports Industry Association, as of 2021, the number of members of fitness clubs has continued to grow, exceeding 66 million. Developed countries such as Japan and South Korea have formed new markets in intelligent fitness equipment, virtual fitness courses and sports tourism[3]. It can be predicted that service transformation has become the key path to realize the sustainable development of sports industry, however, it has also brought a series of difficulties and challenges. For example, the lack of motivation for service-oriented transformation, imperfect management mechanism and lack of management talents, the pressure of economic sustainability, and market competition incentives have become bottlenecks restricting the service-oriented transformation of sports industry.

The service transformation of sports industry refers to the transformation of industrial development from a business model with hardware facilities and competitive training as the core to a service model with sports service and experience as the main[4]. Compared with the traditional business model, this "soft and hard" service model pays more attention to the public's sports needs, focusing on providing consumers with services at different levels, such as sports guidance, fitness consultation, health care, leisure and entertainment, social interaction and event organization, which can more comprehensively meet the consumption needs of different types and ages[5]. This transformation not only enhances user engagement in the sports industry but also brings more diversified revenue streams and fosters innovation in business models[6]. Moreover, by offering high value-added personalized services, it increases the overall value of the industry chain and facilitates the shift from one-

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time product consumption to long-term service-based consumption[7,8]. At the same time, the service-oriented transformation is significantly driven by digitalization. Utilizing the Internet and big data technologies, sports enterprises can deliver intelligent and customized services through online platforms, thereby achieving more precise market positioning and optimized user experiences[9]. As previously mentioned, this transformation not only helps to enhance the market competitiveness of the sports industry but also promotes its integration with other sectors, generating broader social benefits and economic value. It can be seen that the service-oriented transformation of sports industry has become an important strategic choice to adapt to the changes in consumer demand and enhance the overall competitiveness of the industry[10].

The service transformation of sports industry involves many fields, such as economy, society, management and innovation, and has become a new field of great concern[11]. Previous studies usually explain consumers' motivation, experience and satisfaction in choosing sports services by studying their needs, preferences and behaviors[12]. Some scholars have pointed out that digital technologies such as mobile Internet, artificial intelligence and cloud computing have significantly promoted the service transformation of sports industry. The application of these digital technologies not only makes sports services more refined and personalized, but also provides consumers with an immersive experience[13]. Cross-border integration is an important feature of the service transformation of sports industry. Some scholars have discussed the integration mechanism of sports industry with tourism, culture, science and technology and other industries, and proposed to build a diversified industrial ecology, which is conducive to improving the sustainable development capacity of sports industry[14]. In addition, some scholars have pointed out that policy and environmental factors play a guiding and normative role in the service transformation of sports industry[15]. The government's policy guidance is mainly reflected in promoting industrial integration and collaborative innovation, which can provide a favorable external environment for the service transformation of sports industry[16]. At the same time, the formulation and implementation of relevant laws also protect the legitimate rights and interests of stakeholders and promote the healthy and sustainable development of the industry[17]. On this basis, some scholars began to notice the influence of the relationship between stakeholders in the sports industry on the service transformation, which includes collaborative innovation, economy and trade[10], transportation network, etc. These factors jointly promote the sports industry to expand from the traditional product and event management to a wider service field.

To sum up, there have been a lot of studies on the service transformation of sports industry. However, the research perspective usually focuses on one of consumers, enterprises or the government. Although this is essential to reveal the transformation law of sports industry service, it ignores the linkage among the three. In other words, the service transformation of sports industry is a process in which consumers, enterprises and management departments gradually reach a balance through constant strategic games. Therefore, this study explains the interaction among stakeholders (consumers, enterprises and management departments) in the process of service transformation, that is, the logical framework of service transformation of sports industry. At the same time, the three-party evolutionary game model of service transformation is established, and the conditions for a single player and the whole game system to achieve strategic stability are discussed respectively. Finally, the sensitivity of each strategy to external factors is tested by numerical simulation.

The marginal contribution of this study includes two aspects: first, it puts forward and explains the logical framework of sports industry service transformation. Compared with the abstract description of stakeholders' relationship in sports industry, this logical framework is based on evolutionary game theory, which reveals the interaction among sports enterprises, consumers and management departments from a micro perspective, and discusses its influence on service transformation with the strategic game between different subjects as the main line, which not only provides a new research perspective for the service transformation of sports industry, but also provides a paradigm for the construction of service transformation logical framework for related fields. The second is to build a three-way evolutionary game model of service transformation. This model is based on the logical framework of service transformation, and is used to discuss the strategic game among three different participants. The existing research usually focuses on specific game types, such as cooperative game, snowdrift game, intelligent pig game, etc. These games are usually completed at one time, which is difficult to meet the long-term nature of service transformation of sports industry. The model constructed in this paper transforms this long-term feature into a continuous game process, which makes the application of this model no longer limited to the sports industry.

Materials and methods

Logical framework of service transformation of sports industry

The service transformation of sports industry means the transformation from the traditional product sales model to providing comprehensive services, which includes the production and sales of material products, as well as services such as sports entertainment, health management and sports tourism. Its main purpose is to meet the diversified needs of consumers and improve the efficiency of resource allocation in sports industry. The service transformation of sports industry is a long-term systematic project involving society, economy and market. The diversification of subject types and the coupling of competition and cooperation determine the complexity of the transformation process. Therefore, we try to propose an explanatory framework to discuss and analyze this complexity. Figure 1 shows the logical framework of the service transformation of sports industry, and reveals the relationship among sports enterprises, consumers and management departments, which provides theoretical support for discussing the strategic game dependence among the participants.

Sports enterprises are the practitioners of service transformation and the main force to promote industrial transformation, including sports performance enterprises, sports goods manufacturing enterprises, sports information dissemination enterprises, sports tourism enterprises, sports science and technology enterprises and sports education and training institutions. Their main business is to provide consumers with sporting goods, organize sports events and sports tourism, and provide education and training services. Service-oriented

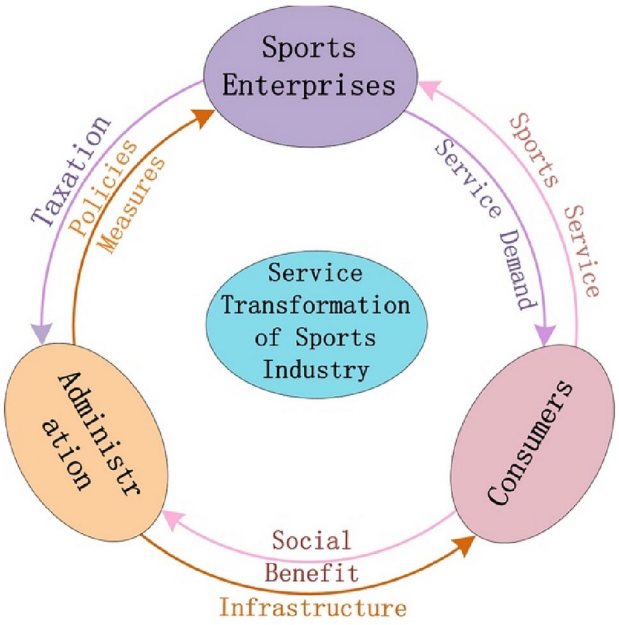

Fig. 1. Logical framework of service transformation of sports industry.

transformation requires sports enterprises to constantly innovate service models and develop new sports technologies. For example, virtual competitions and e-sports are organized with the help of virtual reality, augmented reality and artificial intelligence. Through data analysis and intelligent detection, consumers can better understand their activities, and at the same time, they can provide portraits of consumers' preferences for sports enterprises, which is helpful to provide more accurate sports services and enhance consumer experience. In addition, by establishing cooperative relations with sponsors and advertisers, sports enterprises can not only promote the brand development of sports services, but also facilitate the high-end and professional development of the industry and accelerate the process of service transformation.

Consumers are the demanders of sports industry service transformation, and also the users of transformation results. User demand is the fundamental demand to promote the service transformation of sports industry. With the change of sports consumption mode, consumers' demand for personalization, experience and socialization is growing day by day, which urges sports enterprises to innovate and adjust their service modes and contents. Consumers' preferences and behaviors provide important market feedback for sports enterprises. Through data collection and analysis of digital platform, sports enterprises can identify consumers' needs more accurately and optimize service design. In addition, consumers' sense of participation and expectation of service quality have also promoted the continuous improvement of service level of sports enterprises and accelerated the transformation of sports industry from product-oriented to service-oriented.

The management department is the supervisor and promoter of the service transformation of sports industry, and its main responsibility is to formulate relevant control measures to provide a good business environment and policy support for the service transformation of sports enterprises. Including sports management agencies, cultural tourism departments, industry associations, consumer rights protection agencies, education departments, etc., they can promote cooperation and innovation among enterprises, optimize the allocation and flow of industrial resources, and improve the efficiency of industrial transformation. In addition, the management department has also played an active role in promoting the innovation of sports industry, providing financial support and promoting the technological upgrading of sports enterprises, further promoting the in-depth development of the service transformation of sports industry.

From the perspective of game theory, the coupling relationship among sports enterprises, consumers and management departments in the service transformation of sports industry is a multi-party game process, each party has its own interests and strategic choices, and the interaction and strategic adjustment of the three jointly promote or determine the service transformation process of sports industry.

①The game between sports enterprises and consumers

There is a typical "supply–demand" game between sports enterprises and consumers. Specifically, consumers hope to obtain high-quality sports services through consumption, while sports enterprises systematically obtain economic profits and market share by providing corresponding services. In this bilateral game, sports enterprises need to adjust their service strategies according to consumers' needs, and consumers will reflect whether to support sports enterprises' strategies through consumption behavior.

②The game between management and sports enterprises

The game relationship between management department and sports enterprises can be described as "supervision-supervision", that is, management department restricts the behavior of sports enterprises through policies and supervision tools, while sports enterprises adjust their service transformation strategies according to the measures of management department, while maintaining the maximization of their own economic benefits. This benign game relationship encourages the innovation enthusiasm of sports enterprises, and also ensures the orderly development of the market.

③The game between consumers and management departments

The game relationship between consumers and management departments is mainly reflected in "public interest and individual demand". For the management department, its goal is to protect the basic rights and interests of consumers through laws or regulations, and at the same time guide the improvement of the service level of the sports industry. Consumers' feedback and demand expression on service quality and service level can directly affect the policy adjustment direction of management departments.

④Tripartite equilibrium game

In the game of three stakeholders, each participant is seeking to achieve a Pareto optimal equilibrium state, that is, to maximize his own interests without damaging the benefits of other stakeholders.

Construction of evolutionary game model

Model assumption

Evolutionary game theory describes the process that the strategies of different game groups change with time in a certain time range[18]. This process is similar to the survival competition between different biological populations in nature, and the same population may show a preference for different strategies. In the process of continuous competition with other species[19,] individuals within the population will learn or imitate strategies, so that the dominant strategies will be gradually retained and finally stabilized[20]. The core idea of evolutionary game theory is that players have limited rationality (Jiang et al., 2024). Bounded rationality means that before the game process starts, the players' cognitive range and preferences make them unable to fully obtain all the information about the game strategy, which means that they can't choose the optimal strategy through one game, but gradually approach the optimal strategy through trial and error[5]. Evolutionary game model focuses on the strategic changes among game participants, and the influence of these changes on other players and the basic conditions for the strategy to reach stability[21]. Similarly, the service transformation of sports industry is a process of repeated games among sports enterprises, management departments and consumers[22]. Specifically, the diversified demand of consumers for sports services can stimulate sports enterprises to actively carry out service transformation, and the management department has issued a series of support policies to encourage more enterprises to join the service transformation,On the contrary, when the enthusiasm of sports enterprises for service transformation is not high and consumers' demand for sports services is weak, the management department can also provide them with strong support through policy regulation. Obviously, in the process of service transformation of sports industry, the strategies among sports enterprises, consumers and management departments have strong correlation and conform to the bounded rationality in evolutionary game theory.

Existing research provides reference for us in the selection of variables in the game model of service transformation and evolution of sports industry. Generally, the benefits of enterprise service transformation are divided into direct benefits and indirect benefits, and indirect benefits show consumers' preference for sports services. Furthermore, the service transformation of enterprises will also generate additional costs, such as purchasing new equipment[4,19]. Government and industrial associations, as regulators, will also generate additional costs in the process of regulating the service transformation, mainly from the implementation of policies and communication costs[1,3]. At the same time, when the service transformation of sports industry fails or is unsuccessful, they may also face the responsibility of higher authorities[17]. As far as consumers are concerned, choosing sports service products will be able to get higher income, but at the same time it will also generate additional costs due to the purchase of equipment. Based on this, this study puts forward a series of assumptions for building the model, as shown in Table 1.

Sports enterprises, consumers and management departments are all players in the game model of service transformation and evolution, and they all have independent strategic space[18]. Specifically, sports enterprises can choose to implement service transformation to meet the diversified needs of consumers, but they can also

	Description
Hypotheses 1	Sports enterprises, consumers and management departments all have independent strategic space
Hypotheses 2	Sports enterprises will generate additional costs while gaining additional benefits
Hypotheses 3	Consumers will generate additional costs while gaining more utility of sports services
Hypotheses 4	The management department will pay more cost when adopting ACS, and it can also promote consumers to obtain more utility
Hypotheses 5	Sports enterprises and consumers have the function of mutual encouragement
Hypotheses 6	Management departments can adjust and control through financial subsidies and penalties
Hypotheses 7	Superior departments will also hold the management accountable

Table 1. Research hypotheses.

keep the traditional business model unchanged in order to reduce operating costs and risks. Therefore, the strategic space of sports industry is [service transformation, maintaining traditional business] (SET, MTB). If the proportion of enterprises that choose SET is x, the proportion of enterprises that choose MTB is $(1-x)$; Consumers can choose to accept the extra experience and benefits brought by service products, or they can choose to refuse, thus avoiding the possibility of uncertainty or low cost performance[5]. Therefore, the consumer's strategic space is [accepting service products, rejecting service products] (ASP, RSP). If the proportion of consumers who choose ASP is y, the proportion of consumers who choose RSP is $1-y$; The management department can provide policy support for the service transformation of the sports industry, and it can also give other players more freedom. Therefore, the strategic space of the management department is [active supervision, passive supervision] (ACS, NES). If the management department proportion of ACS is z, the management department proportion of NES is $(1-z)$.

Sports enterprises adopt SET strategy to attract more consumers to participate in sports activities, thus obtaining extra income (Q_e), but in the process of transformation, they need to buy new equipment, develop new platforms, train talents and promote marketing, which constitutes the extra cost of service transformation (C_e); Consumers who choose ASP strategy can experience more sports services and get more utility $(Q_u$), but they also have to pay extra cost (C_u) to buy related courses and equipment. When consumers accept service products, they can attract more people to join the ranks of physical fitness, create a good cultural scope, and at the same time increase the number of physical fitness coaches, operators and production enterprises, that is, generate additional social benefits (Q_m); Management departments need to pay extra costs (C_m) when adopting ACS strategy, including institutional costs and infrastructure investment. Among them, institutional cost refers to the cost of formulating and implementing control measures. Infrastructure investment is the cost paid by the management department to ensure the equalization of regional sports facilities, with the purpose of meeting the basic sports needs of residents and making consumers gain additional utility (Q_{um}).

Consumer's demand can stimulate sports enterprises to speed up service transformation, and service transformation can also develop new consumer demand, and the incentive coefficient (γ) reflects the mutual promotion relationship between them[2]. When consumers choose ASP strategy and sports enterprises choose MTB strategy, they can't meet their service needs, which makes consumers' satisfaction with sports enterprises decline,As a supervisor, the administration department can reduce the cost paid by sports enterprises or consumers in the process of transformation through cultural propaganda and financial tools, and improve their income. This study selects the common measures in promoting the service transformation of sports industry around the world as variables. Financial subsidies (S) can effectively reduce the risk in the process of service transformation of sports enterprises, and more importantly, encourage social investment and sports service innovation[17],If a sports enterprise violates the relevant laws or standards of service transformation, it will be punished by the management department (P), which can also be regarded as the opportunity cost lost by the enterprise because it has not carried out service transformation[1],Similarly, if the management department does not provide favorable support for the service transformation of sports enterprises, it may also be held accountable by superiors (M).

Parameter setting

Based on the above hypotheses, we set the parameters in Table 2 to represent the benefits of different players.

Combined with the above parameters, Table 3 shows the payoff function of each player under different strategy combinations.

Parameter	Mean
Q_e	additional benefits obtained by sports enterprises when adopting SET strategy
Q_u	consumers accept the benefits of service transformation
Q_m	consumers accept the social benefits of service transformation
Q_{um}	benefits gained by consumers in sports infrastructure construction of management departments
C_e	the cost of service transformation of sports enterprises
C_u	the cost paid by consumers to purchase sports services
C_m	costs incurred by management system construction and infrastructure investment
M	costs incurred when the management department is held accountable by the superior
S	management subsidies for service transformation of sports enterprises
P	punishment of sports enterprises for failing to take transformation measures as required
H	loss of income when consumer demand is not met
γ	incentive coefficient between consumers and sports enterprises
δ	when NES is adopted by the management department, the income loss rate of consumers and sports enterprises ($\delta \in [0,1]$)
ξ	When NES is adopted by management, the cost growth rate of consumers and sports enterprises ($\xi \geq 1$)
x	Proportion of sports enterprises choosing SET strategy
y	Proportion of consumers choosing ASP strategy
z	Proportion of ACS strategy selected by management department

Table 2. Parameter settings of evolutionary game model.

Strategy combination	Sports enterprises	Consumers	Administration
$[SET,\ ASP,\ ACS]$	$Q_e\gamma - C_e + S$	$Q_u\gamma - C_u + Q_{um}$	$Q_m - S - C_m$
$[SET,\ ASP,\ NES]$	$\gamma Q_e\delta - C_e\xi$	$Q_u\gamma\delta - C_u\xi$	$Q_m - M$
$[SET,\ RSP,\ AES]$	$Q_e - C_e + S$	$Q_{um} - H$	$-Q_m - S - C_m$
$[SET,\ RSP,\ NES]$	$Q_e\delta - C_e\xi$	$-H$	$-Q_m - M$
$[MTB,\ ASP,\ ACS]$	$-P - H$	Q_{um}	$-Q_m + P - C_m$
$[MTB,\ ASP,\ NES]$	$-H$	0	$-M$
$[MTB,\ RSP,\ ACS]$	$-P$	Q_{um}	$-Q_m + P - C_m$
$[MTB,\ RSP,\ NES]$	0	0	$-Q_m - M$

Table 3. Payment matrix.

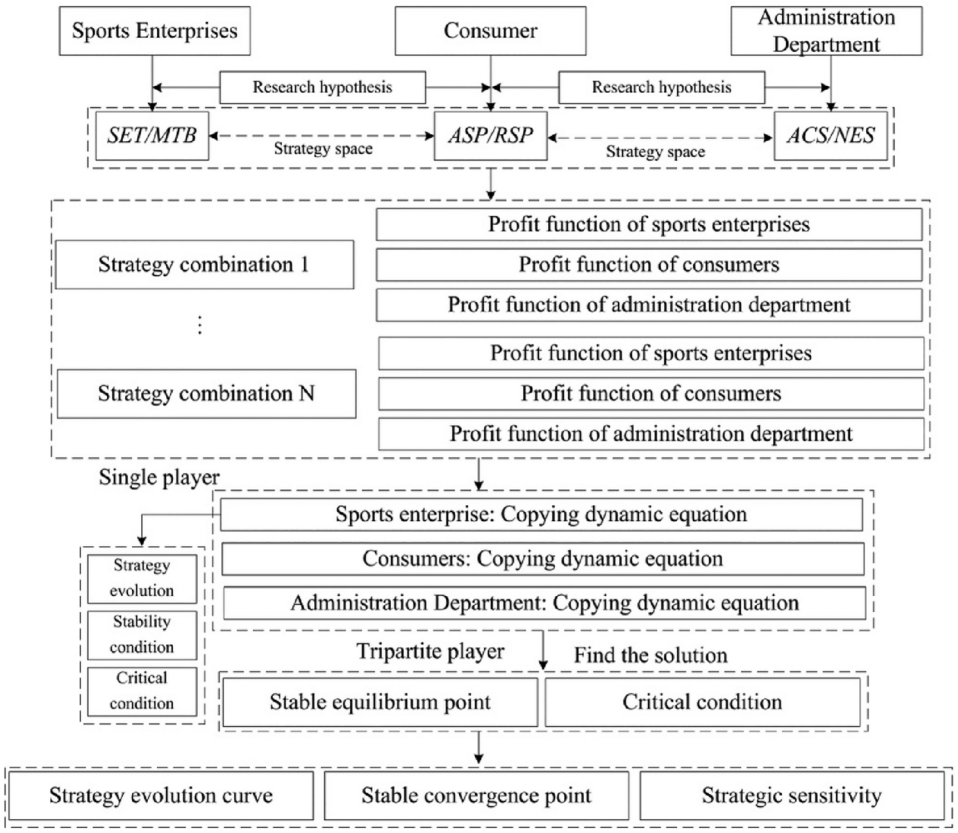

Fig. 2. Game process.

Game process

Figure 2 describes the game participants and game process in the service transformation of sports industry. Sports enterprises, consumers and management departments are three independent game groups. Based on the above assumptions, they all have independent strategy space and eight strategy combinations, which determine the player's revenue function. This research is carried out from two aspects: single player and three-way game system. As for a single player, we have deduced the strategic selection conditions of sports enterprises, consumers and management departments in different situations by copying dynamic equations. These deductions are necessary and reveal the complexity of the game system. In the three-way game system, the possible stable points of the whole system are obtained by solving simultaneous equations, and the strategic equilibrium points of each player are further identified based on the sign judgment of eigenvalues. On this basis, by using Matlab to build a simulation environment, the influence of different factors on the strategic equilibrium point is tested numerically, which provides decision-making reference for optimizing the service transformation of sports industry.

Result analysis

Stability condition analysis of single agent strategy

Analysis on the strategic evolution of sports enterprises

Assuming that the benefits obtained by adopting SET strategy and MTB strategy of sports enterprises are U_{SET} and U_{MTB} respectively, and the expected benefits are U_{EXP}, Eq. 1–3 can be obtained (Refer to Appendix for detailed derivation process).

$$U_{SET} = yz\left(Q_e\gamma - C_e + S\right) + y\left(1-z\right)\left(\gamma Q_e\delta - C_e\xi\right) + z\left(1-y\right)\left(Q_e - C_e + S\right) + \left(1-y\right)\left(1-z\right)\left(Q_e\delta - C_e\xi\right) \quad (1)$$

$$U_{MTB} = yz\left(-P\right) + y\left(1-z\right)\left(-H\right) + z(1-y)(-P) \quad (2)$$

$$U_{EXP} = xU_{SET} + (1-x)U_{MTB} \quad (3)$$

According to the evolutionary game theory, when a certain strategy can make players get higher than the average income, it will attract more players to choose this strategy. This evolutionary process can be described by the replication dynamic equation, and its essence is a differential equation about time t [23]. Therefore, the replication dynamic equation for sports enterprises to choose SET strategy is:

$$U\left(x\right) = \frac{dx}{dt} = x\left(U_{SET} - U_{EXP}\right) = x(1-x)V(y,z) \quad (4)$$

$$V\left(y,z\right) = \xi(C_m - Q_m + S) + z[C_m + P + Q_e - Q_m + 2S + \xi(Q_m - S - C_m) - \delta Q_e] + yz(Q_m - C_e - C_m - Q_e - S + \delta Q_e + \gamma Q_e - \gamma\delta Q_e) - y\delta Q_e(1-\gamma) + yH + \delta Q_e \quad (5)$$

When $U\left(x\right) = 0$ U(x)=0, four feasible solutions can be obtained, including two pure strategic solutions ($x_1 = 1$ and $x_2 = 0$) and two mixed strategic solutions ($y = y^*$ and $z = z^*$). Only when $U\prime\left(x\right) = \frac{du(x)}{dt} = \left(1-2x\right)V\left(y,z\right) < 0$, the strategy of sports enterprises will reach stability Fig. 3 shows the phase diagram of the strategic evolution of sports enterprises in different situations.

Scenario 1: When y $= y^*$ and $z = z^*$, the game space of sports enterprises is located on the curved surface formed by $V\left(y,z\right) = 0$ (Fig. 3-a). At this time, no matter what value x takes, $U\prime(x)$ is always equal to 0. This means that no matter how the strategies of consumers and management departments change, the strategic choice of sports enterprises will not be affected. Obviously, this is not in line with the original hypothesis, so we will not analyze it.

Scenario 2: When y $< y^*$ and $z < z^*$, the game space of sports enterprises is located below the surface formed by $V\left(y,z\right) = 0$ (Fig. 3-b). At this time, $\frac{dU(x)}{dt}|_{x=1} > 0$, $\frac{dU(x)}{dt}|_{x=0} < 0$, then $x = 0$ becomes a stable strategy point. Its practical significance is that when consumers refuse to accept the negative supervision of sports service and management departments, sports enterprises tend to maintain their original business instead of taking the initiative to take service transformation measures. This situation reveals the bottleneck problem of the service transformation of sports industry. The lack of transformation motivation, unclear demand and ineffective management have led to the strategic game among stakeholders falling into a prisoner's dilemma.

Scenario 3: When $y > y^*$ and $z > z^*$, the game space of sports enterprises is below the curve formed by $V\left(y,z\right) = 0$ (Fig. 3-c). At this time, $\frac{dU(x)}{dt}|_{x=1} < 0$, $\frac{dU(x)}{dt}|_{x=0} > 0$, then $x = 1$ becomes a stable strategy point. When consumers are willing to accept sports services, under the active control measures of management departments, sports enterprises often choose SET strategy. This situation describes the ideal state of service transformation of sports industry, and a stable and close dependence relationship is formed among all stakeholders, which promotes the efficiency of service transformation of sports industry. At the same time, it is conducive to the formation of a "product + service" sports industry ecology and the realization of the value creation of all players.

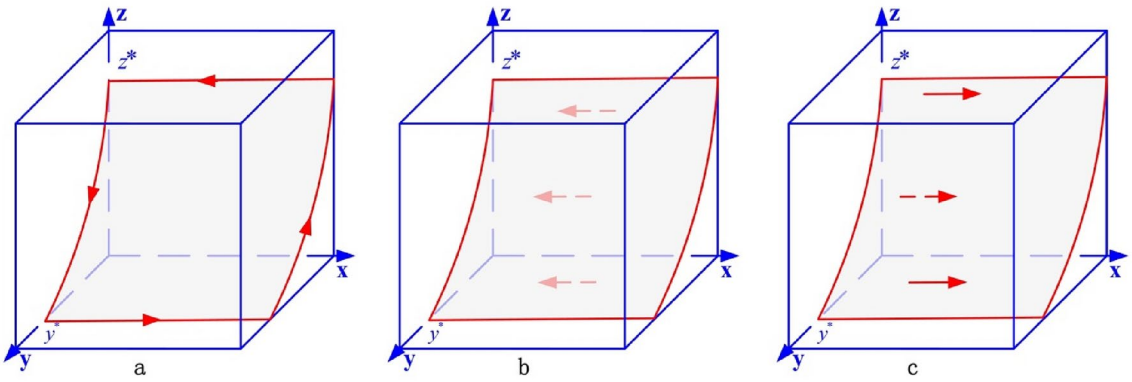

Fig. 3. Phase diagram of strategic evolution of sports enterprises in different situations.

Analysis on the strategic evolution of consumers

Suppose that the benefits of consumers choosing ASP and RSP are G_{ASP} and G_{RSP} respectively, and the expected benefit is G_{EXP}. The following equation can be obtained:

$$G_{ASP} = xz\left(Q_u\gamma - C_u + Q_{um}\right) + x\left(1-z\right)\left(Q_u\gamma\delta - C_u\xi\right) + z\left(1-x\right)\left(Q_{um}\right) \tag{6}$$

$$G_{RSP} = xz\left(Q_{um} - H\right) + x\left(1-z\right)\left(-H\right) + z(1-x)(Q_{um}) \tag{7}$$

$$G_{EXP} = yG_{ASP} + (1-y)G_{RSP} \tag{8}$$

Furthermore, the replication dynamic equation of consumer strategy evolution is obtained:

$$G\left(y\right) = \frac{dy}{dt} = y(1-y)R(x,z) \tag{9}$$

$$R\left(x,z\right) = x[H - \xi C_u - zC_u + z\xi C_u + \delta\gamma Q_u + z\gamma Q_u(1-\delta)] \tag{10}$$

Let $G\left(y\right) = 0$, we can get two pure strategic solutions of $y_1 = 1$ and $y_2 = 0$, and two mixed strategic solutions of $x = x^*$ and $z = z^*$. When $G\prime(y) = \frac{dG(y)}{dy} = (1-2y)\,R\left(x,z\right) < 0$, the evolution of consumer strategy reaches a stable point. Figure 4 shows the phase diagram of strategy evolution in different scenarios.

Scenario 1: When $x = x^*$ and $z = z^*$, the consumer's game space is located on the plane formed by $R\left(x,z\right) = 0$ (Fig. 4-a). At this point, $G\prime\left(y\right)$ is equal to 0, which shows that no matter what strategy sports enterprises and management departments adopt, it will not affect consumers' strategic choice. This situation does not exist, so we will not discuss it.

Scenario 2: When $x < x^*$ and $z < z^*$, the consumer's game space is below the plane formed by $R\left(x,z\right) = 0$ (Fig. 4-b). At this time, $\frac{dG(y)}{dt}|_{y=1} < 0$, $\frac{dG(y)}{dt}|_{y=0} > 0$, and $y = 0$ becomes the stable point of consumer strategy evolution. When sports enterprises tend to maintain the original traditional business and the management department adopts a negative supervision strategy, it will lead to an increase in consumers' rejection of service products, thus choosing traditional sports products. This situation may appear in the initial stage of service transformation, which is characterized by the fact that sports enterprises and management departments have not yet formulated effective service transformation measures, and consumers are skeptical about the cost performance and practicality of sports services, so they choose traditional sports products and refuse sports services.

Scenario 3: When $x > x^*$ and $z > z^*$, the consumer's game space is above the plane formed by $R\left(x,z\right) = 0$ (Fig. 4-b). At this time, $\frac{dG(x)}{dt}|_{y=0} < 0$, $\frac{dG(x)}{dt}|_{y=1} > 0$, and y = 1 becomes the stable point of consumer strategy evolution. Its practical significance is that under the active supervision of the management department, sports enterprises choose service transformation, and consumers tend to accept sports services. This situation may appear in the middle of service transformation. The management department encourages the service transformation of sports enterprises through policy measures. At the same time, sports enterprises also guide and develop consumers' demand for sports services through cultural propaganda, market research and other means, and the players initially form a strategic dependence of mutual promotion.

Analysis on the strategic evolution of management department

Assuming that the revenue of ACS and NES selected by the management department is S_{ACS} and S_{NES} respectively, and the expected revenue is S_{EXP}, the following equation can be obtained:

$$S_{ACS} = xy\left(Q_m - S - C_m\right) + x\left(1-y\right)\left(-Q_m - S - C_m\right) + y\left(1-x\right)\left(-Q_m + P - C_m\right) + (1-x)(1-y)(-Q_m + P - C_m) \tag{11}$$

$$S_{NES} = xy\left(Q_m - M\right) + x\left(1-y\right)\left(-Q_m - M\right) + y\left(1-x\right)\left(-M\right) + (1-x)(1-y)(-Q_m - M) \tag{12}$$

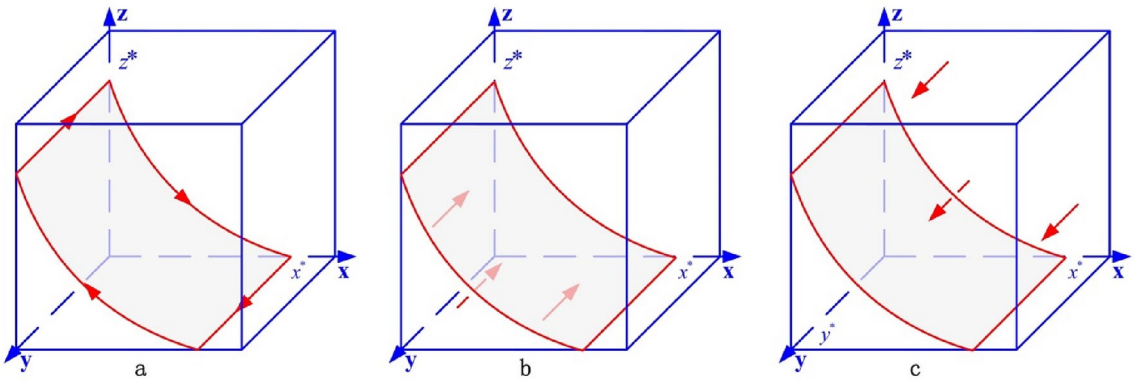

Fig. 4. Phase diagram of strategy evolution of consumers in different situations.

$$S_{EXP} = zS_{ACS} + (1-z)S_{NES} \tag{13}$$

The replication dynamic equation of the management department's strategy evolution is:

$$S(z) = \frac{dz}{dt} = z(1-z)F(x,y) \tag{14}$$

$$F(x,y) = C_m + M + P + Q_m + S - x(2C_m + P + Q_m + 2S) + yQ_m(x-1) \tag{15}$$

Let $S(z) = 0$, we can get two pure strategy solutions ($z = 1$ and $z = 0$) and two mixed strategy solutions ($x = x^*$ and $y = y^*$). When $S2032(z) = \frac{dS(z)}{dt} = (1-2z)F(x,y) < 0$, the management department's strategy will reach stability. Figure 5 shows the strategy evolution phase diagram of the management department in different situations.

Scenario 1: When $x = x^*$ and $y = y^*$, the game space of management department is located on the surface formed by $F(x,y) = 0$. At this point, it is satisfied that $S\prime(z)$ is always equal to 0, that is, no matter how the strategies of sports enterprises and consumers change, it will not affect the strategies of management departments. In other words, there is no dependence among players, which obviously does not conform to the original hypothesis, and this article will not discuss it.

Scenario 2: When $x < x^*$ and $y < y^*$, the game space of the management department is located on the side of the surface formed by $F(x,y) = 0$ near the z axis. At this time, $\frac{dS(z)}{dt}|_{z=1} < 0$, $\frac{dS(z)}{dt}|_{z=0} > 0$, and $z = 0$ becomes the stable point of the management department's strategy evolution. This shows that when sports enterprises adopt MTB strategy and consumers adopt RSP strategy, management departments tend to choose NES strategy. In this situation, the management department did not play a planning and guiding role.

Scenario 3: When $x > x^*$ and $y > y^*$, the game space of the management department is located on the side of the plane formed by $F(x,y) = 0$ which is far from the z axis. At this time, $\frac{dS(z)}{dt}|_{z=1} > 0$, $\frac{dS(z)}{dt}|_{z=0} < 0$, and $z = 1$ becomes the stable point of the management department's strategy evolution. Its practical significance is that when sports enterprises choose service transformation and consumers actively accept sports services, management departments will also adopt active supervision strategies to provide policy support for the service transformation of sports industry.

Stability conditions of multi-agent strategy

By comparing the changes of single agent's strategic stability point in different situations, we can find that in the process of service transformation, sports enterprises, consumers and management departments have formed a game trap similar to "prisoner's dilemma". Only when a certain condition is triggered, will players form a positive promotion relationship, otherwise, it will evolve in the direction of deterioration. Therefore, this study further discusses the conditions for each player to achieve strategic stability in multi-agent situations. The specific form is as follows:

$$\begin{aligned} U(x) &= \tfrac{dx}{dt} = x(1-x)V(y,z) \\ G(y) &= \tfrac{dy}{dt} = y(1-y)R(x,z) \\ S(z) &= \tfrac{dz}{dt} = z(1-z)F(x,y) \end{aligned} \tag{16}$$

Let $U(x) = G(y) = S(z)$, and 16 groups of equilibrium solutions are obtained, including 8 groups of pure strategy solutions ($\pi_1(1,1,1)$, $\pi_2(1,1,0)$, $\pi_3(1,0,1)$, $\pi_4(1,0,0)$, $\pi_5(0,1,1)$, $\pi_6(0,1,0)$, $\pi_7(0,0,1)$, $\pi_8(0,0,0)$). The mixed strategy solution can be understood as the equilibrium points in the phase diagram that are far away from the coordinate axis. These points indicate that the player with $x^*(y^*$ or $z^*)$ proportion has chosen the SET (ASP or ACS) strategy, and the player with $1-x^*$ $(1-y^*$ * or $1-z^*)$ proportion has chosen the MTB. This shows that there is no obvious strategic preference, and there is still strategy learning or imitation

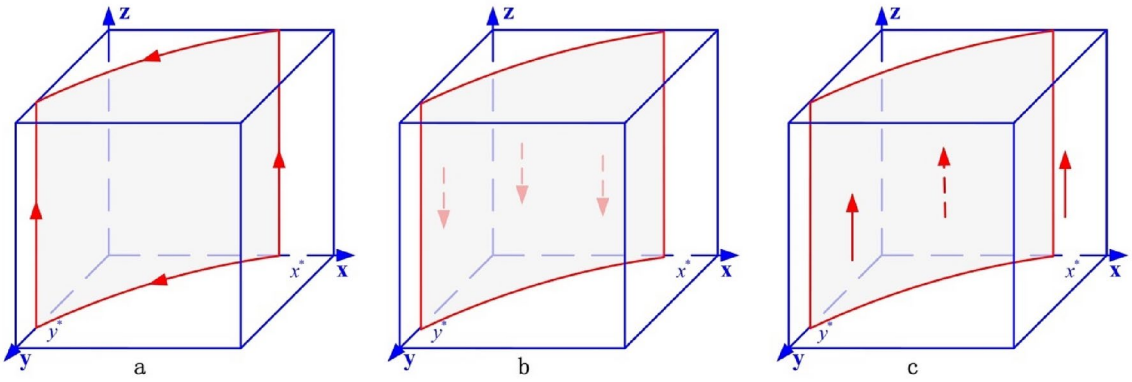

Fig. 5. Phase diagram of management department's strategy evolution.

among players, so it is impossible to form a stable point. Therefore, this paper does not discuss the stability of mixed strategies.

According to Friedman's theory, the Jacobian matrix is established as follows:

$$JAC = \begin{matrix} \frac{\partial U(x)}{\partial x} & \frac{\partial U(x)}{\partial y} & \frac{\partial U(x)}{\partial z} \\ \frac{\partial G(y)}{\partial x} & \frac{\partial G(y)}{\partial y} & \frac{\partial G(y)}{\partial z} \\ \frac{\partial S(z)}{\partial x} & \frac{\partial S(z)}{\partial y} & \frac{\partial S(z)}{\partial z} \end{matrix} \tag{17}$$

Each equilibrium point is brought into the matrix, and the eigenvalues under different equilibrium points are calculated. When the eigenvalues are all greater than 0, the equilibrium point is unstable; When the eigenvalues are not all greater than 0, the equilibrium point is asymptotically stable; When the eigenvalues are all less than 0, it indicates that the equilibrium point is a stable point. Table 4 shows the eigenvalues at different equilibrium points.

According to Table 4, it can be seen that there is no strategic stability point of the three-way evolutionary game under the original assumption, but there are two potential stability points. The details are as follows:

Scenario 1: when $C_m + S < M$, $C_u < H + \gamma Q_u$ and $C_e < H + P + S + \gamma Q_e$ are satisfied, $\pi_1\,(1,1,1)$ becomes the stable point of the three-way evolutionary game of service transformation. In other words, if sports enterprises, consumers and management departments adopt SET, ASP and ACS strategies respectively, they need to meet the following three conditions: (1) The system construction cost and subsidy expenditure of management departments are lower than the accountability cost of superiors; (2) The utility that consumers get from sports services under the encouragement of sports enterprises is higher than the cost they pay; (3) The sum of the benefits obtained by sports enterprises under the incentive of sports service demand and the cost of subsidy and punishment is higher than the cost of service transformation.

Scenario 2: when $M < C_m + S, \zeta < \frac{\delta\gamma Q_e}{Q_m - C_m - S}$ and $\zeta C_u < H + \delta\gamma Q_u$ are satisfied, $\pi_2\,(1,1,0)$ becomes the stability of the three-way evolutionary game of service transformation. At this time, the sports enterprises choose the SET strategy, the consumers choose the ASP strategy, and the management department chooses the NES strategy. The conditions required for this situation are: (1) the system construction cost and subsidy expenditure of the management department are higher than the accountability cost of the superiors; (2) In the absence of the supervision of management departments, the ratio of the benefits obtained by sports enterprises under the incentive of sports service demand to the net social benefits generated by service transformation is higher than the cost growth rate; (3) The sum of the utility gained by consumers in sports service and the utility that may be lost is higher than the cost paid.

Sensitivity analysis

Benchmark scenario simulation

Based on the two situations in which there are stable points, this paper further simulates the sensitivity of these stable points under different parameters. First, set the initial simulation parameters $Q_e = 27$, $Q_u = 30$, $Q_m = 24, Q_{um} = 16, C_e = 19, C_u = 18, C_m = 15, M = 35, S = 10, P = 13, H = 16, \gamma = 1.25, \delta = 0.75$, $\xi = 1.13$. These values are obtained through many simulations, and they meet the conditions of potential stable equilibrium points in Tab.4. It should be noted that these values may have errors with the actual values, but the evolution trend of the simulation strategy used for simulation is reasonable. The simulation period is 100 times ($T = 100$).At the same time, the proportion of sports enterprises, consumers and management departments choosing SET, ASP and ACS strategies in the first game is set to 0.1, 0.3, 0.5, 0.7 and 0.9 respectively. Different initial strategy initial ratio (ISP) reflects the different stages of service transformation of sports industry, which is necessary for testing the sensitivity of parameters. The strategy evolution curve of each player in the benchmark situation is obtained by simulation in Matlab environment (Fig. 6). In order to discuss the curve characteristics under different parameters, this paper puts forward the concepts of evolution depth (EVD) and evolution breadth (EVB). The former describes the convergence level of the strategy evolution curve, and the higher the convergence level, the more obvious the player's preference for a certain strategy. If $EVD = 1$, it means that all players have chosen the same strategy, that is, complete convergence. The latter reflects the number of cycles required for the convergence and stability of the evolution curve, and the greater its value, the longer it takes to reach stability.

Strategy	Eigenvalue1	Eigenvalue2	Eigenvalue3	Symbol
$\pi_1\,(1,1,1)$	$C_m - M + S$	$C_u - H - \gamma Q_u$	$C_e - H - P - S - \gamma Q_e$	***
$\pi_2(1,1,0)$	$M - C_m - S$	$-H - \zeta\,(C_m - Q_m + S) - \delta\gamma Q_e$	$\zeta C_u - H - \delta\gamma Q_u$	***
$\pi_3(1,0,1)$	$C_m - M + S$	$H - C_u + \gamma Q_u$	$Q_m - P - Q_e - C_m - 2S$	*+-
$\pi_4(1,0,0)$	$-\delta Q_e - \zeta(C_m - Q_m + S)$	$M - C_m - S$	$H - \zeta C_u + \delta\gamma Q_u$	**+
$\pi_5(0,1,1)$	0	$-C_m - M - P - S$	$H - C_e + P + S + \gamma Q_e$	*-*
$\pi_6(0,1,0)$	0	$H + \zeta(C_m - Q_m + S) + \delta\gamma Q_e$	$C_m + M + P + S$	*++
$\pi_7(0,0,1)$	0	$C_m + P + Q_e - Q_m + 2S$	$-C_m - M - P - Q_m - S$	*+-
$\pi_8(0,0,0)$	0	$\delta Q_e + \zeta(C_m - Q_m + S)$	$C_m + M + P + Q_m + S$	*++

Table 4. Eigenvalues at different equilibrium points. Note: * indicates that the symbol is uncertain.

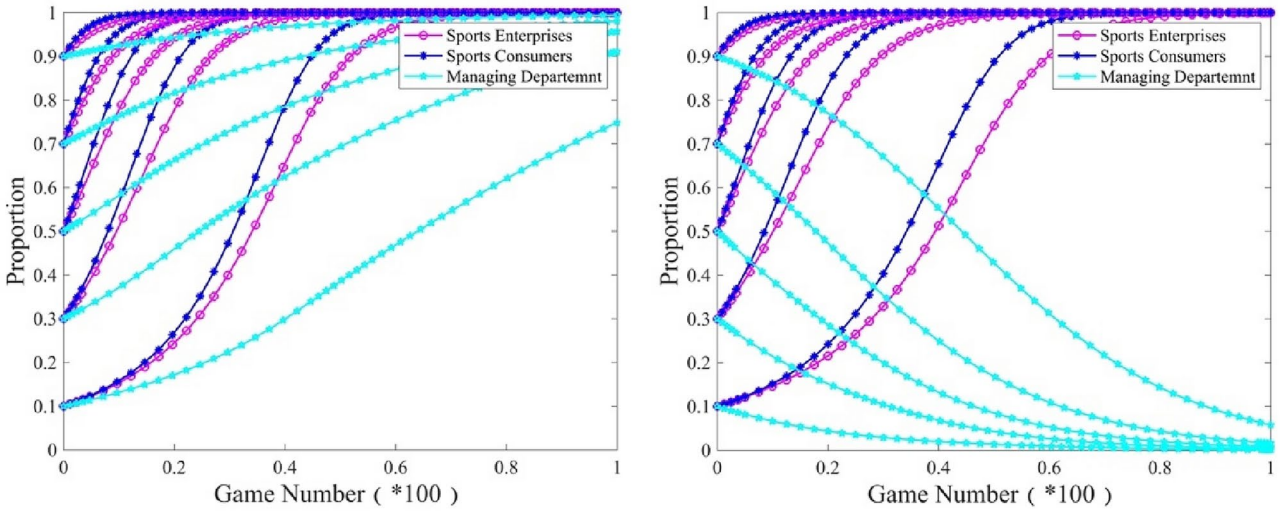

Fig. 6. Simulation results of benchmark scenario 1 (left) and benchmark scenario 2 (right).

In benchmark scenario 1, the strategy evolution curves of sports enterprises and consumers under different ISPs all converge to $EVD = 1$, and with the increase of ISPs, the evolution curves begin to shift to the left, and the period required to achieve stable convergence is also greatly shortened ($EVB = 10$). This shows that the service transformation of sports industry is a process of continuous iteration and accumulation. When more than a certain proportion of players choose a certain strategy, it will have spillover effect, attracting more players to choose this strategy, thus accelerating the ervice transformation of industry. But this is not significant in the evolution curve of management departments. When $ISP < 0.5$, the strategy evolution curve of management department can't completely converge to $EVD = 1$, and more cycles are needed to achieve this goal. Similarly, in benchmark scenario 2, the strategy evolution curve of sports enterprises and consumers has not changed much, while the strategy evolution curve of management departments converges to $EVD = 0$, which means that all management departments have adopted NES strategy. This paper holds that this situation may appear in the late stage of service transformation, and the sports industry has formed a good demand environment and market environment, and the management department has begun to reduce its intervention in service transformation. For example, in the process of industrial service transformation, China usually adopts two strategies: government intervention and market regulation. After the industrial transformation reaches a certain stage, intervention will be reduced to ensure that the market can play the role of resource allocation.

Strategic sensitivity under different financial subsidies

As can be seen from Fig. 7, when $\mathrm{S} = 8$, the strategy evolution curves of all players are completely convergent, that is, $\mathrm{EVD} = 1$. And with the increase of ISP, the EVB of evolution curve is smaller. When S continues to increase, the strategic evolution curve of sports enterprises and consumers begins to shift to the upper left, but the fluctuation range of consumer evolution curve is significantly lower than that of sports enterprises, which shows that financial subsidies from management departments are beneficial to encourage sports enterprises to choose SET strategy, but the incentive effect on consumers is limited. Specifically, financial subsidies can provide financial support and wider financing channels for sports enterprises, which can not only effectively alleviate the cost increase brought about by service transformation, but also weaken the risks faced by sports enterprises in developing and innovating new technologies or products. At the same time, it also makes sports enterprises increase investment in marketing and talent training, which is helpful to activate the internal motivation of sports industry's service transformation. In addition, it is worth noting that with the increase of S, the EVB of the strategy evolution curve of the management department is gradually increasing, which means that the preference of the players for ACS strategy is weakening, especially when the ISP is less than 0.6. The main reason is that financial subsidies increase the cost of the management in the process of service transformation of sports industry, which makes the management more cautious about the social benefits brought by the service transformation of sports industry. In addition, the use of financial subsidies is usually accompanied by a series of management measures to ensure its effectiveness and openness, such as the allocation of funds, efficiency evaluation, etc., which also brings more management costs to the management department. Britain's "Sports England" plan is a typical case of financial subsidies to promote the service transformation of sports industry, which effectively promotes the sports industry to change from material facilities as the core to service as the center. The financial subsidies from the management departments have provided support for the development of many fitness clubs and community sports activities, and promoted the diversification of service contents.

Strategic sensitivity under different superior accountability pressure

Figure 8 shows the influence of superior accountability on the sensitivity of each player's strategy evolution curve in the service transformation of sports industry. When $\mathrm{M} = 30$, the strategy evolution curve of sports enterprises

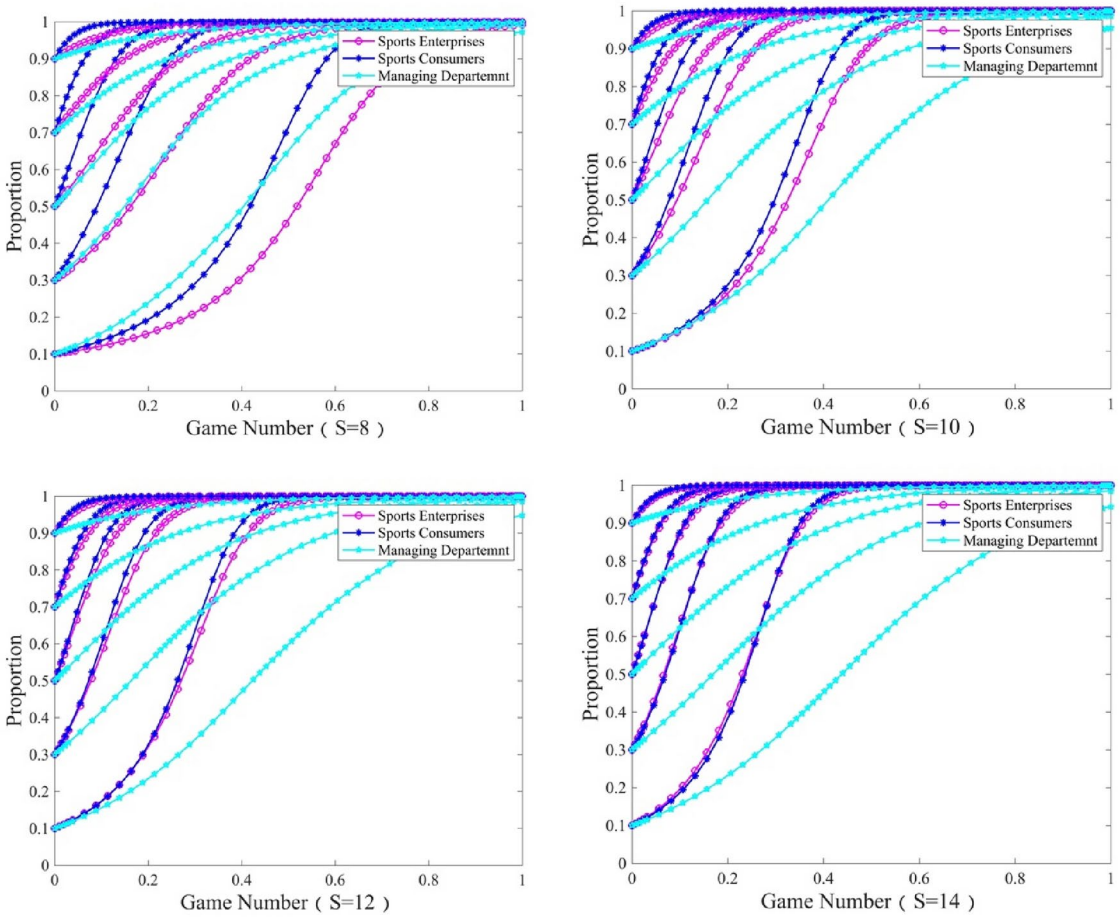

Fig. 7. Simulation results under different financial subsidies.

and consumers converges to EVD = 1, while that of management departments converges to EVD = 0. With the continuous increase of M, the strategy evolution curve of the management department began to rise, and EVB continued to increase. When M = 50 and ISP > 0.7, the strategy evolution curve of the management department converges to EVD = 1, until M = 60, it all converges to EVD = 1. The practical significance of this change process is that when the accountability pressure of superiors is small, management departments usually choose NES strategy, but with the increase of accountability pressure, they will prefer ACS strategy. If the superior management department puts forward clear goals or requirements for the service transformation of the sports industry and sets up a strict accountability mechanism, the lower management department is more inclined to actively supervise to avoid being held accountable. This may bring enlightenment to the management mechanism construction of the service transformation of sports industry. On the one hand, a multi-level accountability management mechanism is established, which requires all management departments to clarify their functions and responsibilities in the service transformation, and through regular reports and reviews, all stakeholders are guaranteed to perform relevant responsibilities efficiently. On the other hand, build a series of standard operating procedures and requirements, reduce the illegal behavior of policy implementation in service transformation, enhance the coordination of relevant departments in service transformation, and form an open, transparent and efficient.

Strategic sensitivity under different punishment levels

Figure 9 shows the influence of different punishment levels on the sensitivity of players' strategy evolution curve in service transformation. Similar to the benchmark scenario 1, when P = 0, the strategy evolution curves of all players converge to EVD = 1. With the increasing level of punishment, the strategic evolution curve of sports enterprises began to shift to the upper left, and the EVB decreased slightly, while the strategic evolution curve of consumers and management departments was less sensitive to the level of punishment. This means that when the management department increases the punishment pressure on enterprises that fail to carry out service transformation as required, it will force sports enterprises to choose SET strategy. The results are similar to those of Pate et al.,[11] mentioned in Section "Strategic Sensitivity under Different Superior Accountability Pressure". Severe punishment can make sports enterprises realize the urgency of service transformation, enable them to implement relevant measures or regulations more strictly, and even give priority to allocating resources to service transformation projects. In addition, in order to avoid the risk of being punished, sports enterprises

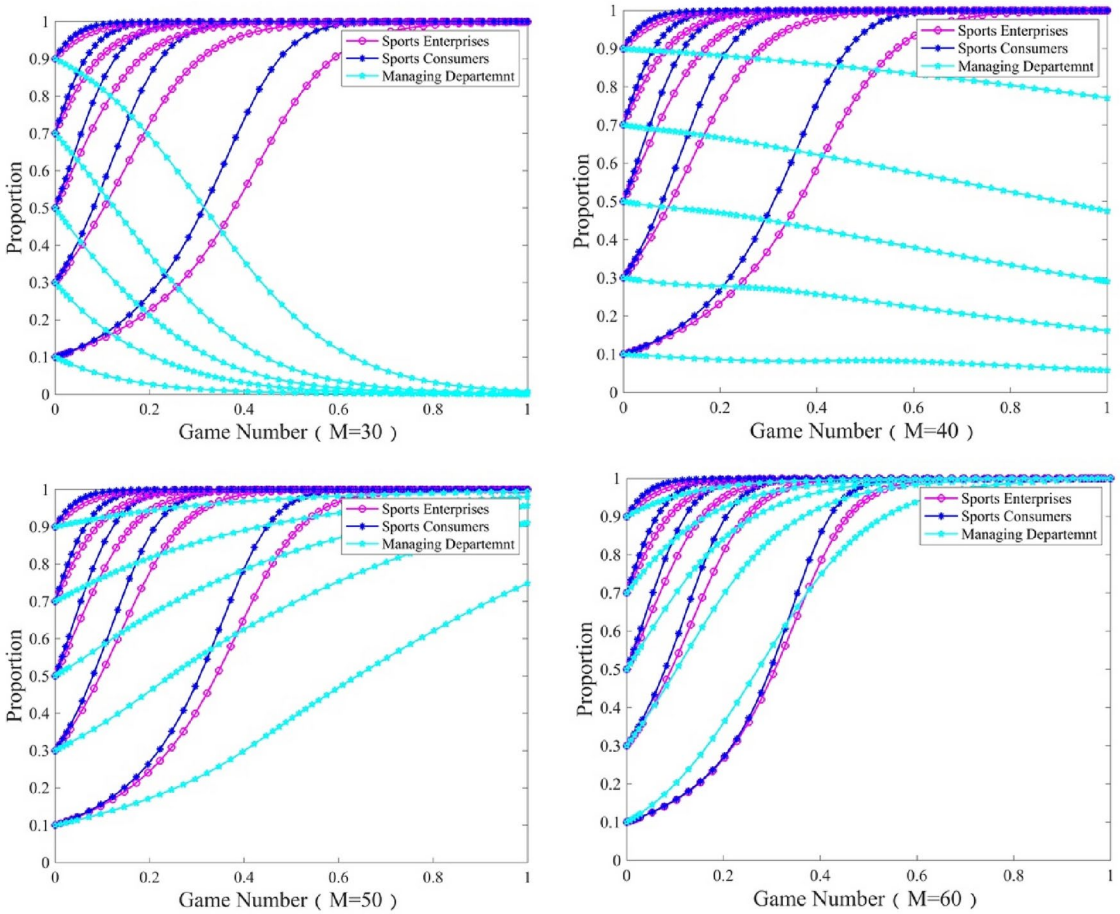

Fig. 8. Simulation results under different accountability pressures of superiors.

will be more inclined to seek external help, and through cooperation with other enterprises and organizations, the progress of service transformation will be accelerated.

Strategic sensitivity under different service costs

Figure 10 describes the influence of different sports service costs on the sensitivity of players' strategy evolution curve in service transformation. When $C_u = 8$, the strategy evolution curves of all players converge to $EVD = 1$. With the increasing of C_u, the evolution curve of consumer strategy began to shift to the right, and EVB gradually increased. When $C_u = 19$, the evolution curve of sports enterprise strategy shifts to the right, but still converges to $EVD = 1$. The evolution curve of consumer strategy began to sink, EVB increased significantly, and tended to converge at $EVD = 0$. It is worth noting that the evolution curve of the management department's strategy also began to sink, and it could not converge when the ISP was less than 0.8. This change process shows that with the increasing cost of consumers in experiencing sports services, they tend to refuse sports services, and management departments tend to be passive in supervision. The increase in the cost of sports services will make consumers re-evaluate their budget and the priority of sports services, and may choose more easily available or lower-cost substitutes, thus leading to a decline in the demand for sports services. This conclusion is similar to that of Yang et al.,[2] and others. Service cost management sports enterprises pay more attention to the improvement of resource allocation and service quality in the process of service transformation, and the service cost structure also affects market positioning and transformation strategy. The above simulation results can provide reference for the choice of service transformation strategy for sports enterprises. In the process of promoting digital fitness services, American fitness companies Peloton and Planet Fitness are faced with high costs such as equipment upgrading, platform construction, technology development and maintenance[24]. At one time, it fell into a loss because of the high cost of transformation. Although the service transformation increased customer stickiness, it also exposed the risk of high-cost model. The high transition cost urges enterprises to flexibly adjust their business models or provide lower-cost services.

Policy implications

The service transformation of sports industry is a complex process involving many stakeholders. Based on the above research results, this paper puts forward the following targeted policy implications:

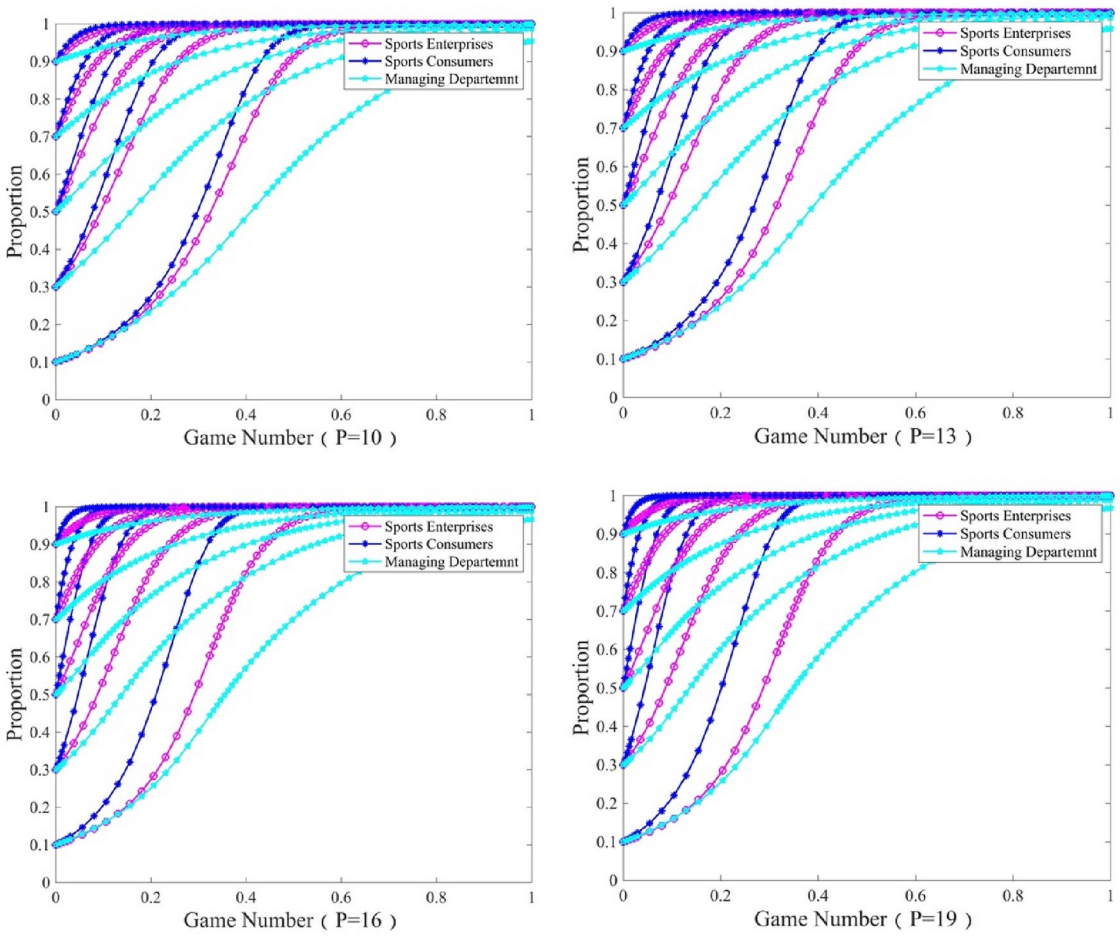

Fig. 9. Simulation results under different punishment levels.

(1) To promote the service-oriented transformation of the sports industry, government authorities in various countries and regions should prioritize and implement fiscal subsidies and tax incentives. This includes providing tax reductions or production subsidies to sports enterprises and sports equipment manufacturers, while also encouraging private and social capital investment to create diverse financing channels. Additionally, there should be a focus on enhancing the market-oriented operations and social services of sports projects. This can be achieved by supporting the development of emerging sectors such as fitness, recreational services, and sports training through policy measures. Furthermore, fostering sports intermediary organizations, introducing competitive mechanisms, and optimizing service processes are essential for improving the quality and social benefits of sports services.

(2) Further clarify the responsibilities and division of labor among management departments, sports associations, enterprises, and institutions, while strengthening interdepartmental linkage and cooperation. It is also essential to establish and improve the legal system governing the sports industry, clearly defining the legal responsibilities of all stakeholders, and fostering an open and transparent reward and punishment mechanism. A progressive punishment approach should be adopted, where initial violations are met with warnings and corrective measures, escalating only for repeated non-compliance. This strategy helps to avoid excessive penalties that could dampen sports enterprises' enthusiasm for service transformation, while simultaneously ensuring the effectiveness and precision of the reward and punishment system.

(3) In terms of competitive dynamics, market entry and exit mechanisms should be established to maintain healthy competition, complemented by a diversified service evaluation system that enhances transparency and incentivizes innovation. Additionally, a dynamic supervision and evaluation system is crucial for ensuring ongoing compliance, supported by third-party audits to maintain fairness. Moreover, an honor mechanism could be implemented to encourage compliance by recognizing exemplary enterprises, while increasing the reputation risk of non-compliant entities through the public disclosure of bad records. By balancing incentives and penalties, this framework will promote both adherence to legal norms and a competitive, service-oriented transformation within the sports industry.

(4) Sports enterprises should rely on Internet technologies such as cloud computing, big data, and AI to build diversified sports consumption service platforms and develop new consumption patterns by combining online and offline. At the same time, give full play to the professional service advantages of physical stores to ensure

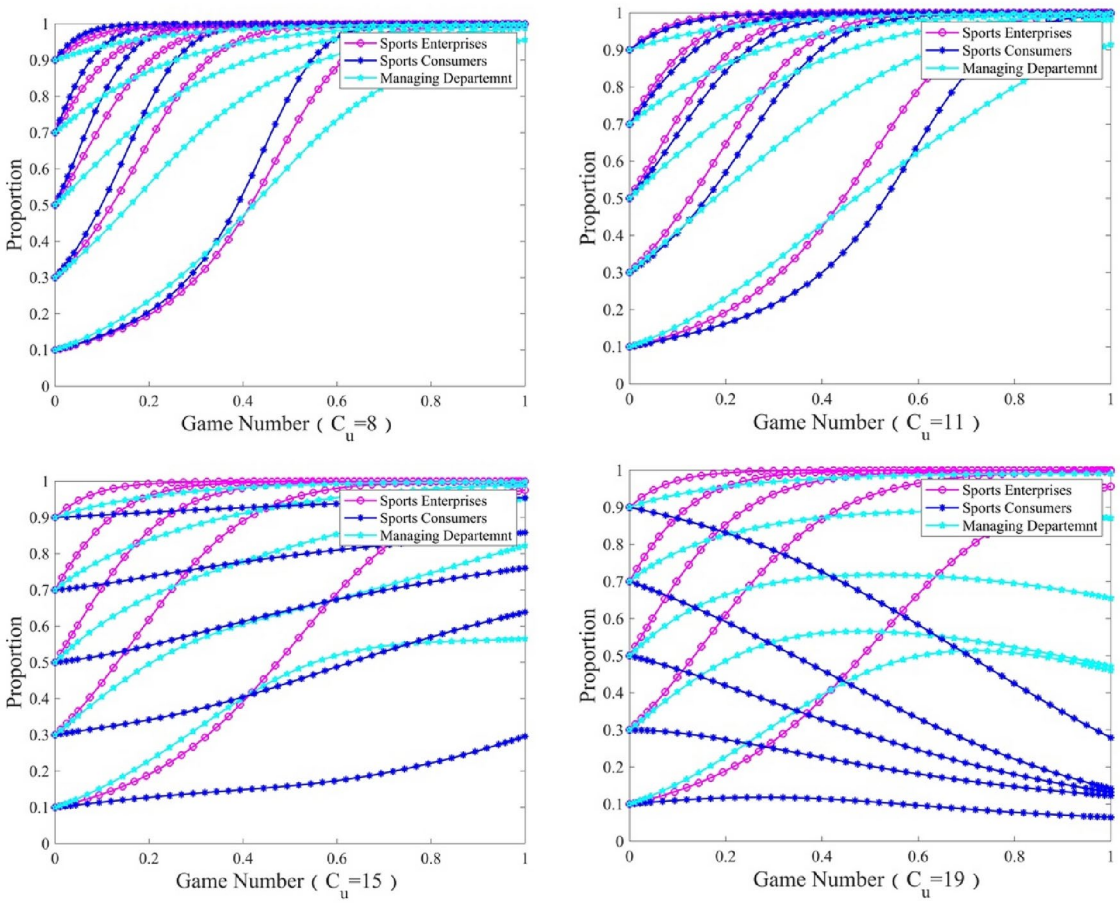

Fig. 10. Simulation results under different service costs.

that consumers can get personalized and professional sports service experiences. In addition, we should pay attention to brand building and user stickiness, improve service levels, and meet the service needs of different consumption levels by launching discount promotions and membership services, to cultivate consumers' loyalty to the brand. You can attract target users by holding offline activities such as image display competitions and experience competitions and building a user community to increase interaction.

Conclusion and discussion

Research conclusion

Based on the interactive relationship among sports enterprises, consumers and management departments, this study puts forward the logical framework of sports industry service transformation, constructs a three-way evolutionary game model of sports industry service transformation, discusses the strategic stability conditions of different players and three-way game system respectively, and finally tests the sensitivity of various stakeholders' strategies under different conditions through simulation. The main conclusions are as follows:

(1) There is a strong dependence on the strategic game among sports enterprises, consumers and management departments, and there is a game trap similar to the "prisoner's dilemma". When the strategic choices of at least two stakeholders reach a certain threshold, the three-party game **Action:** The modification is located in the highlighted part on pages 21.

system will be triggered to form a positive relationship, otherwise, it will evolve in the direction of deterioration.

(2) Under certain conditions, the service transformation of sports industry can reach an ideal state, that is, sports enterprises choose SET strategy, consumers choose ASP strategy, and management departments choose ACS strategy. However, when the sum of the system construction cost and subsidy expenditure of the management department is higher than the accountability cost of the superior, the management department's strategy degenerates to NES.

(3) Financial subsidies can promote the service transformation of sports enterprises, but have no significant incentive effect on consumers, which will inhibit the supervision enthusiasm of management departments to some extent. With the increase of accountability cost, the management department will change from passive supervision strategy to active supervision strategy. The management department can stimulate the enthusiasm of service transformation by increasing the punishment level for sports enterprises.

Discussion

This study discusses the strategic game relationship between different stakeholders in the process of service transformation of sports industry, which may have some enlightenment for the sustainable development of sports industry, but there are still some areas worthy of improvement. On the one hand, service transformation is a complicated process. This paper reveals the strategic game behavior among different participants in the process of service transformation of sports industry from the perspective of evolutionary game theory, which provides a valuable analytical framework for related research. However, this theory is only applicable to the tripartite game system composed of sports enterprises, consumers and management departments. If more stakeholders are included, the application scope of this theory may be further developed. On the other hand, adding more stakeholders also means considering more parameters in the modeling process, which can make the model more accurate and the results more explanatory, but it also greatly increases the difficulty and complexity of modeling. We will continue to pay attention to these problems and try to explore new solutions.

Data availability

The datasets generated during or analyzed during the current study are available from the corresponding author on reasonable request.

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Declarations

Competing interests
The authors declare no competing interests

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