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An Evolutionary Game-Based Decision Framework for Value Co-Destruction in Virtual Brand Communities: Modeling and Simulation Analysis

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ABSTRACT

This study constructs a decision-support framework for value co-destruction (VCD) in virtual brand community based on the perspective of evolutionary game theory. By constructing an evolutionary game model of VCD in virtual brand communities, the evolution process and influencing factors are deeply analyzed. MATLAB simulation is used to verify the impact of relevant parameter changes on evolutionary outcomes, thereby revealing the inherent mechanism of the coordination mechanism between brand and customer community interaction behaviors. The research results indicate that the interaction behaviors between brands and customers in virtual communities exhibit an evolutionary characteristic of coexistence of "co-destructive interaction" and "co-creative interaction"; an increase in the cost coefficient leads to a trend towards incoordination in the interaction behaviors between brands and customers, with both parties converging towards "co-destructive interaction" and resulting in VCD; an increase in willingness to invest resources and resource integration profitability promotes the coordination and stability of the interaction behaviors between brands and customers, with both parties converging towards "co-creative interaction" and achieving value co-creation.

1. Introduction

With the rapid development of the information and communication industry, some enterprises have gradually established virtual brand communities, seeking to establish dialogue with customers and provide services to them. By drawing on external knowledge and customer creativity through digital platforms, firms can strengthen their innovation capacity and develop new mechanisms for organizational value creation [1]. Smart mobile devices enable customers to access virtual brand communities anytime and anywhere and to interact with firms through multiple digital touchpoints. Evidence from digital service systems indicates that users evaluate such interactions in terms of convenience, reliability, perceived value, and trust [2]. Evidence from other community-based digital

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environments further shows that ICT platforms can facilitate user engagement, information transparency, and coordinated resource sharing among participating actors [3]. Within virtual brand communities, customers may further participate in experience sharing, product ideation, technical discussions, and new product evaluation, thereby contributing their knowledge and other resources to brand value creation [4]. However, digital interactions do not invariably produce the outcomes expected by either firms or users. Variations in user behaviour, information processing, and interface responses may introduce interaction risks and reduce the quality of the user experience [5]. Research on community-based organizations also indicates that limited organizational capacity, weak transparency, inadequate collaboration, and low levels of community participation can constrain the achievement of collective value outcomes [6]. In virtual brand communities, these problems may be compounded by resource scarcity, resource misuse, conflicting goals, incomplete information, and insufficient resource-integration capabilities, preventing the interacting parties from achieving the expected value outcomes [7–9]. Therefore, interactions between brands and customers in virtual brand communities can achieve value co-creation, but they may also lead to value co-destruction (VCD). The outcome of value creation is influenced by the action decisions of the participants.

To achieve positive value creation outcomes, brand enterprises need to adopt appropriate strategies to reduce the probability of VCD in virtual brand communities. Value creation occurs during interactions between brands and customers in virtual brand communities, which is a game process where both parties continuously learn from each other and adjust their strategies [10]. The interacting parties are not necessarily in an equilibrium state at the initial stage, but through mutual learning in the long-term game process, both parties continuously adjust their behavioral strategies and eventually reach an equilibrium state [11]. Therefore, it is reasonable to explore the brand-customer VCD interaction process from the perspective of evolutionary game theory.

In view of this, this study constructs a decision-support framework for VCD in virtual brand community based on theories such as VCD and evolutionary game theory: building an evolutionary game model of brand-customer VCD interaction, and using MATLAB to simulate and test the impact of changes in model parameters on game outcomes. It aims to understand the strategic evolution process of brand and customer interaction in virtual brand communities, in order to provide management decision support for enterprises and community managers to reduce the possibility of shared destruction of virtual brand community value.

2. Literature review and research commentary

2.1 VCD

To systematically examine the negative impacts of value creation, Plé and Cáceres [7] introduced the concept of VCD based on the service-led logic. They argue that VCD is an interactive process leading to a decline in the welfare of at least one service system, where the service system can be an individual or an organization. Meanwhile, Echeverri and Skålén [12] developed the concept of VCD from the perspective of Interactive Value Formation (IVF) theory, aiming to supplement the lack of negative impacts of value formation in the IVF framework, thereby forming a complete interactive value formation framework. They defined VCD as the joint destruction or reduction of value caused by service providers and customers during the interaction process.

With the deepening of research on VCD, some scholars have raised doubts or provided supplements to the definition of VCD. Smith [13] explored the process of VCD caused by enterprises abusing customer resources from the perspective of customers, based on the Conservation of Resources (COR) theory. He believed that there were situations of uneven value distribution or

insufficient co-created value in VCD, and defined VCD as the loss of resources caused by enterprises failing to fulfill their value proposition. Vefeas *et al*. [14] believed that the term "destruction" in VCD indicates irreparable losses, applicable to the permanently lost parts of the value proposition. However, the process of resource integration may still enable the realization of some promised or expected value components, making the term "value diminution" more appropriate. Prior and Marcos-Cuevas [15] believed that VCD in the service ecosystem is not only the opposite of value co-creation, but also includes neutral and below-expectation value creation; there are many participants in the service ecosystem, with inconsistent goals and always weighing pros and cons, so value co-creation and VCD can occur simultaneously. Therefore, the concept of VCD has gradually evolved from the reduction of participants' value to include three scenarios: participants' value decreases, value remains unchanged, and value increases but is below expectations.

2.2 Value co-creation

The concept of value co-creation emerged from the co-production influenced by the goods-dominant logic. It was first proposed by Prahalad and Ramaswamy from the perspective of customer experience, suggesting that its essence lies in the joint creation of customer experiences by businesses and customers, with the core being the interaction between customers and businesses [16]. Value co-creation has continuously evolved and improved based on the service-dominant logic, arguing that participants co-create value through resource integration through interaction [17]. Therefore, interaction and resource integration are key to achieving value co-creation, and related research mainly revolves around two categories: one is the participants' willingness to interact, such as their motivation and experience; the other is the participants' ability to integrate resources for co-creating value, such as their knowledge, skills, creativity, and networks [18].

Value co-creation and VCD are different states of value creation through resource integration. Value co-creation is an interactive process where participants jointly create use value by integrating their own resources and utilizing the resources of others, implying that all participants benefit from the interaction. On the other hand, VCD refers to a failed interactive process that may occur due to the failure of resource integration, indicating that participants fail to achieve the optimal welfare state during the interaction [19]. Both value co-creation and VCD evolve from the service-dominant logic and share certain commonalities. Both involve enterprises, customers, and multiple stakeholders, demonstrating multi-party participation. Simultaneously, both occur during the interaction process among participants and cannot be independently generated by a single participating entity. Value co-creation and VCD are closely related and are not simply in opposition to each other. VCD encompasses three possible states: a decline in participant welfare, no change, or an increase that fails to meet expectations. There is a critical point between value co-creation and VCD, and the two can transform into each other [20]. Value co-creation and VCD are outcomes of different participants in the same value creation process. VCD may be a stage in the process of value co-creation, and vice versa [21]. Especially in service ecosystems, where numerous participants interact, there is a possibility of coexistence between value co-creation and VCD [22].

As a typical service ecosystem, virtual communities may coexist with value co-creation and VCD as outcomes of value creation [23]. Ind *et al*. [24] found in their study on the outcomes of value co-creation in online brand communities that the lack of a fair and reciprocal concept in organizations, failure to listen to customer opinions or suggestions, provide timely feedback, and take action may lead to the failure of value co-creation. Abedin and Bidar [25] discovered that social enterprises generate value co-creation and VCD through online community interactions. Lack of trust, insufficient

communication, lack of transparency, and low-quality information are the fundamental reasons for VCD. Lv *et al*. [26] believed that the antecedents of VCD in online travel communities include social loafing, knowledge hiding, communication overload, distrust, misconduct, and conflict. Bidar *et al*. [27] categorized the causes of VCD in Online Collaborative Networks (OCNs) into three groups of eleven: resource constraints before collaboration, individual differences and lack of perception of resourcefulness, poor coordination during collaboration, lack of communication, conflicting expectations among participants, destructive feedback, and irresponsibility, as well as lack of recognition, low quality, and low participation of community members' contributions after collaboration.

2.3 Research Review

Looking at existing literature, although scholars have achieved certain results in exploring VCD, there are still obvious shortcomings: (1) Existing research mostly explores and analyzes the concept, antecedents, and processes of VCD through theoretical analysis, case studies, and text mining. Existing research on VCD in virtual brand communities mainly focuses on qualitative studies such as online ethnography, key event technology, and case studies, with relatively few quantitative empirical studies, thus unable to provide strong evidence of VCD in virtual brand communities. (2) The existing research mainly explores from a static perspective, lacking research on the evolution process of brand and customer value creation interaction behavior from a dynamic perspective. Further exploration is needed on the evolution process, factors that affect the decision-making of interactive behavior between both parties, and how to coordinate interactive behavior to reduce the probability of VCD. In view of this, this study constructs a decision-support framework for VCD in virtual brand community based on theories such as VCD and evolutionary game theory: building an evolutionary game model of brand-customer VCD interaction, and using MATLAB to simulate and test the impact of changes in model parameters on game outcomes.

3. Evolutionary Game Models

3.1 Basic assumptions of the model

Brands and customers invest various resources in virtual brand communities, and the value creation results are influenced by the interaction process between both parties. Effective resource integration will increase brand assets and customer value, that is, value co-creation; Invalid resource integration will lead to a decrease in value for at least one party, i.e. VCD.

The premise of resource integration is that both brands and customers can acquire and invest resources. When both parties actively invest resources in the interaction, sufficient resources are needed for value creation, and other participants can achieve effective resource integration and value co-creation; When one party in the interaction refuses to invest resources that can help create value, the value creation resources are insufficient, and other participants are unable to effectively integrate resources, resulting in VCD. Therefore, the result of value creation is related to the willingness of both parties to invest resources.

Brands and customers need to pay costs when investing resources, and the perception of value creation results may vary depending on the participants' ability to control costs. When participants have a high ability to control costs, the lower their resource input costs, the more likely the benefits obtained from value creation are to be higher than the resource input costs, achieving value co-

creation; When participants have a lower ability to control costs, the higher their resource input costs, and the benefits obtained from value creation may be lower than the resource input costs, leading to VCD. Therefore, the value creation outcome is also influenced by the participants' ability to control costs, namely the cost coefficient.

In addition, the different abilities of brands and customers to create value through the use of resources may also affect the results of value creation. When participants have a high ability to use resources to create value, the higher the value created by resource integration, the greater the value of participants, and the realization of value co-creation; When the ability of participants to create value using resources is low, the value created by their resource integration is also low, and there may even be resource abuse, resulting in a decrease in the value of participants and the co-destruction of value. Therefore, the result of value creation is also influenced by the ability of participants to create value through practical resources, namely the coefficient of resource integration profitability.

Based on the research on customer VCD behavior in virtual brand communities, hypotheses are proposed:

Assumption 1: In the interactive process of virtual brand community, brand B and customer C can freely use their own resources for VCD or co-creation.

Assumption 2: Brand's behavioral choices manifest as a set of strategies (co-creation strategy, co-destruction strategy), while customers' behavior manifests as a set of strategies (co-creation behavior, co-destruction behavior).

Assumption 3: Both brand and customer are bounded rationality, and they learn from each other in a long-term game, constantly adjusting their behavioral strategies and ultimately reaching an equilibrium state.

Assumption 4: Brand and customer have initial resources, and when participants choose a co-creation strategy or behavior, the willingness to invest resources reaches 1; When participants choose a co-destruction strategy or co-destruction behavior, the degree of willingness to invest resources ranges from 0 to 1.

Assumption 5: The benefits obtained by brand and customer in the interaction of the virtual brand community are a linear function of the level of resource investment. The size of participants' benefits is not only influenced by the amount of resource investment from both parties, but also by their own ability to integrate resources and generate benefits.

Assumption 6: When brand chooses a co-destruction strategy and customers choose co-creation behavior, the brand will be punished by customers; When brand chooses a co-creation strategy and customers choose a co-destruction behavior, customer value will also decrease, and customers will be punished.

The assumptions for the relevant parameters are shown in Table 1, and all parameters are greater than zero.

3.2 Construction of Evolutionary Game Model

In virtual brand community interaction, the probability of a brand choosing a co-destruction strategy is x, and the probability of choosing a co-creation strategy is $(1-x)$, where $x \in [0,1]$; The probability of customers choosing co-destruction behavior is y, and the probability of choosing co-creation behavior is $(1-y)$, where $y \in [0,1]$. The profit matrix of the brand customer VCD interactive evolutionary game is shown in Table 2.

Table 1
Evolutionary game parameters and meanings

Parameters	Meanings
K_B	Initial resources of the brand
K_C	Initial resources of the customers
α_B	The cost coefficient of the brand, $\alpha_B \in (0,1)$
α_C	The cost coefficient of customers, $\alpha_C \in (0,1)$
β_B	The willingness of a brand to invest resources, when choosing a co-creation strategy (such as authentic promotion, fair strategy), $\beta_B = 1$; when a brand chooses a co-destruction strategy (such as false advertising, unfair tactics), $0 \le \beta_B < 1$
β_C	The willingness of customers to invest resources, when customers choose co-creation behavior, $\beta_C = 1$; when customers choose to engage in co-destruction behavior, $0 \le \beta_C < 1$
γ_B	Brand resource integration profitability coefficient
γ_C	Customer resource integration profitability coefficient
W_B	When a brand chooses a co-destruction strategy (such as false advertising, unfair tactics), the punishment received by the brand
W_C	Punishment received by customers when they choose to engage in co-destruction behavior

Table 2
Evolutionary game benefit matrix

Brand	Customers	
	co-destruction behavior y	co-creation behavior $(1-y)$
co-destruction strategy x	$\gamma_B(\beta_B K_B + \beta_C K_C) - \alpha_B \beta_B K_B$, $\gamma_C(\beta_C K_C + \beta_B K_B) - \alpha_C \beta_C K_C$	$\gamma_B(\beta_B K_B + K_C) - \alpha_B \beta_B K_B - W_B$, $\gamma_C(K_C + \beta_B K_B) - \alpha_C K_C$
co-creation strategy $(1-x)$	$\gamma_B(K_B + \beta_C K_C) - \alpha_B K_B$, $\gamma_C(\beta_C K_C + K_C) - \alpha_C \beta_C K_C - W_C$	$\gamma_B(K_B + K_C) - \alpha_B K_B$, $\gamma_C(K_C + K_B) - \alpha_C K_C$

Assuming the expected benefits of choosing a co-destruction strategy for the brand are E_{11}, the expected benefits of choosing a co-creation strategy are E_{12}, the average expected benefits are E_1, and the replication dynamic equation is dx/dt.

$$E_{11} = y\left[\gamma_B(\beta_B K_B + \beta_C K_C) - \alpha_B \beta_B K_B\right] + (1-y)\left[\gamma_B(\beta_B K_B + K_C) - \alpha_B \beta_B K_B - W_B\right] \quad (1)$$

$$E_{12} = y\left[\gamma_B(K_B + \beta_C K_C) - \alpha_B K_B\right] + (1-y)\left[\gamma_B(K_B + K_C) - \alpha_B K_B\right] \quad (2)$$

$$E_1 = xE_{11} + (1-x)E_{12} \quad (3)$$

$$F_x = \frac{dx}{dt} = x(1-x)\left[K_B(1-\beta_B)(\alpha_B - \gamma_B) + (1-y)W_B\right] \quad (4)$$

If the expected return for customers choosing co-destruction behavior is E_{21}, the expected return for choosing co-creation behavior is E_{22}, the average expected return is E_2, and the replication dynamic equation is dy/dt.

$$E_{21} = x\left[\gamma_C(\beta_C K_C + \beta_B K_B) - \alpha_C \beta_C K_C\right] + (1-x)\left[\gamma_C(\beta_C K_C + K_B) - \alpha_C \beta_C K_C - W_C\right] \quad (5)$$

$$E_{22} = x\left[\gamma_C(K_C + \beta_B K_B) - \alpha_C K_C\right] + (1-x)\left[\gamma_C(K_C + K_B) - \alpha_C K_C\right] \quad (6)$$

$$E_2 = yE_{21} + (1-y)E_{22} \quad (7)$$

$$F_y = \frac{dy}{dt} = y(1-y)\left[K_C(1-\beta_C)(\alpha_C-\gamma_C)+(1-x)W_C\right] \tag{8}$$

In summary, a two-dimensional dynamic system can be obtained for both the brand and customer sides:

$$\begin{cases} F(x) = \dfrac{dx}{dt} = x(1-x)\left[K_B(1-\beta_B)(\alpha_B-\gamma_B)+(1-y)W_B\right] \\ F(y) = \dfrac{dy}{dt} = y(1-y)\left[K_C(1-\beta_C)(\alpha_C-\gamma_C)+(1-x)W_C\right] \end{cases} \tag{9}$$

3.3 Stability Analysis of Evolutionary Game Theory

The stability of the system refers to the constant proportion of strategic choices between the brand and the customer in the game, at which point the replication behavior of the two participating entities remains in equilibrium. So, when $F(x)=0$, $F(y)=0$,we can obtain 5 local equilibrium points: $O(0,0)$, $A(1,0)$, $B(0,1)$, $C(1,1)$, $D(x^*,y^*)$. Among which

$$x^* = \frac{W_C + K_C(1-\beta_C)(\gamma_C-\alpha_C)}{W_C} = 1-\frac{K_C(1-\beta_C)(\alpha_C-\gamma_C)}{W_C}$$

(10)

$$y^* = \frac{W_B + K_B(1-\beta_B)(\gamma_B-\alpha_B)}{W_B} = 1-\frac{K_B(1-\beta_B)(\alpha_B-\gamma_B)}{W_B}$$

(11)

The local stability of the equilibrium point can be determined based on the trace (TrJ) and determinant ($DetJ$) of the Jacobian matrix.

$$J = \begin{bmatrix} J_{11} & J_{12} \\ J_{21} & J_{22} \end{bmatrix}$$

(12)

Among which

$$\begin{cases} J_{11} = (1-2x)\left[K_B(1-\beta_B)(\alpha_B-\gamma_B)-(1-y)W_B\right] \\ J_{12} = x(x-1)(-W_B) \\ J_{21} = y(y-1)(-W_C) \\ J_{22} = (1-2y)\left[K_C(1-\beta_C)(\alpha_C-\gamma_C)-(1-x)W_C\right] \end{cases}$$

(13)

The determinant and trace of the Jacobian matrix are:

$$DetJ = J_{11}\times J_{22} - J_{12}\times J_{21} \tag{14}$$

$$TrJ = J_{11} + J_{22}$$

(15)

From the above analysis, studying is meaningful when $\alpha_B > \gamma_B$, $\alpha_C > \gamma_C$. The characteristic values of each equilibrium point are shown in Table 3.

Table 3
Eigenvalues of system equilibrium points

Equilibrium point	Eigenvalue 1	Eigenvalue 2
$O(0,0)$	$-\left[W_B - K_B(1-\beta_B)(\alpha_B-\gamma_B)\right]$	$-\left[W_C - K_C(1-\beta_C)(\alpha_C-\gamma_C)\right]$
$A(1,0)$	$W_B - K_B(1-\beta_B)(\alpha_B-\gamma_B)$	$K_C(1-\beta_C)(\alpha_C-\gamma_C)$
$B(0,1)$	$K_B(1-\beta_B)(\alpha_B-\gamma_B)$	$W_C - K_C(1-\beta_C)(\alpha_C-\gamma_C)$
$C(1,1)$	$-K_B(1-\beta_B)(\alpha_B-\gamma_B)$	$-K_C(1-\beta_C)(\alpha_C-\gamma_C)$

The stability analysis results of each equilibrium point are shown in Table 4. From the table, it can be seen that $D\left(x^*, y^*\right)$ is the saddle point, $A(1,0)$ and $B(0,1)$ are unstable points, $O(0,0)$ and $C(1,1)$ are evolutionarily stable strategies (ESS). Among them, the corresponding strategy combination of $O(0,0)$ is (co-creation strategy, co-creation behavior), which represents the state where the brand adopts co-creation strategies such as real promotion or fair strategy, and customers choose co-creation behavior. The formation conditions include $W_B - K_B(1\text{-}\beta_B)(\alpha_B-\gamma_B) > 0$, $W_C - K_C(1-\beta_C)(\alpha_C-\gamma_C) > 0$. The corresponding strategy combination of $C(1,1)$ is (co-destruction strategy, co-destruction behavior), which represents the state in which the brand adopts co-destruction strategies such as false advertising or unfair strategies, and customers choose co-destruction behavior. The formation conditions include $K_B(1-\beta_B)(\alpha_B-\gamma_B) > 0$, $K_C(1-\beta_C)(\alpha_C-\gamma_C) > 0$.

Table 4
Stability analysis of system equilibrium points

Equilibrium point	$DetJ$ symbol	$\mathrm{Tr}J$ symbol	Stability
$O(0,0)$	+	-	ESS
$A(1,0)$	+	+	Unstable
$B(0,1)$	+	+	Unstable
$C(1,1)$	+	-	ESS
$D\left(x^*, y^*\right)$	$\pm$	0	Saddle point

Describe the evolutionary process of interaction between the brand and customer sides in the virtual brand community on a flat surface $M = \left\{(x,y) \mid 0 \le x, y \le 1\right\}$, as shown in Figure 1. The ADB curve in the figure represents the critical line at which the interaction between the brand and customer sides converges to different evolutionary stable strategies in the virtual brand community. In the ADBC area at the upper right corner of the curve, the interaction between the brand and the customer converges to $C(1,1)$ (co-destruction strategy, co-destruction behavior); In the ADBO area at the bottom left of the curve, the interaction between the brand and the customer converges to $O(0,0)$ (co-creation strategy, co-creation behavior); The position of the saddle point $D\left(x^*, y^*\right)$ determines the area size of the ADBC and ADBO regions, which affects the probability of brand and customer game strategy choices. As shown in the figure, the area of the ADBC region is:

$$S_{ADBC}=1-\frac{1}{2}\left(x^{*}+y^{*}\right)=\frac{1}{2}\left[\frac{K_C\left(1-\beta_C\right)\left(\alpha_C-\gamma_C\right)}{W_C}+\frac{K_B\left(1-\beta_B\right)\left(\alpha_B-\gamma_B\right)}{W_B}\right] \tag{16}$$

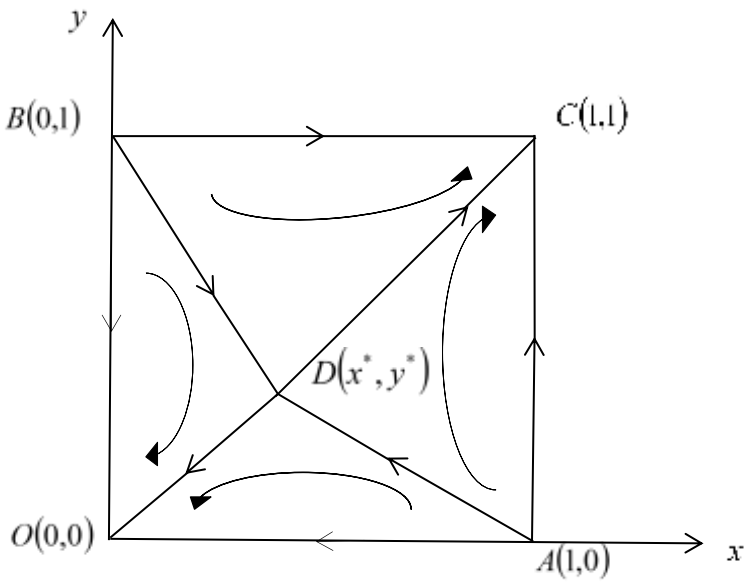

Fig. 1. Phase diagram of brand customer interaction evolution game

3.4 Evolutionary Game Analysis and Discussion

According to the analysis of the brand customer community VCD interactive evolutionary game model, the value creation interaction behavior between brands and customers exhibits the characteristics of "VCD interaction" and "value co-creation interaction" coexisting. The eigenvalues of the equilibrium point (0,0) are all less than 0, corresponding to the combination of co-creation strategy and co-creation behavior. The reason is that when a brand adopts co-creation strategies such as real promotion or fairness strategy, customers will have reasonable expectations or perceive fairness, and then choose co-creation behaviors such as sharing user experience and making friendly suggestions. Under this strategic combination, brand and customer interaction will generate value co-creation. The eigenvalues of the equilibrium point (1,1) are all less than 0, corresponding to the combination of (co-destruction strategy, co-destruction behavior) strategies. The reason is that when a brand adopts co-destruction strategies such as false advertising or unfair strategies, customers will have high expectations and perceive unfairness towards the brand's products, services, and community itself, and then choose co-destruction behaviors such as knowledge hiding and conflict. Under this strategic combination, brand and customer interaction can lead to VCD. Due to the existence of saddle points, the area size of regional ADBC and ADBO determines the probability of brand and customer game strategy selection and the evolutionary path of their interactive behavior. To further analyze the evolution process and results of the interaction behavior between the brand and the customer, the influence of various parameters in the model on the direction of interaction behavior evolution between the two parties is explored based on the area formula of the ADBC region.

By taking the derivative of α_B and α_C respectively, it can be concluded that $\frac{dS_{ADBC}}{d\alpha_B}=\frac{K_B(1-\beta_B)}{W_B}>0$, $\frac{dS_{ADBC}}{d\alpha_C}=\frac{K_C(1-\beta_C)}{W_C}>0$. S_{ADBC} is a monotonically increasing function of α_B and α_C, that is, as α_B and α_C increase, the saddle point D moves in the direction of $O(0,0)$, the area of ADBC increases, the probability of brand customer interaction evolving $O(0,0)$ decreases, and the probability of evolving $C(1,1)$ increases. Both parties tend to choose (co-destruction strategy, co-destruction behavior). This indicates that a high-cost coefficient will lead to negative brand customer interaction value creation outcomes and increase the probability of VCD. The smaller the cost coefficient, the stronger the brand or customer's cost control ability. In order to obtain equal benefits in interaction, less resources need to be invested, resulting in lower interaction costs; The higher the cost coefficient, the more likely it is that the brand or customer lacks cost control ability. In order to obtain equal benefits in interaction, more resources need to be invested, resulting in higher interaction costs. Therefore, when the cost coefficient of a brand or customer is larger, if the resources invested in interaction remain unchanged, the benefits obtained will be lower than expected, leading the brand or customer to believe that the benefits obtained are lower than the costs paid, resulting in the brand and customer choosing a (co-destruction strategy, co-destruction behavior) strategy, and VCD occurring. Therefore, improving the cost control ability of brand owners and optimizing community platform design to reduce customer interaction costs can effectively avoid VCD.

By taking the derivative of β_B and β_C respectively, it can be concluded that $\frac{dS_{ADBC}}{d\beta_B}=\frac{-K_B(\alpha_B-\gamma_B)}{W_B}<0$, $\frac{dS_{ADBC}}{d\beta_C}=\frac{-K_C(\alpha_C-\gamma_C)}{W_C}<0$. S_{ADBC} is a monotonically decreasing function of β_B and β_C, that is, as β_B and β_C increase, the saddle point D moves in the direction of $C(1,1)$, the area of ADBC decreases, the probability of brand customer interaction evolving $O(0,0)$ increases, and the probability of evolution $C(1,1)$ decreases. Both parties tend to choose (co-creation strategy, co-creation behavior). This indicates that a high coefficient of willingness to invest resources will lead to positive brand customer interaction value creation results and reduce the probability of VCD. The higher the coefficient of willingness to invest resources, the more willing the brand or customer is to invest their resources in virtual brand community interaction, providing sufficient resources for value creation activities and achieving value co-creation; The smaller the coefficient of willingness to invest resources, the more willing the brand or customer is to retain the resources they hold. Value creation activities in virtual brand communities may not achieve the expected value output due to insufficient resources, leading brands or customers to believe that the value output obtained is lower than the resources invested, resulting in VCD. Therefore, by designing and optimizing reasonable incentive mechanisms, increasing the willingness of brand and customer resource investment, and improving the quality of brand and customer interaction, it is an effective way to avoid VCD.

By taking the derivative of γ_B and γ_C respectively, it can be concluded that $\frac{dS_{ADBC}}{d\gamma_B}=\frac{-K_B(1-\beta_B)}{W_B}<0$, $\frac{dS_{ADBC}}{d\gamma_C}=\frac{-K_C(1-\beta_C)}{W_C}<0$. S_{ADBC} is a monotonically decreasing function of γ_B and γ_C, that is, as γ_B and γ_C increase, the saddle point D moves in the direction of $C(1,1)$, the area of ADBC decreases, the probability of brand customer interaction evolving $O(0,0)$ increases, and the probability of evolution $C(1,1)$ decreases. Both parties tend to choose (co-creation strategy, co-creation behavior). This indicates that the high resource integration profitability coefficient will lead to positive brand

customer interaction value creation results and reduce the probability of VCD. The higher the coefficient of resource integration profitability, the more likely the brand or customer is to effectively integrate and utilize various resources provided by participants in the virtual brand community for value creation. At this time, the brand or customer is more inclined to provide their own resources to obtain higher returns, that is, to adopt an active value creation strategy and achieve brand customer value co-creation; The smaller the coefficient of resource integration profitability, the more likely the brand or customer is to effectively integrate and utilize the various resources provided by participants in the virtual brand community. In the process of value creation, there is a possibility of resource abuse by the brand or customer, resulting in lower returns and a situation where the returns do not meet expectations, leading the brand or customer to believe that the returns are lower than the costs paid. At this time, the brand or customer is more inclined to protect their own resources to reduce the potential risk of resource loss, that is, to adopt a negative value creation strategy, and the VCD of the virtual brand community occurs. Therefore, improving the brand's ability to integrate its own resources and generate revenue, effectively identifying target customer groups and pushing services and information to them, can effectively avoid VCD.

4. Simulation of Evolutionary Game Theory

In order to further verify the impact of parameter changes in the initial state and evolution model on the brand customer VCD interaction evolution results, MATLAB was used for simulation and the influence of evolution results was discussed.

4.1 The Influence of Initial State on Evolutionary Results

Based on the above analysis, referring to relevant research [28] and combined with actual situations, the following initial values are assigned to each parameter: $K_B = 100$, $K_C = 70$, $\alpha_B = 0.6$, $\alpha_C = 0.6$, $\beta_B = 0.8$, $\beta_C = 0.8$, $\gamma_B = 0.4$, $\gamma_C = 0.4$, $W_B = 15$, $W_C = 10$, with an evolution period t value of [0,50], to obtain the saddle point. The evolution process of the initial state of brand customer VCD interactive behavior over time is shown in Figure 2. There are two stable points in the interactive evolutionary game of brand customer VCD in virtual brand communities, namely (0,0) and (1,1). When the value is less than the saddle point, the evolutionary result will converge to a stable point (0,0), and the behavior strategy of the brand and customers is (co-creation strategy, co-creation behavior); When the value is greater than the saddle point, the evolutionary result will converge to the stable point (1,1), and the behavior strategy of the brand and customers is (co-destruction strategy, co-destruction behavior). It can be seen that the brand customer VCD interactive game has two equilibrium points: co-creation strategy, co-destruction behavior, and co-destruction strategy, co-destruction behavior. The evolution of the brand customer VCD interactive game is closely related to the initial states of the participants, and whether the final evolution converges to (co-creation strategy, co-destruction behavior) or (co-destruction strategy, co-destruction behavior) is related to the initial probability of the strategy choices made by both parties and the position of the saddle point.

4.2 Impact of Parameter Changes on Evolutionary Results

Assuming that the probability of the brand choosing a co-destruction strategy in the initial state is $x = 0.5$, and the probability of the customer choosing a co-destruction behavior is $y = 0.5$, the impact

of changes in the cost coefficient, resource investment willingness coefficient, and resource integration profitability coefficient on the evolutionary game results is simulated as follows.

When the cost coefficient α_B and α_C values are 0.1, 0.3, 0.5, 0.7, and 0.9, the simulation results over time are shown in Figure 3. According to Figure 3, when the cost coefficient is less than or equal to 0.5, the smaller the cost coefficient, the greater the probability of brand and customer selection (co-creation strategy, co-creation behavior) over time; When the cost coefficient is greater than 0.5, the higher the cost coefficient, the greater the probability of brand and customer selection (co-destruction strategy, co-destruction behavior) over time. In the case of fixed resource investment, an increase in the cost coefficient means an increase in the interaction cost between the brand and the customer, resulting in lower-than-expected benefits from the interaction and leading to VCD.

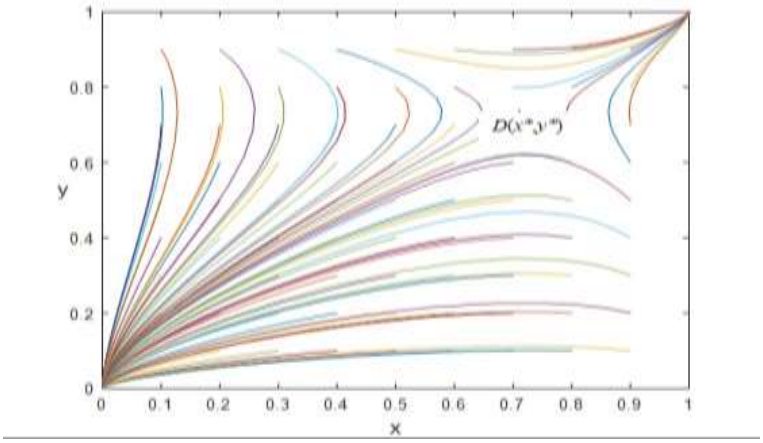

Fig. 2. Brand customer evolution game process

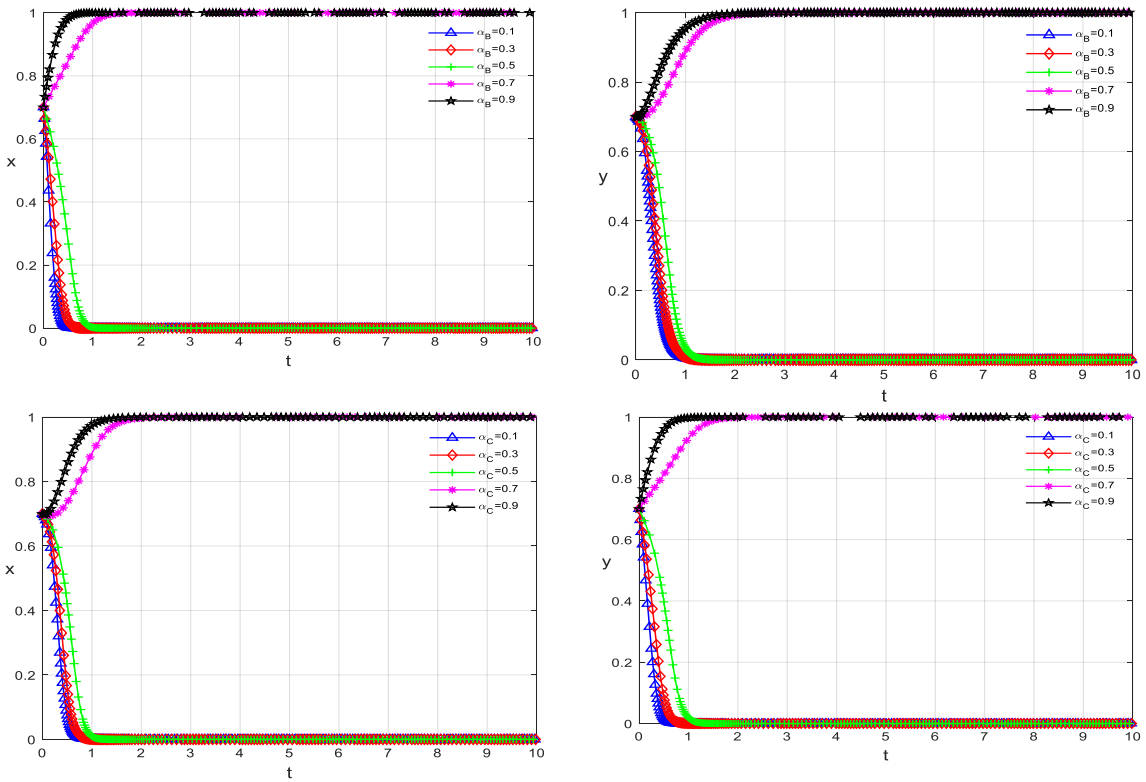

Fig. 3. Simulation results of cost coefficient variation

When the coefficient of willingness to invest resources β_B and β_C values are 0.75, 0.80, 0.85, 0.90, and 0.95, the simulation results over time are shown in Figure 4. As shown in Figure 4, the greater the willingness of a brand or customer to invest resources, the higher the probability of the brand and customer choosing (co-creation strategy, co-creation behavior) over time; The smaller the willingness of a brand or customer to invest resources, the greater the probability of the brand and customer choosing (co-destruction strategy, co-destruction behavior) over time. The increase in willingness to invest resources means that the available resources for brand and customer interaction increase, and the benefits generated by resource integration are higher than expected, thereby avoiding VCD.

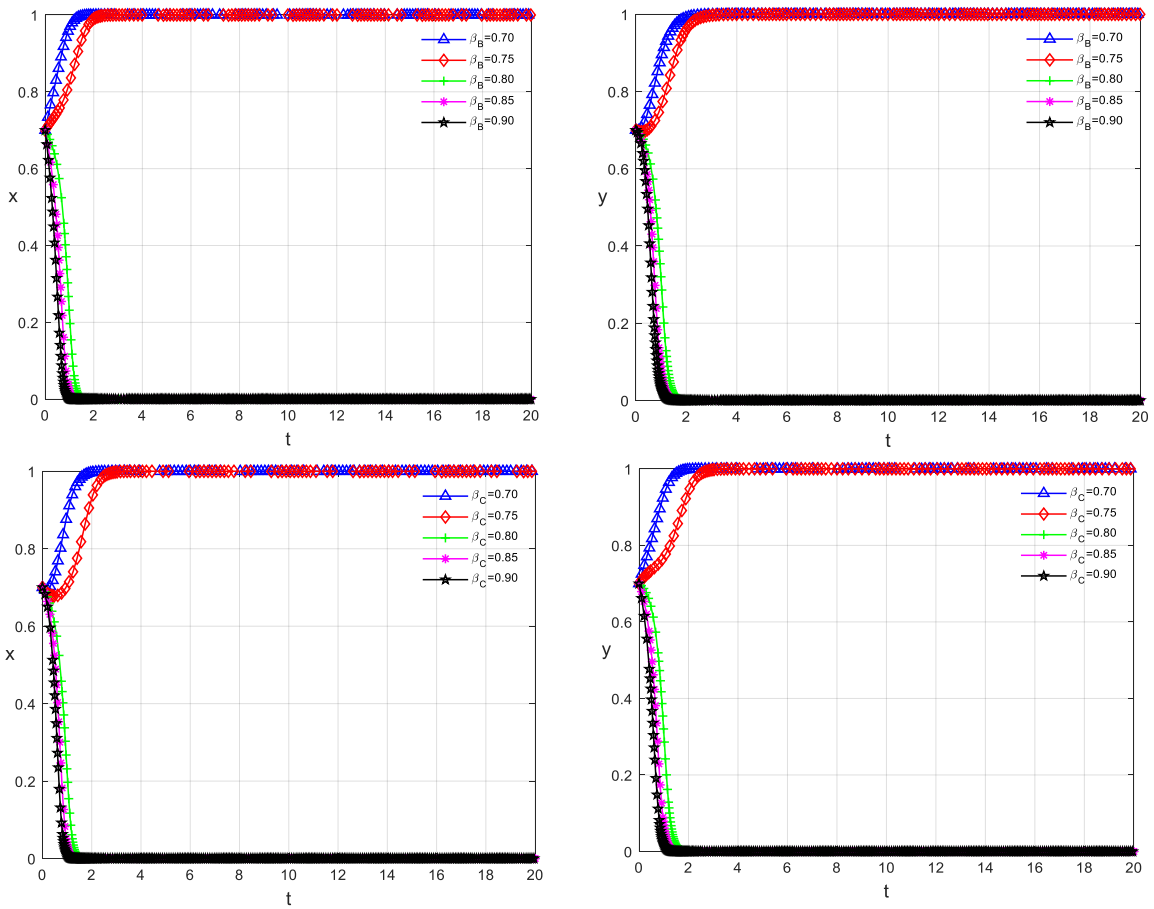

Fig. 4. Simulation results of changes in willingness to invest resources

When the coefficient of resource integration profitability γ_B and γ_C values are 0.1, 0.3, 0.5, 0.7, and 0.9, the simulation results over time are shown in Figure 5. According to Figure 4-4, when the coefficient of resource integration profitability is less than or equal to 0.5, the smaller the coefficient of resource integration profitability, the greater the probability of brand and customer selection (co-destruction strategy, co-destruction behavior) over time; When the coefficient of resource integration profitability is greater than 0.5, the larger the coefficient of resource integration profitability, the lower the probability of brand and customer selection (co-destruction strategy, co-destruction behavior) over time. The increase in the coefficient of resource integration profitability means that the resource integration ability of both the brand and customer sides is enhanced, and the benefits obtained from value creation are higher than expected, thereby avoiding VCD.

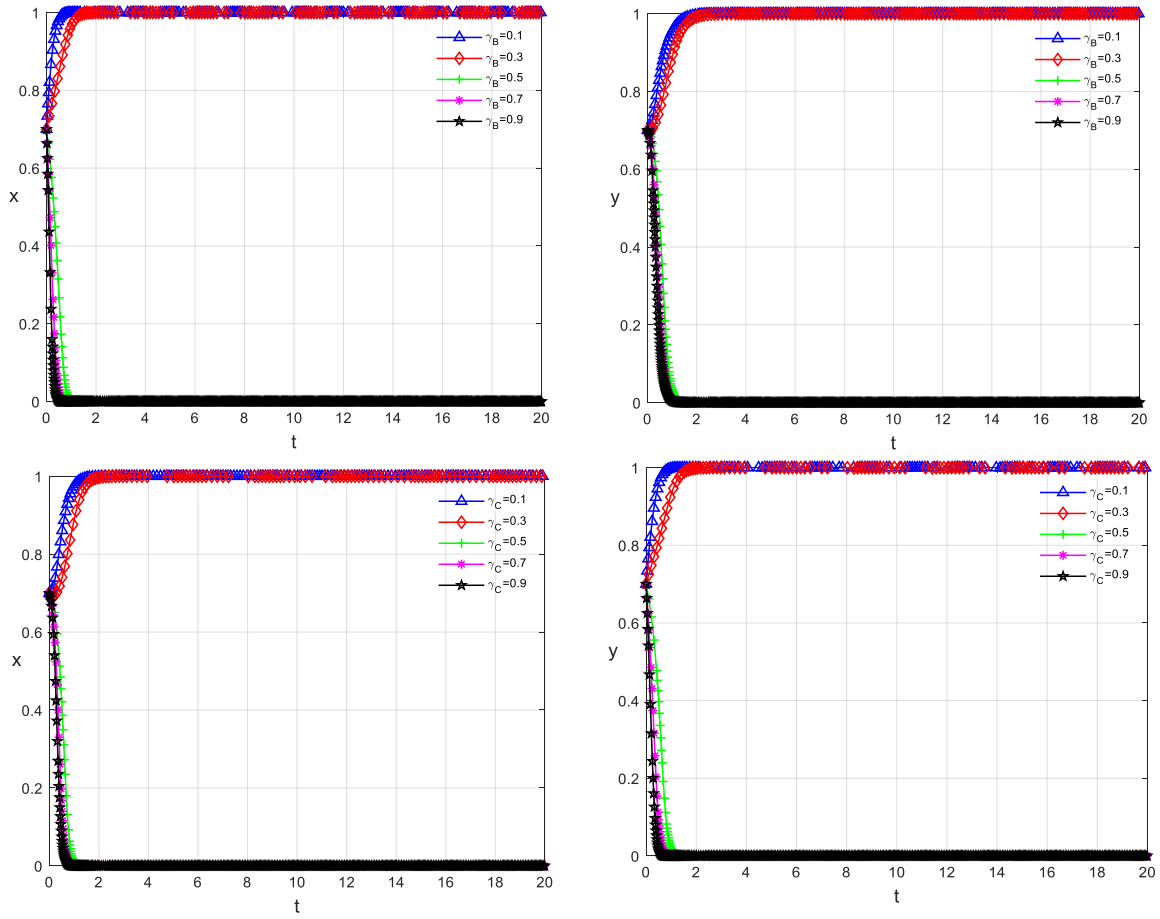

Fig. 5. Simulation results of changes in the coefficient of resource integration profitability

Through the analysis of the impact of parameter changes in the three evolutionary game models of cost coefficient, resource input willingness coefficient, and resource integration benefit coefficient on the evolutionary results, it can be concluded that a decrease in the cost coefficient of the brand or customer, an increase in the resource input willingness coefficient, and an increase in the resource integration benefit ability coefficient will cause both parties in the game to converge to the equilibrium point (co-creation strategy, co-creation behavior) over time, ultimately achieving value co-creation; The increase in cost coefficient, decrease in willingness coefficient for resource input, and decrease in ability coefficient for resource integration benefits will cause both parties in the game to converge to the equilibrium point (co-destruction strategy, co-destruction behavior) over time, leading to VCD. Therefore, brand owners can improve their cost control and resource integration capabilities, while setting up reasonable incentive mechanisms in virtual brand communities to increase customer willingness to invest resources, reduce the probability of customers choosing VCD behavior strategies, and thus reduce the occurrence of VCD in virtual brand communities.

5 Conclusion

5.1 Research Conclusion

Based on the perspective of evolutionary game theory, this study constructed a decision-support framework for VCD in virtual brand community, by building a brand customer VCD interactive

evolutionary game model and conducting data simulation analysis. By analyzing the impact of initial state on the evolutionary results and the influence of cost coefficient, resource investment willingness coefficient, and resource integration profitability coefficient on the evolutionary results, we further understand the strategic evolution process of brand and customer interaction in virtual brand communities. There are two equilibrium points in the brand customer VCD interactive evolutionary game: co-creation strategy and co-destruction behavior. An increase in cost coefficient, a decrease in resource investment willingness, and a decrease in resource integration profitability will all lead to VCD.

This study uses evolutionary game theory to analyze the equilibrium strategy of brand customer VCD interaction in virtual brand communities. From a game perspective, it confirms the coexistence of value co-creation and VCD in virtual brand communities, providing a new perspective for the study of VCD in virtual brand communities. This study analyzed the impact of parameter changes in evolutionary game models on simulation results and provided decision support for brands to reduce the possibility of joint destruction of virtual brand community value.

5.2 Managerial Decision Implications

Research has shown that an increase in the cost coefficient of a brand or customer, a decrease in the willingness to invest resources, and a decrease in the ability to integrate resources can all increase the probability of customer VCD behavior in virtual brand communities, leading to VCD. Therefore, the cost control and resource integration capabilities of a brand are key to preventing VCD. If a brand cannot effectively optimize incentive costs and manage resource allocation, it may lead to customer expectations being dashed or feeling unfairly treated, resulting in trust collapse and even large-scale negative information dissemination. Therefore, building a refined management decision-making system has become an inevitable choice for brands to overcome the dilemma of value co destruction and achieve the cultivation of a healthy community ecology.

This system aims to prevent VCD and promote value co-creation, with the fundamental goal of maintaining community health, optimizing resource efficiency, and enhancing customer trust. As key triggers for VCD, the three major risk sources of rising costs, weakened willingness to invest resources, and insufficient integration capabilities urgently require high brand attention and systematic control. Based on this, brands should focus on three core areas at the management decision-making level: establishing dynamic and refined cost and resource optimization mechanisms, building efficient response links for data and supply chain collaboration, and designing intelligent user incentives and layered operation strategies.

At the level of strategic execution, brands need to take data collaboration and cost control as the dual cores to promote the implementation of decisions. On the one hand, it is necessary to achieve deep integration of data closed-loop and flexible supply chain, and build an intelligent resource integration system. Specifically, brands should integrate multi-channel user data, operational data, and supply chain data online and offline, use intelligent analysis technology to draw accurate user profiles, accurately identify user demand preferences and satisfaction pain points, and feedback the demand analysis results to the supply chain management loop, driving the supply chain to achieve flexible adjustment and dynamic adaptation; At the same time, real-time feedback of supply chain operation data is provided to the data loop, continuously optimizing data models and decision-making logic, forming a virtuous cycle of "data integration demand analysis supply chain adaptation data iteration". On the other hand, brands should establish a refined cost control system based on dual track incentives and dynamic algorithms, taking into account both user incentive effects and

cost efficiency. Satisfy users' functional needs through material incentives such as equity exchange, point rewards and so on, combined with spiritual incentives such as exclusive identity, honor authentication, emotional interaction and so on, that meet users' emotional needs, and achieve the synergistic effect of dual incentives. By relying on dynamic reward algorithms and combining indicators such as user historical contribution, participation quality, and behavioral preferences, the incentive intensity and form are dynamically adjusted to improve user participation quality, guide users to convert to high-value groups, and prevent cost waste caused by incentive abuse, achieving the optimal match between incentive costs and user value.

To ensure the implementation of the above strategies, brands need to rely on intelligent data platforms, dynamic algorithm models, and cross system integration technologies, as well as corresponding evaluation and collaborative management mechanisms. Finally, by continuously monitoring key indicators such as VCD rate, user satisfaction, and incentive return rate, brands can provide feedback on evaluation results to the decision-making process, thereby continuously optimizing cost parameters, adjusting incentive strategies, and improving response processes, forming a management loop from goals to execution, and then from feedback to optimization.

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