Analysis of Quality Input Problems in Automobile Dealerships Based on a Tripartite Evolutionary Game

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Abstract. With the release of the potential of the automobile consumer market, the quality problems of automobile dealers are highlighted. Based on this status quo, an evolutionary game model of automobile suppliers, dealers and consumers is constructed using evolutionary game theory, the long-term evolutionary trend of the three parties' behavioural strategy choices is investigated, and simulation analysis is carried out using MATLAB software. It is found that the long-term stable behavioural strategies of dealers, consumers and auto suppliers are (quality input, rights protection, passive governance) and (quality input, rights protection, active governance). The cost of corporate governance and the cost of quality input from dealers are of major significance in influencing the behavioural strategies of automotive suppliers and dealers, while consumers' rights defending behaviours also play a key role.

Keywords: Dealers; Quality Inputs; Evolutionary Game.

1 Introduction

The automotive industry holds a significant position in the global economy and is an essential component of it. In 2023, China's auto sales exceeded 30 million units, reaching 30.094 million units, a year-on-year increase of 12%, demonstrating the continuous enthusiasm of the automotive consumer market. However, with the rapid development of the automotive economy, some problems that urgently need to be addressed have emerged. For instance, according to the data from the 12345 Government Hotline Service Center in Quzhou City, there were 568 complaints regarding automobile sales in the city in 2023, mainly involving issues such as vehicle quality, deposits, and after - sales service. Wang[1]used questionnaires to conclude that product quality has a positive impact on consumer loyalty. Zeng[2]pointed out that consumers' safety is directly affected by vehicle quality. Therefore, consumers' role in product quality supervision not only significantly influences enterprises' product quality strategic decisions[3],but also represents an inevitable path to improving the efficiency of product quality supervision.

Regarding research on quality supervision, Zhao[4] explored the influencing mechanisms of consumers and the government on enterprise quality supervision. Gao[5]

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found that recalls of defective medicines were accelerated under social media regulation. Xie[6] found that the quality of vaccines could be guaranteed under government regulation.

This paper aims to deeply analyze the tripartite relationship among automakers, dealers, and consumers, and explore its evolution from a game-theory perspective. In this system, each participant pursues the maximization of its own interests, but inevitably affected by the behavior of other participants, and ultimately the behavioral decisions of the participants will achieve a Nash equilibrium[7].By analyzing these game behaviors, we can better understand the automotive industry's internal dynamics, offering theoretical support and practical guidance for their cooperation and competition. This is crucial for promoting the industry's sustainable development.

2 Construction of the Evolutionary Game Model

2.1 Basic Assumptions

Assumption 1: The game involves three players: automakers, dealers, and consumers. Given the differences in accessible information, information-processing capabilities, and the complexity of situations they face, automakers, dealers, and consumers cannot make the optimal choice for "maximum profit". Thus, the three-party game is assumed to be a bounded-rationality game.

Assumption 2: the three-party players have different behavioral strategies. The automaker's strategies are "active governance" and "passive governance". "Active governance" means the automaker conducts full-process tracking and management of the dealer's operations, sales, and after-sales services, with a choice probability of $z(0\leq z\leq 1)$;"Passive governance" means the automaker compensates the dealer after receiving consumer complaints, with a choice probability of 1-z.The dealer's strategies are "quality investment" and "no-quality investment". "No-quality investment" means the dealer does not carry out quality-building activities to improve consumer satisfaction, with a choice probability of $x(0\leq x\leq 1)$;"Quality investment" is the opposite, with a probability of 1-x.The consumer's strategies are "rights-protection" and "no-rights-protection". "Rights-protection" means that when problems such as vehicle quality or after-sales issues are discovered, the consumer reports and complains to the automaker, with a probability of $y(0\leq y\leq 1)$;"No-rights-protection" means the consumer ignores the damage to their rights and interests, with a probability of 1-y.

Assumption 3:When the automaker adopts passive governance, its normal revenue is R, Active governance can increase sales and bring an additional revenue r, but incurs a governance cost n(approximately equal to the dealer's additional revenue). When the dealer makes "no-quality investment" and the automaker uses "passive governance", the automaker pays an additional loss cost c. The dealer's revenue from "no-quality investment" is T, “the cost of "quality investment" is u, and the fine for violations is m.Due to vehicle problems causing customer loss, the dealer's loss is aie(i=1,2),a1, a2 are the probabilities of problems occurring with and without quality investment respectively($a1<a2$).When vehicle problems occur, the automaker's reputation loss is aiMi($M1<M2$),and the customer-loss cost is Di($D1<D2$).The consumer

gains a functional benefit G from the vehicle, an emotional benefit Q, If the consumer discovers a problem but does not take rights-protection action, the loss is aiS1,and if taking rights-protection action, the loss is aiS2(S1<S2),When the consumer adopts the rights- protection strategy, a certain psychological satisfaction is obtained due to fulfilling social responsibility, denoted as K.

2.2 Model Construction

Based on the above assumptions, the payment matrix of the three-party evolutionary game among automakers, dealers, and consumers is constructed as shown in Table 1.

Table 1. Payment matrix of the tripartite game

dealer / consumer		No-quality investment(x)		Quality investment(1-x)	
		Rights-protection(y)	No-rights-protection(1-y)	Rights-protection(y)	No-rights-protection(1-y)
automaker	Active govern-ance(z)	T+n-a_2m-a_2e	T+n-a_2m	T-u+n-a_1m-a_1e	T-u+n-a_1m
		G-a_2S_2+K	Q-a_2S_1	G-a_1S_2+K	Q-a_1S_1
		R+r-n+a_2m-a_2M_1-D_1	R+r-n+a_2m-a_2M_1	R+r-n+a_1m-a_1M_1-D_1	R+r-n+a_1m-a_1M_1
	Passive govern-ance(1-z)	T-a_2m-a_2e	T-a_2m	T-a_1m-a_1e	T-a_1m
		G-a_2S_2+K	Q-a_2S_1	G-a_1S_2+K	Q-a_1S_1
		R+a_2m-c-a_2M_2-D_2	R+a_2m-c-a_2M_2	R+a_1m-a_1M_2-D_2	R+a_1m-a_1M_2

3 Model Analysis

3.1 Solution of the Three - Party Game Model and Evolutionary Stability Analysis

Based on the above pay - off matrix, we first calculate the expected pay-off function of the dealer. Let the expected pay-offs when the dealer chooses the strategies of "no-quality investment" and "quality investment" be E1 and E2respectively, and the average pay - off be $\overline{E}$.Then we have:

$$E1 = yz(T+n-a2m-a2e)+y(1-z)(T-a2m-a2e)+(1-y)z(T+n-a2m)+(1-y)(1-z)(T-a2m) \quad (1)$$

$$E2 = yz(T-u+n-a1m-a1e)+y(1-z)(T-a1m-a1e)+(1-y)z(T-u+n-a1m)+(1-y)(1-z)(T-a1m) \quad (2)$$

$$\overline{E} = xE1+(1-x)E2 \quad (3)$$

Therefore, the replicator-dynamic equation of the dealer is:

$$F(x) = \frac{dx}{dt} = x(1-x)(E1-E2)=x(1-x)[(a1-a2)m+uz+(a2-a1)ey] \quad (4)$$

Similarly, the replicator - dynamic equations of the other two players, the consum-

er's F(y) and the automaker's F(z), can be obtained as follows:

$$F(y) = y(1-y)[G+K-Q+(S2-S1)a1+(S1-S2)(a1+a2)x+(2a1S1-2a1S2)z+(2a1S2-2a1S1)xz] \quad (5)$$

$$F(z) = z(z-1)[n-r+(M1-M2)a1+(D1-D2)y+(a2M1+a1M2-a1M1-a2M2)x] \quad (6)$$

3.2 Analysis of the Three - Party Evolutionary Path and Stability

According to the stability theorem of differential equations, if a certain strategy adopted by the game players is in a stable state, the probabilities x, y and z of the dealer, the consumer, and the automaker choosing this strategy need to meet the following conditions respectively:

F(x)=0,$\frac{\partial F(x)}{\partial x}$<0, F(y)=0,<0, F(z)=0,$\frac{\partial F(z)}{\partial z}$<0

Where,

$$\frac{\partial F(x)}{\partial x} = (1-2x)[(a1-a2)m+uz+(a2-a1)ey] \quad (7)$$

$$\frac{\partial F(y)}{\partial y} = (1-2y)[(G+K-Q+(S2-S1)a1+(S1-S2)(a1+a2)x+(2a1S1-2a1S2)z+(2a1S2-2a1S1)xz] \quad (8)$$

$$\frac{\partial F(z)}{\partial z} = (2z-1)[n-r+(M1-M2)a1+(D1-D2)y+(M2-M1)(a1-a2)x] \quad (9)$$

(1) Analysis of the Dealer's Evolutionary Path

Let G(y)=(a1-a2)m + uz + (a2-a1)ey, Since $\frac{\partial G(y)}{\partial y}$>0,G(y) is an increasing function of y. So when y=[-(a1-a2)m+uz]/ (a2-a1)e=y*,F(x)=0 and $\frac{\partial F(x)}{\partial x}$=0.At this time, the dealer cannot determine a stable strategy. When y<y*, G(y)<0, So at this time x=0, $\frac{\partial F(x)}{\partial x}$<0 is the evolutionary stable strategy (ESS) of the dealer. When y>y*,G(y)>0, So at this time, x=1, $\frac{\partial F(x)}{\partial x}$<0 is the ESS of the dealer. Figure 1 shows the phase diagram of the dealer's strategy evolution.

(2)Analysis of the Consumer's Evolutionary Path

Let G(z)=(G+K-Q+(S2-S1)a1+(S1-S2)(a1+a2)x +(2a1S1-2a1S2)z +(2a1S2-2a1S1)xz, Since$\frac{\partial G(z)}{\partial z}$<0,G(z) is a decreasing function of z. So when z=[-(G+K-Q+(S2-S1)a1+(S1-S2)(a1+a2)x]/(2a1S2-2a1S1)x=z**,F(y)=0 and $\frac{\partial F(y)}{\partial y}$=0.At this moment, the consumer cannot determine a stable strategy. When z<z**,G(z)>0.So at this time, y=1, $\frac{\partial F(y)}{\partial y}$<0 is the evolutionary stable strategy (ESS) of the consumer. Similarly, when z>z**,y=0 is the ESS.Figure 2 shows the phase diagram of the consumer's strategy evolution.

(3) Analysis of the Automaker's Evolutionary Path

Let G(x)=n-r+(M1-M2)a1+(D1-D2)y+(M2-M1)(a1-a2)x, Since $\frac{\partial G(x)}{\partial x}$<0, so G(x)is a decreasing function of x. So when

x=[r-n-(M1-M2)a1-(D1-D2)y]/(M2-M1)(a1-a2)=x*,F(z)=0 and $\frac{\partial F(z)}{\partial z}$ =0.Thus, the automaker cannot determine a stable strategy at this point. When x<x*, G(x)>0.So at this time, z=0, $\frac{\partial F(z)}{\partial z}$<0 is the evolutionary stable strategy (ESS) of the automaker. Similarly, when x>x*,G(x)<0.So at this time, z=1, $\frac{\partial F(z)}{\partial z}$<0 is the ESS of the automaker. Figure 3 shows the phase diagram of the automaker's strategy evolution.

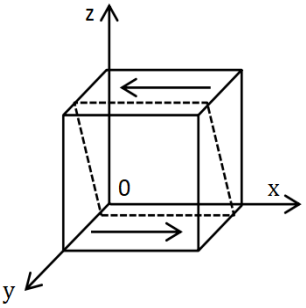

Fig. 1. Phase diagram of dealer strategy evolution

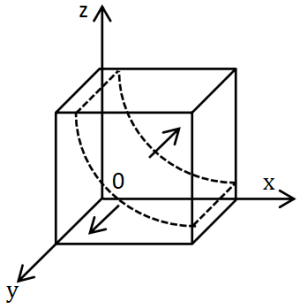

Fig. 2. Phase diagram of consumer strategy evolution

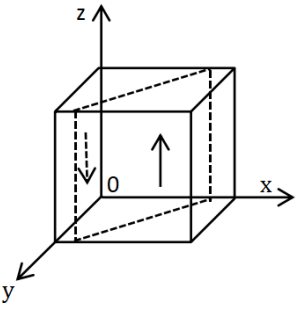

Fig. 3. Phase diagram of automotive supplier strategy evolution

3.3 Stability Analysis of the Equilibrium Points of the Three - Party Evolutionary Game System

The stability of the system is analyzed through the Jacobian matrix. The Jacobian matrix J of the three-party game system among automakers, dealers, and consumers is:

$$J=\begin{pmatrix} \frac{\partial F(x)}{\partial x} & \frac{\partial F(x)}{\partial y} & \frac{\partial F(x)}{\partial z} \\ \frac{\partial F(y)}{\partial x} & \frac{\partial F(y)}{\partial y} & \frac{\partial F(y)}{\partial z} \\ \frac{\partial F(z)}{\partial x} & \frac{\partial F(z)}{\partial y} & \frac{\partial F(z)}{\partial z} \end{pmatrix}=\begin{pmatrix} n11 & n12 & n13 \\ n21 & n22 & n23 \\ n31 & n32 & n33 \end{pmatrix} \tag{10}$$

The values of n11, n12, n13, n21, n22, n23, n31, n32, n33 are obtained as follows:

$$n11=(1-2x)[(a1-a2)m+uz+(a2-a1)ey] \tag{11}$$

$$n12=x(1-x)(a2-a1)e \tag{12}$$

$$n13=x(1-x)u \tag{13}$$

$$n21=y(1-y)[(S1-S2)(a1+a2)+(2a1S2-2a1S1)z] \tag{14}$$

$$n22=(1-2y)[(G+K-Q+(S2-S1)a1+(S1-S2)(a1+a2)x+(2a1S1-2a1S2)z+(2a1S2-2a1S1)xz] \tag{15}$$

$$n23=(1-2y)[(2a1S1-2a1S2)+(2a1S2-2a1S1)x] \tag{16}$$

$$n31=z(z-1)[(M2-M1)(a1-a2)] \tag{17}$$

$$n32=z(z-1)(D1-D2) \tag{18}$$

$$n33=(2z-1)[n-r+(M1-M2)a1+(D1-D2)y+(M2-M1)(a1-a2)x] \tag{19}$$

According to the research conclusions of Ritzberger and Weibull, we can simplify the analysis of the evolutionary game model by only considering the asymptotic stability of the eight possible equilibrium points of the replicator - dynamic equations.

This paper studies how automakers and consumers can jointly govern the "no - quality investment" behavior of auto dealers. When looking for the optimal stable points, we find that the evolutionary stable strategies of auto dealers tend to "no - quality investment" and those of consumers tend to "no-rights-protection", which are not the main focuses of this paper. Therefore, this paper mainly focuses on the two stable states of (quality investment, rights - protection, passive governance) and (quality investment, rights - protection, active governance), i.e., the equilibrium points E3(0,1,0) and E7(0,1,1).

(1)Stability Analysis of the Equilibrium Point E3(0,1,0)

The conditions for the stability of the equilibrium point E3 need to satisfy the following three requirements simultaneously: e<m; Q-K-G<a1(S2-S1); D1-D2+(M1-M2)a1>r-n.

For automakers, when the net revenue obtained by adopting the active strategy is less than the overall comparison of the reputation loss and customer - loss loss caused by the two different governance strategies, automakers tend to adopt the "passive governance" strategy. To maximize profits, automakers will govern their dealers after consumers' rights - protection actions.

For consumers, when the difference between the emotional benefit and the sum of the car-purchase benefit and rights-protection benefit is less than the comparison of the utility losses caused by the "rights - protection" and "no-rights-protection" strategies, consumers have the motivation to cooperate with automakers in the joint governance of dealers.

For dealers, when the loss caused by customer loss due to problems is less than the fine that dealers need to pay to automakers after violations, dealers tend to adopt the "quality investment" strategy.

(2)Stability Analysis of the Equilibrium Point

The conditions for the stability of the equilibrium point E7 need to satisfy the following three requirements simultaneously: Q-K-G<(S1-S2)a1; u<(a2-a1)(m-e); D1-D2+(M1-M2)a1<r-n

For automakers, this is exactly the opposite of the equilibrium point E3. When the net revenue obtained by automakers is greater than the overall comparison of the reputation loss and customer - loss loss caused by the two different governance strategies, automakers tend to adopt the "active governance" strategy. To maximize profits, automakers will govern their dealers.

For consumers, when the difference between the emotional benefit and the sum of the car - purchase benefit and rights - protection benefit is greater than the comparison of the utility losses caused by the "rights - protection" and "no-rights-protection" strategies, consumers have the motivation to protect their rights.

For dealers, when the cost paid after quality investment is less than the comparison of the customer-loss loss and fine loss caused by the two different governance strategies when problems occur, dealers have the motivation to adopt the "quality investment" strategy.

4 Model Simulation

By using MATLAB to simulate the evolutionary game model, we can intuitively reflect the model's evolutionary process and find its stable state.

According to the relevant literature of the equilibrium point E3(0,1,0) and the actual situation, we give array1:R=80, r=20, n=30, c=30, T=50, u=10, m=10, e=5, G=10, Q=7, S1=1, S2=2, K=3, M1=5, M2=8, D1=6, D2=10, a1=0.4, a2=0.8.We use MATLAB software to conduct a numerical simulation on array 1, and the simulation results are shown in Figure 4. Three groups of initial values, 0.4, 0.5, and 0.6, are selected. However, regardless of the initial values, the probabilities of automakers adopting the "active governance" strategy and dealers adopting the "no - quality investment" strategy will gradually decrease. Meanwhile, under the influence of the above two strategies, consumers' strategies will stabilize at the "rights - protection"

strategy. Eventually, the three parties will evolve stably to the equilibrium point E3(0,1,0). In the initial stage, when automakers have a high probability of choosing passive governance, dealers tend to choose no - quality investment. When consumers start to protect their rights due to the decrease in their perceived benefits, under the coordinated governance of consumers and automakers, dealers' strategies will quickly shift to "quality investment". This indicates that the combined mechanism of automakers and consumers can effectively regulate dealers' behaviors.

Based on the equilibrium point E7(0,1,1),we adjust array 1 to get array 2:R=80, r=20, n=20, c=30, T=50, u=1, m=10, e=5, G=10, Q=7, S1=1, S2=2, K=3, M1=5, M2=8, D1=6, D2=10, a1=0.4, a2=0.8.The simulation results are shown in Figure 5. As the number of evolutionary iterations increases, regardless of the initial proportions, the strategies of dealers and consumers evolve in the same way as in array 1, converging to the "quality investment" and "rights - protection" strategies respectively. With the increase in the reputation loss and customer - loss loss caused by automakers' "passive governance" strategy, the decrease in the obtained revenue, and the further reduction of the active governance cost, the proportion of automakers adopting the "active governance" strategy continuously increases and gradually converges to this strategy. Eventually, the evolutionary stable point of the three parties is(0,1,1),which represents a relatively rational stable state.

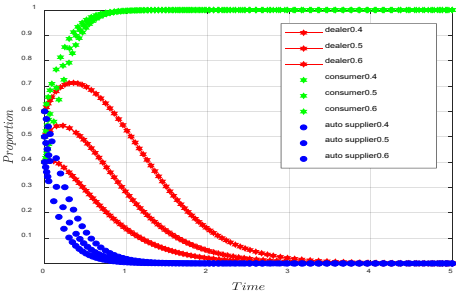

Fig. 4. Simulation of evolution of array 1

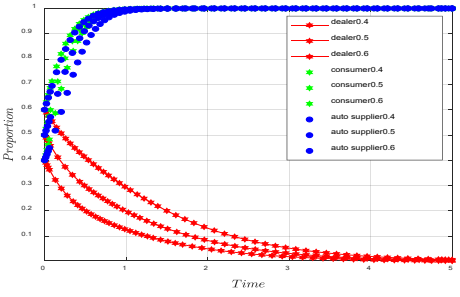

Fig. 5. Simulation of evolution of array 2

5 Summary and Discussion

5.1 Conclusion

By weighing revenues and losses, a game model among automakers, dealers, and consumers was developed to address the issue of dealers' lack of quality investment. A thorough analysis was conducted on the strategy choices of each participant, and the stability of these choices and the equilibrium strategy combination of the entire game system was explored. Simulation analysis verified the validity of the research findings and identified the conditions for the emergence of stable strategy combinations. Based on these conditions, relevant countermeasures and suggestions for supervising dealers' quality investment were proposed.

5.2 Management Insights

(1) Auto Dealers: Increased consumer feedback, complaints, and automaker governance raise the risk of fraud detection, reducing dealers' net revenue and pushing them to invest in quality. Growing consumer rights awareness also pressures dealers to improve quality to avoid customer loss and penalties from automakers.

(2) Consumers: The decision to protect rights hinges on functional versus emotional benefits. Pragmatic consumers prioritize functional attributes and are more likely to act, while others may tolerate low quality. Rising awareness of rights and social responsibility encourages rights-protection behaviors, offering psychological comfort.

(3) Automakers: Passive governance may boost short-term profits but risks reputation damage and customer loss from quality scandals. High rights-awareness among consumers can lead to significant customer loss. As active governance costs decrease and passive governance costs rise, automakers are incentivized to adopt active governance strategies.

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