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Research Article

Marketing Resource Allocation Strategy Optimization Based on Dynamic Game Model

Yan Long [1] and Hongshan Zhao [2]

[1] *Geely Automotive Institute, Hangzhou Vocational & Technical College, Hangzhou 310018, China*
[2] *Institute of Business and Tourism, Hangzhou Vocational & Technical College, Hangzhou 310018, China*

Correspondence should be addressed to Yan Long; 2007010016@hzvtc.edu.cn

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Game theory has become an important tool to study the competition between oligopolistic enterprises. After combing the existing literature, it is found that there is no research combining two-stage game and nonlinear dynamics to analyze the competition between enterprises for advertising. Therefore, this paper establishes a two-stage game model to discuss the effect of the degree of firms' advertising input on their profits. And the complexity of the system is analyzed using nonlinear dynamics. This paper analyzes and studies the dynamic game for two types of application network models: data transmission model and transportation network model. Under the time-gap ALOHA protocol, the noncooperative behavior of the insiders in the dynamic data transmission stochastic game is examined as well as the cooperative behavior. In this paper, the existence of Nash equilibrium and its solution algorithm are proved in the noncooperative case, and the "subgame consistency" of the cooperative solution (Shapley value) is discussed in the cooperative case, and the cooperative solution satisfying the subgame consistency is obtained by constructing the "allocation compensation procedure." The cooperative solution is obtained by constructing the "allocation compensation procedure" to satisfy the subgame consistency. In this paper, we propose to classify the packets transmitted by the source nodes, and by changing the strategy of the source nodes at the states with different kinds of packets, we find that the equilibrium payment of the insider increases in the noncooperative game with the addition of the "wait" strategy. In the transportation dynamic network model, the problem of passenger flow distribution and the selection of service parameters of transportation companies are also studied, and a two-stage game theoretical model is proposed to solve the equilibrium price and optimal parameters under Wardrop's criterion.

1. Introduction

In the last two decades, with the emergence and development of network games, the game theory topics of studying the generation and evolution of networks, the interaction of strategies, and their dynamic processes in the network environment have gained critical progress [1]. The introduction of network games in the theoretical system of the economic field has achieved great success, which has set off a boom in the study of network games. We can foresee that the study of network games can help in understanding such important phenomena as macroeconomic fluctuations and cycles, contagion and risks in economic and social systems, changes in the development of the economy, development patterns of international trade, social unemployment, and inequality. In recent years, wireless networks have undergone a radical change, evolving from a technical term to a part of our daily life that is closely related to us [2]. The need for individual nodes in a network to share a transmission medium when performing data transmission is an important feature of wireless networks. Therefore, when two or even more network nodes perform data transmission at the same time, the destination node of the data transmission receives multiple transmitted data, and at this time, the destination node may not be able to distinguish between these simultaneously arriving transmitted data. Eventually, the data transmissions from all nodes in the network are not properly received by the destination node, a phenomenon we call data transmission conflict or data transmission interference [3]. Therefore, designing algorithms that allow efficient data transmission and avoid data transmission conflicts becomes an extremely important aspect of operating a wireless network, and we classify such algorithms into centralized and distributed algorithms. The centralized algorithms perform global control that regulates the activities of all nodes, for example, cellular networks. In the distributed algorithms, on the contrary, the network nodes can determine their own activity times based on local information, e.g., wireless local area networks [4].

There is a long history of research on media access control protocols, such as the time-gap ALOHA protocol, using game theory. Many articles have analyzed the noncooperative behavior of nodes in time-gap ALOHA networks. Grover et al. investigated the problem of distributing the total cooperative revenue and analyzes the effect of three different cooperative solutions, namely, core, Shapley, and compromise, on the network throughput. Using stochastic game theory, this paper investigated the data transmission model for regulating the behavior of nodes in the network by the time slot ALOHA protocol [5]. A stochastic game is a game played at each stage, where the insider plays a matrix game against the insider at each stage, called the state, and the state at the first stage depends on the actions of the insider at the stage and at the stage before that. In this paper, we consider a stochastic game in which the insiders use static strategies. The article proves that any zero-sum game with discounted perfect information has the same value by introducing a discount factor to calculate the payoff of the insider [6]. The article also proves that the static strategy is the optimal one for the insider under the stochastic game, which means that the insider's strategy depends only on the current state and is independent of the historical state of the game. In this paper, we assume that the nodes in the network have a buffer for storing the packets that were not successfully sent in the previous time slot phase due to data transmission conflicts and the new packets generated in the current time slot phase [7]. In this paper, it is assumed that each relay node in the network has a buffer, the source node can transmit the packets directly to the destination node or transmit the packets to the relay node, and then the relay node transmits them to the destination node. In the paper, it is assumed that the relay node rejects the packet from the source node when the packet is present in the buffer of the relay node, which leads to the problem of incomplete use of the transmission channel. This model is improved by assuming that the relay node has two different types of buffers for receiving packets from the source node and storing its own generated packets. In this way, packets from the source node can be received normally even if there are packets in the buffers of the relay node, which improves the efficiency of the transmission channel usage [8]. In a network without relay nodes, it is assumed that each source node in the network has a buffer and the source node transmits packets with different probabilities in two different states of full and empty buffers. In this paper, we study the data transmission network without relay nodes. Unlike the article, this paper does not focus on the buffers of source nodes being full or not full but considers the packets being transmitted to be classified [9]. At this point, when there are multiple types of packets in the buffer of the source node, the probability of different kinds of packets being transmitted is different. As with most articles on stochastic games, this paper addresses the noncooperative behavior of the insiders [10]. In the noncooperative case, the Nash equilibrium is taken as the noncooperative solution and is solved according to the Lemke–Howson algorithm [11]. On the contrary, the cooperative game enables an effective analysis of node behavior when source nodes in the network collaborate to transmit packets [12]. In recent years, a number of scientists have dealt with these issues. Researchers have developed a duopoly model with interfirm externalities and analyzed the multistability of the system.

A similar stability criterion in dynamic cooperative stochastic games is what we call "subgame consistency." We call a solution subgame consistent if in each subgame, the solution to the game can be determined by the same allocation [13]. That is, if the insiders choose the solution of the whole game, then they will also use this solution in any subgame. Subgame inconsistency means that, in some subgames, it is not optimal to use the payment allocation specified at the beginning of the game [14]. This is because the insiders calculate the payoffs according to their stage payment functions and then the payment allocation rules may change over time.

For this reason, this paper constructs a two-stage theoretical model of the game. In the first stage of the game, each transportation company chooses their service parameters; in the second stage of the game, each transportation company chooses their service price, and each passenger chooses the transportation vehicle provided by the transportation company that minimizes his or her travel cost.

In this paper, we propose to classify the packets transmitted by the source nodes, and by changing the strategy of the source nodes at the states with different kinds of packets, we find that the equilibrium payment of the insider increases in the noncooperative game with the addition of the "wait" strategy.

In the transportation dynamic network model, the problem of passenger flow distribution and the selection of service parameters of transportation companies are also studied. The decisions of the "leaders" are fixed. According to this approach, solving the transportation model constructed in this paper, each insider is represented as two different "agents," a "leader agent" and a "follower agent." In this case, the "leading agent" is responsible for deciding the service parameters, and the "following agent" is responsible for deciding the service price. By applying this approach, the equilibrium price and the optimal service parameters are solved, and the results are compared by numerical simulations.

2. Related Work

The researchers have developed a differentiated game model with advertising distributors based on differentiated products. The researchers have developed a stochastic differential model for advertising competition between unsafe companies. The researchers created and analyzed a dynamic advertising model with spillover effects. The researchers analyzed the dynamic advertising strategies of the companies and their corresponding impact on the industry environment [15]. One of the problems that dynamic models face is complexity. Economic and sociological models are in fact always very complex because they relate to the decisions of a finite number of rational people. The complexity of the advertising competition model as an economic model has also attracted the attention of many scientists. The researchers have expanded the static model of Krishnamurthy to a dynamic model and discussed the dynamic complexity of the developed model [16]. Thus the researchers developed a nonlinear Cournot-2 oligarchy model using advertising and described the behavior of local and global dynamics in the model. The researchers developed an advertising model with multiple occupations and nonlinear costs, noting that the cause of the chaos has no advantage over its competitors when it enters the chaos.

Since the above model only takes into account the effects of advertising revenue on profit, the constructed model is only a one-tier game model. In recent years, more and more scientists have been involved in the two-stage game of companies. However, few scientists have chosen the two-stage dynamic game approach to analyze the complexity of advertising competition between companies, so that this area is worth further investigation. Another important issue of nonlinear dynamics is global dynamics, synchronization, and multistability. In recent years, a number of scientists have dealt with these issues [17]. Researchers have developed a duopoly model with interfirm externalities and analyzed the multistability of the system. Researchers found that the global dynamics behavior becomes more complex when multistability occurs. Scholars then investigated synchronization and intermittency phenomena in two-dimensional discrete dynamical systems. Researchers have studied the intermittent phenomena between synchronization and desynchronization that occur in systems when firms operate cross-regional operations. In summary, both domestic and foreign scholars have contributed to the study of oligopoly games. From static games to dynamic games, and then combining dynamic games with nonlinear theory, new ideas and methods are gradually proposed for the study of game theory [18].

The maturity of computer technology has made numerical simulation an important tool for studying the evolution of oligopolistic games. However, this aspect is not perfect, and there are some issues to be studied [19]. Other scholars have studied advertising competition using static and dynamic games, respectively, and there are also studies using numerical simulations to analyze oligopoly models. However, few scholars have combined these methods to analyze and discuss the advertising competition strategies among oligopolistic firms. Moreover, most of the studies only unilaterally consider the impact of advertising input on profits and establish one-stage game models [20, 21]. However, in the actual economic market, not only the relationship between sales and advertising is dynamic, but also the advertising competition among enterprises. Therefore, under the influence of these factors, we establish a two-stage dynamic game model to analyze the dynamic evolution, and complexity of advertising competition between enterprises has positive research value. In fact, two-stage game theory has been applied to decision problems in many fields, such as networks and communications [22].

3. Dynamic Game-Based Marketing Resource Allocation

3.1. Marketing Advertising Competition Model. A small change in the initial value will result in an exponential multiplication of the difference between the tracks of two identical systems, making it difficult for synchronization to occur between two separated or even identical systems. Therefore, whether and when the systems are synchronized is another subject that we will be concerned with. Since the stability or chaos of a system has a crucial effect on equilibrium competition, the effect on system stability when firms' behavior converges can be explained by studying the phenomenon of system synchronization. In the following, it is assumed that two firms have the same speed of adjustment, and the subsequent analysis is based on $v1 = v2 = v$. At this point, the behavior of the two firms is identical, and the mapping T is equivalent to

$$\begin{aligned} \widetilde{A} &= \sum_{i=0}^{n} \oiint_{i=0,j=1} \mu_A\left(x_{ij}\right), \\ \widetilde{A} &= \frac{\sum_{i=0}^{n} \mu_A\left(a_{ii}\right)}{q_{ij} + p_{ij}}. \end{aligned} \tag{1}$$

It can be shown that the mapping T' has symmetry, i.e., there exists a mapping S: $(x1, x2)$ such that $T * S = S * T$, and furthermore, if we let $x1\ (t) = x2\ (t)$, we have $x1\ (t+1) = x2\ (t+1)$. The symmetry of T' implies that the diagonal is an invariant manifold of the system, so we have that T belongs to the system. However, synchronization may occur when there is a one-dimensional invariant manifold of the system. Therefore, the synchronization phenomenon of the system is analyzed by discussing the invariant set, as shown in Figure 1.

Invariant manifolds, also known as invariant sets, are an important basis for the study of synchronous phenomena:

$$f_{ij}(x) = \begin{cases} e^{\left(\left(\mathrm{d}Q_i/\mathrm{d}t\right)-\left(\mathrm{d}Q_j/\mathrm{d}t\right)\right)}, \dfrac{\mathrm{d}Q_i}{dt} < \dfrac{\mathrm{d}Q_j}{dt}, \\ e^{\left(\left(dQ^*/\mathrm{d}t\right)-\left(\mathrm{d}Q_j/\mathrm{d}t\right)\right)}, \dfrac{\mathrm{d}Q^*}{dt} < \dfrac{\mathrm{d}Q_j}{dt}. \end{cases} \tag{2}$$

That is, if we choose the initial conditions on the $x1$-axis, the dynamical behavior of the system on the $x1$-axis is controlled by the mapping. The mapping is equivalent to the standard logistic mapping topology through a linear transformation:

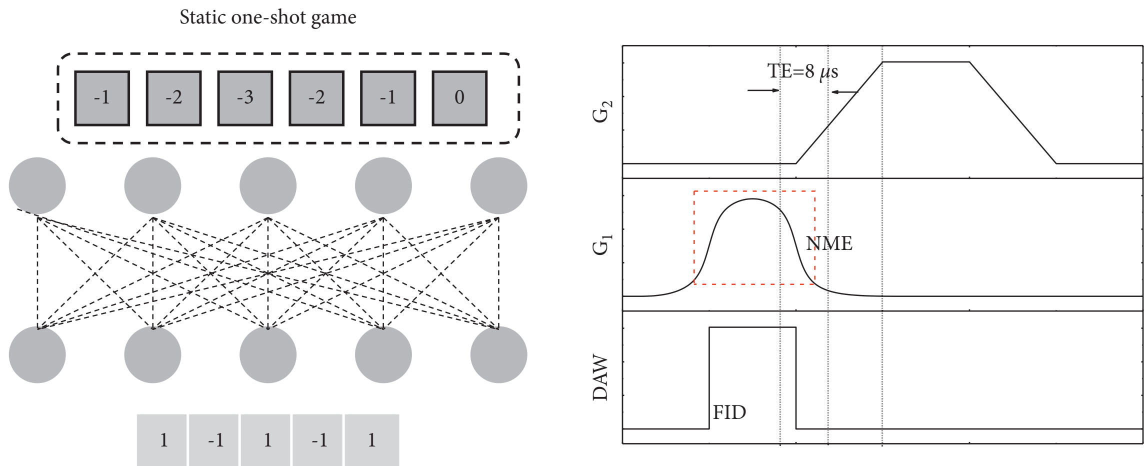

Figure 1: Data transfer in dynamic games.

$$y = f(x) = \frac{\exp(\mu_A(x) + \mu_B(x))}{\exp(\mu_A(x) - \mu_B(x))} \tag{3}$$

.

It can be shown that the diagonal is also an invariant set of the system, i.e., the trajectory starting at the diagonal will always remain on it, and we restrict the mapping T to the diagonal to discuss its dynamical behavior. Let $x1 = x2 = x$, and then it follows that the two-dimensional mapping is controlled on the diagonal by the following one-dimensional mapping:

$$t = \prod_{i=1}^{n-1} \prod_{j=i+1}^{n} q_{ij}, \tag{4}$$

then the mapping is transformed into a logistic mapping where

$$p = \min\{q_{ij}\}, i < j;\ i = 1, 2, \ldots, (n-1) \tag{5}$$

.

With the logistic mapping, we can clearly understand the dynamic behavior of the 2-dimensional mapping T' on the diagonal. We take the values of the logistic mapping at different bifurcation points, and we can get that the system flip bifurcates at $b = 3$, the Nash equilibrium point $*E$ loses stability, and a 2-cycle ring around $*E$ is formed:

$$W(\theta) = \sum_{i=1}^{T} \left[\sum_{k=1}^{3} \mathrm{v}_k c_k (u_{1t} \cdots u_{dt}; \theta_k) \right] \tag{6}$$

.

The 2-periodic ring is bifurcated by flip to produce a 4-periodic ring. The general track of the mapping is divergent, as shown in Figure 2.

3.2. Marketing Resource Allocation Based on Initial Value Sensitivity. We next investigate the change in system stability when the dynamical behavior of two firms is synchronized by multiple initial value bifurcations. For a nonlinear dynamical system, the final state is the focus of our attention, and its final state reflects the final behavior of the system. The final state is represented by an attractor, which is the asymptotic behavior of a nonlinear system as the number of iterations t tends to infinity. The set of points attracted to an attractor is called the basin of attraction of that attractor. We will discuss the effect of adjusting the speed v on the final behavior of the system by studying the attractors and their basins of attraction. The chaotic state suddenly changes to a 2-cycle state at $v = 0.998$. However, if we choose the initial conditions of $x_1 = 0.61$, then it is also given the parameter sets $a = c = 7.98, b = 2.01$, and $u = 4.11$ for the Nash equilibrium point. As shown in Figure 3, the kinetic behavior under different initial values is the same when $v = 0.998$.

However, the difference between these two graphs is that the system will not bifurcate abnormally as the parameter v increases. That is, after a series of multiplicative cycles of bifurcation, the system enters directly into the chaotic state and will remain chaotic. The choice of different initial values, i.e., different advertising inputs, leads to changes in the stability of the system. In the transportation dynamic network model, the problem of passenger flow distribution and the selection of service parameters of transportation companies are also studied. As can be seen from Figure 4, the firm is able to operate stably when the adjustment rate is low, i.e., the amount of advertising input does not change much.

3.3. Strategy Optimization. Previously, we analyzed the market state corresponding to system T by multiple initial value bifurcation and attraction basin. The adjustment speed of advertising input will have an impact on the system chaos or steady state, and different market states will affect the operation state of the enterprise and thus the enterprise profit. The goal of the enterprise is to maximize profit, so the enterprise cares about the strength of advertising input and the operation state. In the following, we analyze the relationship between advertising input and profit, and analyze the relationship between long-term profit and equilibrium profit when the system is in different states. If the fixed parameters $a = c = 4.98, b = 1.01$, and $u = 3.59$, the

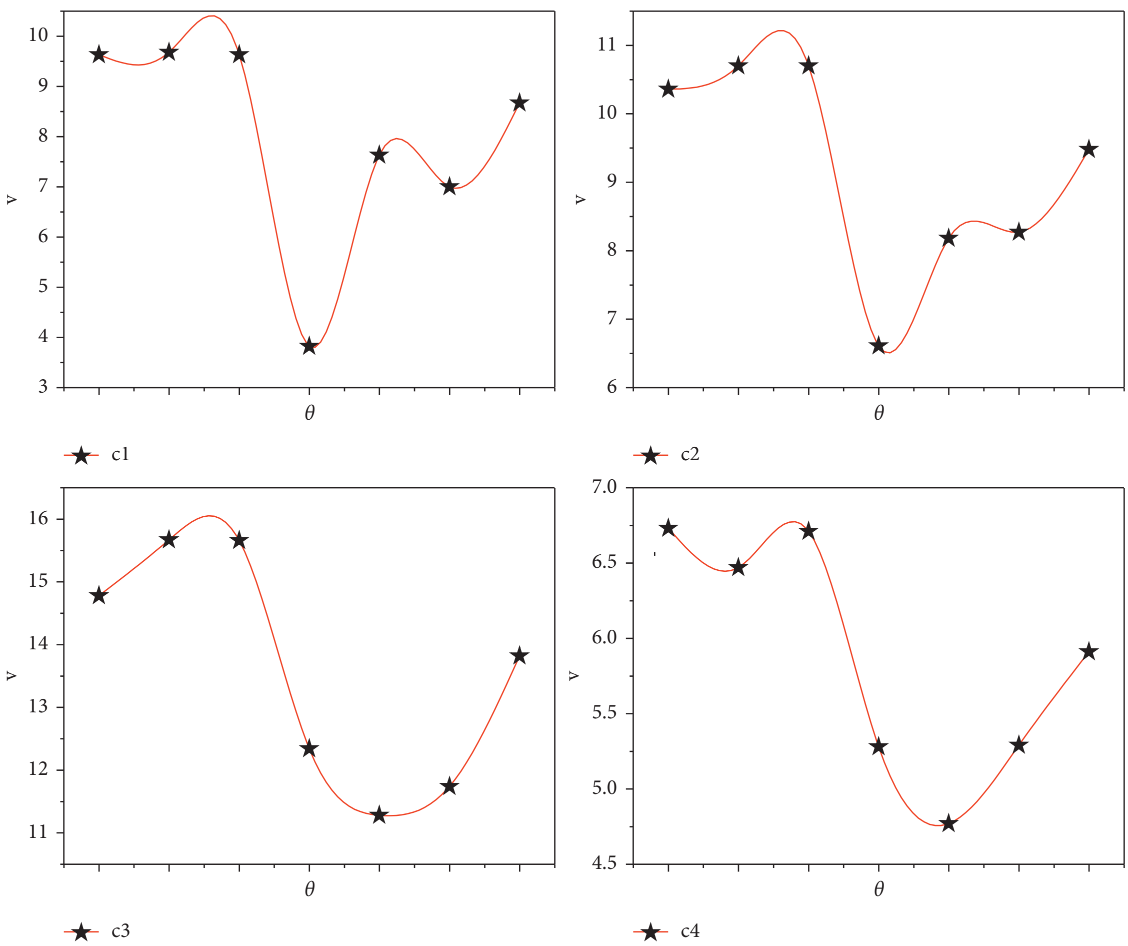

Figure 2: Bifurcation curves mapped on the parameter plane (θ, v) for fixed parameters $a-c=8.73$, $b=1.87$ and $u=3.93$.

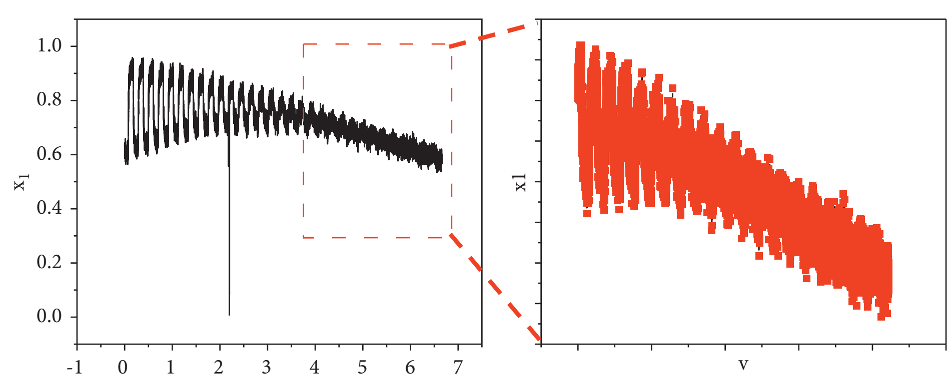

Figure 3: One-parameter bifurcation diagram of the system with respect to v for fixed parameters.

relationship between enterprise profit and the intensity of enterprise advertising is shown in Figure 5.

4. Example Analysis

On this basis, the local stability and stability conditions of each equilibrium point are discussed. For general information classification websites, advertising is directly related to traffic, and traffic means the number of users. But the situation is slightly different due to the special nature of used car e-commerce enterprises, where advertising implies not only traffic, but also brand. In front of a huge market opportunity, if you can win the brand with advertising, then advertising investment is something that is well worth doing for the business. In terms of traffic acquisition alone, advertising investment is also necessary. For example, the C2C model in the used car e-commerce industry is mainly from individuals to collect cars, lacking certain offline promoters,

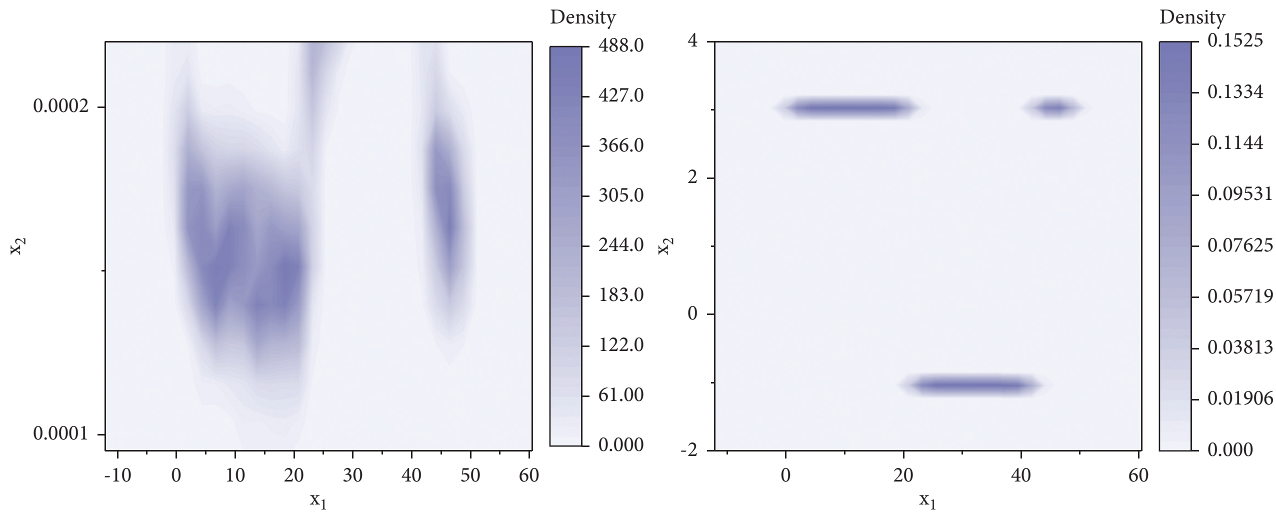

FIGURE 4: A set of attraction basins of the system with varying v.

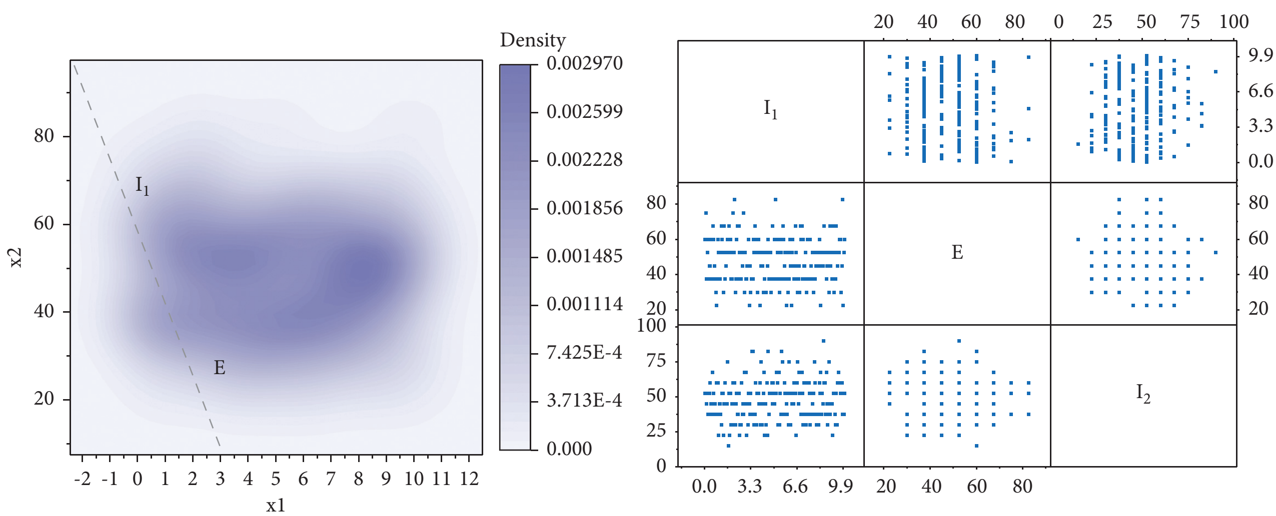

FIGURE 5: Contour through Nash equilibrium point E.

so online promotion and advertising is the main way that companies can get traffic. The importance of advertising for any used car e-commerce business is self-evident. Since 2014, a lot of capital has been invested into used car e-commerce businesses. The first thing you need to do is to solve the problem of who is the second-hand car dealer, that is, you need to do is to get a good idea of what you are getting into. The advertising car has achieved good results, and the major used car e-commerce companies have begun to have a certain degree of visibility, as shown in Figure 6. For a nonlinear dynamical system, the final state is the focus of our attention, and its final state reflects the final behavior of the system. The final state will be represented by an attractor, which is the asymptotic behavior of a nonlinear system as the number of iterations t tends to infinity.

The last issue studied in this chapter is the dynamic effect of parameters on corporate profits. Through the discussion of the firm's profit, we learn that when the firm's advertising effort is high enough, its profit may fall. Another thing that can be obtained is that although the firm's profit seems to be independent of the speed of adjustment, the firm's average profit may move up and down if the value of the speed of adjustment is changed, as shown in Figure 7. In addition, we find that the real cause of the decrease in the average profit is the excessive adjustment of the advertising input. Especially when the system is in a chaotic state, firms with slower adjustment speed can gain more profits. According to the data, most used car e-commerce companies have good brand awareness performance, and among them, the first in brand awareness is the earliest investment in advertising Youxin used car, awareness rate has exceeded 80%, and Guazi used car and RenRen car investment is relatively late but also reached more than 70% of the market awareness. The second thing is that the users know what the used car e-commerce companies are "doing." The fact that consumers can hear advertising slogans such as "no middlemen to earn the

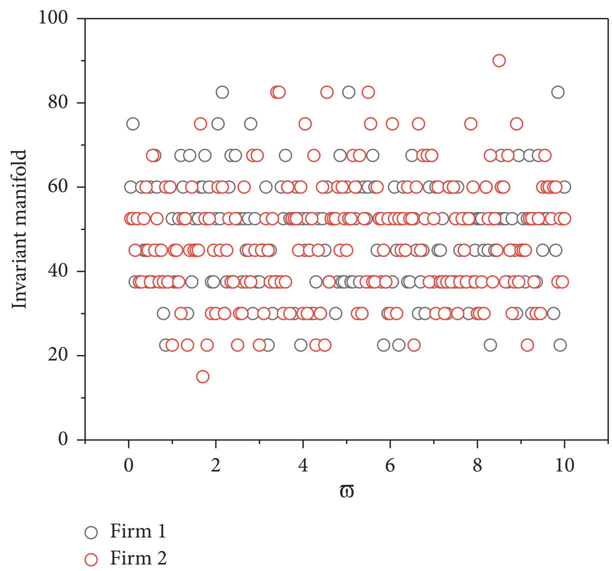

Figure 6: Premarketing strategy results.

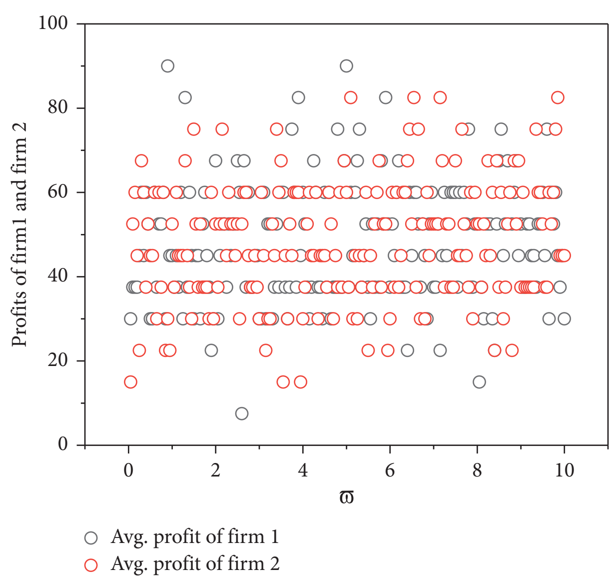

Figure 7: Marketing strategy optimization results.

difference" has eased their worries when buying used cars and has built up a certain word-of-mouth effect for used car e-commerce companies in the consumer market. The cost of running a used car e-commerce business is relatively high, but the business has not yet formed a stable and sustainable profit model.

Numerical simulation results show that excessive advertising investment makes the market unstable, and excessive advertising investment of used car e-commerce companies makes some of them exit the market. In 2017, Guazi used cars spent 500 million yuan on advertising, and RenRen intended to spend 800–1 billion yuan on advertising. Uxin used cars invested 2.203 billion yuan in sales and marketing alone. The practice of advertising a lot of used car e-commerce companies does help them expand their market size, but it also increases the cost of doing business. In fact, when used car e-commerce companies first enter the market, it is common practice to "burn money" on advertising to expand their influence. Although the advertising effect of enterprises such as Guazi used car, Youxin used car, and RenRen car is relatively good, but too much advertising investment makes the enterprises in a loss state, so a single-minded advertising is detrimental to the development of enterprises, which coincides with the results of numerical simulation. Influenced by the overall market environment, the transaction volume of used cars in 2018 showed a decreasing trend. A total of 1,118,800 used cars were traded nationwide, down 3.18% from the previous year. The traffic brought by the crazy money of used car e-commerce companies in advertising can hardly be directly transformed into turnover, and the user experience cannot be guaranteed. The advertising war makes the situation of "losing together" between companies. The company also needs to consider new problems with the huge investment in advertising, and companies need to finance. As of June 2019, the total financing of Guazi used car, Renren car, and Youxin three e-commerce platform is as follows: 3.324 billion dollars, 760 million dollars, and 1.815 billion dollars, respectively. After the huge amount of financing, the e-commerce platform must consider using the new retail model of online and offline connectivity to solve the difficulties of profitability and other problems.

5. Conclusion

For a long time, when investigating advertising competition between companies, scientists have generally only considered the impact of a company's advertising revenue on its profits, so that the current model is classy. This paper develops a two-stage commercial model with multiple occupations based on the Gounod model. First we analyze the strategy of the advertising competition, examine the stable range of the Nash equilibrium point through numerical simulations, and analyze the simultaneous dynamic behavior of the two companies on the basis of invariant quantities, critical curves, and cross-sectional Lyapunov exponents. The relationship between advertising inputs and firm profits is studied and illustrated with real-life examples. With the multiple initial value bifurcation as well as the attractor basin, the analysis concludes that the choice of different initial values, i.e., different amounts of advertising inputs, leads to a change in the stability of the system. Enterprises generally want to operate stably, so they generally do not make the rate of adjustment too large, meaning that the amount of advertising input does not change much from one period to the next. Companies will make advertising investment strategy within the range of advertising investment that can make the business operate stably. By discussing the impact of advertising investment on the profit of a company, we understand that when a company's advertising effort is too large, its profit may decline. If the adjustment rate of advertising is changed, the average profit of the firm may change up or down. Chaos is not always harmful to the market, and even firms that are slow to adjust their advertising inputs can profit from chaos.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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