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Research Article

The Impact of Service and Channel Integration on the Stability and Complexity of the Supply Chain

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This paper constructs a supply chain consisting of a manufacturer and a retailer. Considering channel integration and service cooperation, two dynamic Stackelberg game models are established: one without unit profit allocation (M) and the other one with unit profit allocation (M^{ε}). In two dynamic models, we analyze the influence of relevant parameters on the stability and complexity of the dynamic system and system profit by nonlinear system theory and numerical simulation. We find that the higher adjustment parameters can cause the system to lose stability, showing double period bifurcation or wave-shape chaos. The stable region becomes larger with increase in service value and value of unit profit sharing. Besides, when the system is in chaotic state, we find that the profit of the system will fluctuate or even decline sharply; however, keeping the parameters in a certain range is helpful in maintaining the system stability and is conducive to decision-makers to obtain steady profits. In order to control the chaos phenomenon, the state feedback method is employed to control the chaotic system well. This study provides some valuable significance to supply chain managers in channel integration and service cooperation.

1. Introduction

In recent years, the development of e-commerce has brought a strong impact on offline stores [1]. Customer volume migrates from offline to online on a large scale. In 2018, Tmall platform "double eleven" shopping carnival achieved a total turnover of 12135 billion yuan. This phenomenon is not conducive to the development of offline stores. However, online shopping also brings a series of problems. For example, when buying clothes online, we cannot see the real thing, the clothes we buy often cannot meet our needs, and even the phenomenon of returns occurs. It can be seen that online shopping sometimes cannot bring consumers a perfect shopping experience. Under this background, the retail mode of online order delivery and offline store purchase emerges as the times require, namely, channel integration. At present, JD, Tmall, and Suning have arranged offline retailer outlets to achieve effective integration of online and offline channels. In addition, the international fast fashion brand: UNIQLO and Zara also provides a perfect shopping experience for customers through channel integration. Relevant empirical research studies have proved that this mode not only meets the consumer's shopping needs but also increases the flow of customers in offline stores [2, 3].

Over the past few years, many scholars have conducted in-depth research on dual-channel and multichannel supply chains [4–6] but rarely pay attention to online and offline integration. Because of the conflict between traditional channel and online channel and the change of consumer demand, channel integration as an important model of omnichannel has gained significant interest among academics and practitioners [3, 7]. Through a questionnaire survey, Lin et al. [8] revealed that the drivers of innovation in channel integration are positively correlated with supply performance. The development of channel integration is inseparable from the support of information technology. Based on survey data from 125 multichannel retailers in Singapore, Oh et al. [9] found that retail channel integration enables enterprises to not only provide current products efficiently but also be innovative in creating future products through IT technology. Piotrowicz and Cuthbertson [10] discussed the influence of information technology on the development of channel integration from the technical level. On inventory research of channel integration, considering the randomness of demand, the inventory backlog cost, and the number of BOPS. Chen et al. [11] constructed and analyzed a stochastic equilibrium model. In an omnichannel supply chain, Du et al. [12] studied the impact of consumer disappointment and inventory on retailers' optimal pricing. Based on Gao and Su [13], Kusuda [14] considered the retailer's replenishment of inventory in an omnichannel strategy and found two types of equilibrium. Besides, in the omnichannel retailing, the characteristics of omnichannel retailers play an important role in consumers' response to cross-channel integration [15]. Jin et al. [16] analyzed the influence of orders from integration channels and customer arrival rate on the scale of offline service area.

The above research on channel integration focuses on the applicable conditions of information technology, channel inventory management, and adaptation scenario of channel integration and enriched the research of channel integration. In the channel operation, we find that consumers are increasingly demanding retail services during the shopping process. The relevant literature confirms that service factors have affected customer choice and shopping experience [17].

In the past few years, most of the research focuses on the impact of service factors on dual-channel and multichannel supply chains [18, 19]. In terms of channel coordination, retailers provide services to consumers in a dual-channel supply chain, which can reduce channel conflicts and improve the relationship with the manufacturer [20]. Channel competition is the inevitable result when a manufacturer adds a direct channel. Li and Li [21] discovered that retailers' value-added services help to alleviate this phenomenon, but when the retailer has fair concerns, the entire supply chain will conflict with fixed wholesale price. In supply chain decision making, Jena and Sarmah [22] constructed four price and service competition models consisting of two manufacturers and one retailer and analyzed the equilibrium decision and profit of each model. Considering service value, Zhang and Wang [23] studied the dynamic pricing strategy of dual-channel supply chain under centralized and decentralized conditions. It was found that, with increase in service value, the system stability decreases first and then increases. Considering price, service, and discount contracts, Sadjadi et al. [24] built a Stackelberg game model to analyze the equilibrium solution and found that service and price discounts can improve the performance of the supply chain. In addition, scholars have explored service competition and service contract issues [25]. When the manufacturer's warranty service competes with the retailer's value-added service, Dan et al. [26] found that when the manufacturer improves the level of warranty service, the competition of value-added service would be weakened. Considering the service factor, Li et al. [27] found that the stability of the low-carbon supply chain is related to sales service and player's behavior. Besides, Li et al. [28] established a dual-channel value chain and found that the channel service value and green innovation input would reduce the stability of supply chain.

The above research focuses on the research of the impact of services on the dual-channel supply chain. Few literature studies have been carried out on supply chain channel integration and service cooperation issues. In actual operation, the online and offline integration requires not only the support of information technology but also the close cooperation between members of the supply chain. In order to ensure that consumers get the corresponding services when picking up goods offline, manufacturers and retailers are required to cooperate with the service. In channel integration, how do manufacturer and retailer engage in service cooperation? How is the profit of the channel integration distributed?

It is worth noting that some scholars have recently employed nonlinear dynamics theory and numerical simulation to study supply chain problems and have obtained very good results [29, 30]. Ma and Xie [31] analyzed the dynamic behavior of dynamic game models under two scenarios and found that the stability of system depends on the channel type. Huang et al. [32] showed the smaller risk aversion attitude and fair concern coefficient will delay the occurrence of chaos in the system. In a closed-loop supply chain, Li et al. [33] analyzed the complexity entropy of the price game model with the recovery rate and service. Ma and Xie [34] focused on bundling goods and compared the dynamic price strategies under two different mechanisms. This paper also studies dynamic game models, which is a new model, with relatively little literature on integration channel service cooperation. Based on the nonlinear dynamic theory, this paper mainly focuses on the following issues: What impact does the different service cooperation model have on manufacturers and retailers? What impact does service value and unit profit sharing have on the dynamic behavior of the system?

Based on abovementioned factors, considering the channel integration and service factors, the main contributions of this paper are as follows:

(1) Based on service cooperation, the paper proposes two distribution modes of profit from channel integration, discusses the stability and complexity of the two modes, and provides a reference for decision makers of the integration channel

(2) The paper reveals the impact of service value and value of unit profit sharing on the dynamic evolution of the game model and the profits of decision-makers

(3) The paper applies nonlinear dynamic theory to the study of channel fusion and enriches the research in this field

The rest of this paper is organized as follows. In Section 2, we present the model description and assumptions. In Section 3, we set up a decentralized model without unit profit sharing (M) and give complexity analysis by numerical simulation. Section 4 sets up a decentralized model with unit profit sharing (M^{ε}) and performs the same dynamic analysis as in Section 3. In Section 5, we control the chaotic behavior of the system by employing the state feedback control method. Section 6 concludes this paper and proposes management insights.

2. Problem Description and Model Assumptions

2.1. Model Description. In this paper, we consider a supply chain consisting of one manufacturer and one retailer as shown in Figure 1, where three sales channels are described. On the one hand, the manufacturer sells the product to customers at p_1 by online channel and also sells them to the retailer at the wholesale price w. Then, the retailer, by traditional channel, resells productions to customers at p_2. On the other hand, in order to increase sales and improve customer experience, the integrated channel is established by the manufacturer and retailer where customers can browse products and pay order at p_1 online and pick up products at the retailer offline. Meanwhile, the retailer provides customer from traditional channel and integrated channel with service value s. In terms of profit from the integrated channel, there are two ways of distribution: one is the retailer obtains all the profits without unit profit sharing with the manufacturer and the other is the manufacturer obtains all the profit and shares unit profit ε with the retailer. Based on this, this paper builds two game models and carries out the complexity analysis of models.

2.2. Model Assumptions. Based on the real situation, the following hypothesizes are proposed in this paper:

(1) Online channel and integrated channel adopt the same price strategy, and consumers have channel preferences.

(2) There is a Stackelberg game with the manufacturer as the leader deciding on w and p_1 and retailer as the follower deciding on p_2.

(3) The service cost function of traditional channel can be described as $C_s = \eta s^2$, where $\eta = \eta'/2$. Due to the difference in service cost between the traditional channel and integrated channel, the service cost of the integrated channel can be described as φC_s, where $\varphi \in (0,1)$ is the service cost consistency coefficient.

The related variables and parameters are reported in Table 1.

3. Model without Unit Profit Sharing (*M*)

3.1. Static Model. In this static model, the retailer obtains all the profits of the integration channel without unit profit sharing with the manufacturer. The manufacturer is the leader of the market, and the retailer is the follower. The manufacturer firstly decides w and p_1. Correspondingly, the retailer makes decisions p_2 based on w and p_1.

Considering the service value and integration channel, based on the previous studies [26, 35], the demand functions for the three channels could be given as follows:

Online channel demand is

$$D_o = \theta_1 a - \rho_1 p_1 + \gamma_1 p_2. \quad (1)$$

Integration channel demand is

$$D_B = \theta_2 a - m_B(p_1 - s) + \gamma_1 p_2. \quad (2)$$

Traditional channel demand is

$$D_T = \theta_3 a - m_T(p_2 - s) + \gamma_1 p_1, \quad (3)$$

where $\theta_i, i = 1,2,3,$ meet $\sum_{i=0}^{3}\theta_i = 1$. $m_B > n_1\gamma_1, m_T > n_2\gamma_1$ and $\rho_1 > n_3\gamma_1\,(n_i > 2, i = 1,2,3)$ represent that the price elasticity coefficients are much larger than the cross price elasticity coefficients.

Therefore, the profit-maximizing functions of players can be expressed as follows:

$$\begin{aligned}\max_{p_1,w}\prod_m &= (w-c)\left[(\theta_2+\theta_3)a - m_B(p_1-s) - m_T(p_2-s) + \gamma_1(p_1+p_2)\right] \\ &\quad + (p_1-c)(\theta_1 a - \rho_1 p_1 + \gamma_1 p_2) \\ &\text{s.t. } w + \varphi\eta s^2 < p_1, c < w,\end{aligned} \quad (4)$$

$$\begin{aligned}\max_{p_2}\prod_r &= \left(p_2 - w - \eta s^2\right)\left[\theta_3 a - m_T(p_2-s) + \gamma_1 p_1\right] \\ &\quad + \left(p_1 - w - \varphi\eta s^2\right)\left[\theta_2 a - m_B(p_1-s) + \gamma_1 p_2\right] \\ &\text{s.t. } w + \eta s^2 < p_2.\end{aligned} \quad (5)$$

Proposition 1. *If the manufacturer and retailer pursue the profit maximizing in the supply chain with the integrated channel, their optimal decisions can be obtained as follows:*

$$\begin{cases} w^* = \dfrac{A_5A_4 - A_2A_6}{B_2^2 - B_3B_5}, \\ p_1^* = \dfrac{A_3A_6 - A_2A_4}{A_2^2 - A_3A_5}, \\ p_2^* = \dfrac{\gamma_1(B_3B_6 - B_2B_4)}{m_T(B_2^2 - B_3B_5)} + \dfrac{(m_T-\gamma_1)(B_5B_4 - B_2B_6)}{2m_T(B_2^2 - B_3B_5)} + B_1, \end{cases} \quad (6)$$

where

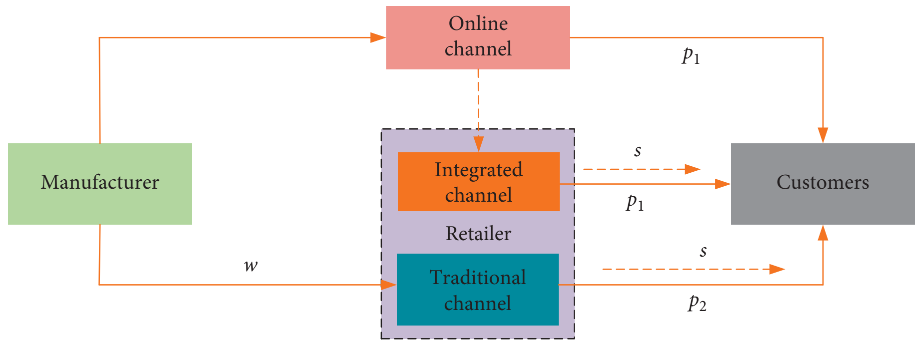


Figure 1: The supply model with the integrated channel.

Table 1: Key notations.

Variables	
D_O	Online channel demand
D_B	Integrated channel demand
D_T	Tradition channel demand
a	The potential market scale
θ_1	The customer's loyalty to the online channel
θ_2	The customer's loyalty to the integrated channel
θ_3	The customer's loyalty to the tradition channel
ρ_1	The elasticity coefficient of the online channel demand for price
m_B	The elasticity coefficient of the integrated channel demand for price
m_T	The elasticity coefficient of the tradition channel demand for price
γ_1	Cross price elasticity coefficient
w	The wholesale price
p_1	Retail price of products in the online channel and integrated channel
p_2	Retail price of products in the tradition channel
s	Service value
ε	Value of unit profit sharing
φ	The service cost consistency coefficient
η	The service cost parameter of the traditional channel
α_1	The limited rational adjustment parameter in model M
α_2	The adaptive adjustment parameter in model M
β_1	The limited rational adjustment parameter in model M^ε
β_2	The adaptive adjustment parameter in model M^ε

$$\begin{aligned}
A_1 &= \frac{\theta_3 a + m_T s + m_T \eta s^2 - \gamma_1 \varphi \eta s^2}{2m_T},\\
A_2 &= -m_B + \frac{\gamma_1}{2} + \frac{\gamma_1^2}{2m_T},\\
A_3 &= -m_T + 2\gamma_1 - \frac{\gamma_1^2}{m_T},\\
A_4 &= m_B s + m_T s - B_1\left(m_T - \gamma_1\right) + \frac{c}{2}\left(m_T - 3\gamma_1 + \frac{2\gamma_1^2}{m_T}\right) + a\theta_2 + a\theta_3,\\
A_5 &= \frac{2\gamma_1^2 - 2m_T\rho_1}{m_T},\\
A_6 &= \frac{A_1 m_T \gamma_1 + a m_T \theta_1 + c\left(m_B m_T - 2\gamma_1^2 + m_T \rho_1\right)}{m_T}.
\end{aligned} \tag{7}$$

Proof. See Appendix A.

Integrating equations (A.5) and (A.6) with equations (4) and (5), their estimated profit can be written as the following equation:

$$\begin{cases} \prod_m = (w^* - c)\left[(\theta_2 + \theta_3)a - m_B(p_1^* - s) - m_T(p_2^* - s) + \gamma_1(p_1^* + p_2^*)\right] + (p_1^* - c)(\theta_1 a - \rho_1 p_1^* + \gamma_1 p_2^*), \\ \prod_r = (p_1^* - w^* - \varphi\eta s^2)\left[\theta_2 a - m_B(p_1^* - s) + \gamma_1 p_2^*\right] + (p_2^* - w^* - \eta s^2)\left[\theta_3 a - m_T(p_2^* - s) + \gamma_1 p_1^*\right]. \end{cases} \quad (8)$$

□

3.2. Dynamic Model. The price game between competitors is a dynamic process. The changing market environment and product update will lead decision-makers to make new decisions for the next cycle, and each decision is not simply a repetition.

In reality, market participants are usually constrained by capital and other factors and cannot grasp the complete market information; therefore, their decisions are based on the bounded rationality and adaptive expectations in the current period. So, we build a dynamic price game model in which players employ different price adjustment strategies. The manufacturer adopts the limit rational expectation to make the wholesale price decision: $w_{t+1} = w_t + \alpha_1 w_t(\partial\prod_m(w_t, p_{1,t})/\partial w_t)$. If the marginal profit of the last period is negative, the manufacturer will reduce the price of the next period by adjusting α_1, otherwise, increase it. The manufacturer makes retail price decision based on adaptive expectations: $p_{1,t+1} = \alpha_2 p_{1,t} + (1-\alpha_2)p_1^*$. That is to say, the manufacturer adjusts the retail price of the next period on the basis of our period and the best reply function.

Therefore, the discrete dynamic system can be modeled as

$$\begin{cases} w_{t+1} = w_t + \alpha_1 w_t\left[\left(-m_B + \frac{\gamma_1}{2} + \frac{\gamma_1^2}{2m_T}\right)p_{1,t} + \left(-m_T + 2\gamma_1 - \frac{\gamma_1^2}{m_T}\right)w_t + A_4\right], \\ p_{1,t+1} = \alpha_2 p_{1,t} + (1-\alpha_2)\frac{A_3A_6 - A_2A_4}{A_2^2 - A_3A_5}, \end{cases} \quad (9)$$

where $\alpha_1\,(\alpha_1 > 0)$ is the limited rational adjustment parameter of the manufacturer and $\alpha_2\,(0 < \alpha_2 < 1)$ is the adaptive adjustment parameter.

It is easy to get the decision of retailer with $w_{t+1}p_{1,t+1}$:

$$p_{2,t+1} = \frac{\gamma_1}{m_T}p_{1,t+1} + \frac{m_T - \gamma_1}{2m_T}w_{t+1} + \frac{\theta_3 a + m_T s + m_T\eta s^2 - \gamma_1\varphi\eta s^2}{2m_T}. \quad (10)$$

3.2.1. Equilibrium Points and Local Stability. This part discusses the stability of system (9) at equilibrium points. By setting $w_{t+1} = w_t$ and $p_{1,t+1} = p_{1,t}$, there are two equilibrium points in the discrete system of equation (9):

$$e_1 = \left(0, \frac{A_3A_6 - A_2A_4}{A_2^2 - A_3A_5}\right),$$
$$e_2 = \left(\frac{A_5A_4 - A_2A_6}{A_2^2 - A_3A_5}, \frac{A_3A_6 - A_2A_4}{A_2^2 - A_3A_5}\right). \quad (11)$$

Correspondingly, the retailer's decisions are expressed as

$$p_2^{e_1} = \frac{\gamma_1(A_3A_6 - A_2A_4)}{m_T(A_2^2 - A_3A_5)} + A_1,$$
$$p_2^{e_2} = \frac{\gamma_1(A_3A_6 - A_2A_4)}{m_T(A_2^2 - A_3A_5)} + \frac{A_4(A_2^2 - A_3A_5)(m_T - \gamma_1)}{2m_TA_2A_3(A_2A_4 - A_3A_6)} + A_1. \quad (12)$$

In a discrete system, the stability of equilibrium points will be determined by the eigenvalues of Jacobian matrix at the corresponding equilibrium points. The Jacobian matrix of system (9) is defined as follows:

$$J(e_i) = \begin{bmatrix} 1 + \alpha_1(A_2p_1 + 2A_3w + A_4) & A_2\alpha_1 w \\ 0 & \alpha_2 \end{bmatrix}, \quad i = 1, 2. \quad (13)$$

Supposing that $f(\lambda) = \lambda^2 - \xi_1\lambda + \xi_2$ is the characteristic polynomial of $J(e_i)$, $(i = 1, 2)$; besides, $\Delta = \xi_1^2 - 4\xi_2$ is its discriminant with $\xi_1 = t_r(j) = 1 + \alpha_1(A_2p_1 + 2A_3w + A_4) + \alpha_2$ and $\xi_2 = \det(j) = \alpha_2 + \alpha_1\alpha_2(A_2p_1 + 2A_3w + A_4)$.

When $\lambda = 1$, the characteristic polynomial of Jacobian matrix is described as follows: $F(1) = 1 - \mathrm{tr}(J) + \det(J) = \alpha_1(A_2p_1 + 2A_3w + A_4)(\alpha_2 - 1)$.

Lemma 1 (see [36]). *Defining the two values of $f(\lambda) = 0$ as λ_1 and λ_2, the eigenvalues of $J(e_i)$ can be judged as follows by Lemma 1. Then,*

(f_1) $|\lambda_1| < 1$ *and* $|\lambda_2| < 1$ *if and only if* $f(-1) > 0$ *and* $\det(J) < 1$

(f_2) $|\lambda_1| > 1$ *and* $|\lambda_2| > 1$ *if and only if* $f(-1) > 0$ *and* $\det(J) < 1$

(f_3) $|\lambda_1| < 1$ *and* $|\lambda_2| > 1$ *or* $|\lambda_1| > 1$ *and* $|\lambda_2| < 1$ *if and only if* $f(-1) < 0$

(f_4) $\lambda_1 = -1$ *and* $|\lambda_2| \neq 1$ *if and only if* $f(-1) = 0$ *and* $\det(J) \neq 0, 2$

(f_5) *both roots are complex and* $|\lambda_1| = |\lambda_2| = 1$ *if and only if* $\Delta < 0$ *and* $\det(J) = 1$

If all eigenvalues are smaller than one in modulus, this equilibrium point is asymptotically stable. Otherwise, bifurcation or chaos may occur in system (9).

Proposition 2. *Obviously, e_1 is an unstable equilibrium point, while e_2 is the Stackelberg equilibrium point.*

Proof. See Appendix B.

According to Lemma 1, the jury stability criterion of system (9) at e_2 can be expressed as follows:

$$\begin{cases} (g_1) = 1 + \operatorname{tr}(J(e_2)) + \operatorname{Det}(J(e_2)) > 0, \\ (g_2) = 1 - \operatorname{tr}(J(e_2)) + \det(J(e_2)) > 0, \\ (g_2) = 1 - \det(J(e_2)) > 0, \end{cases} \tag{14}$$

where

$$\begin{aligned} \operatorname{tr}(J(e_2)) &= 1 + \alpha_1\left(A_2\frac{A_3A_6 - A_2A_4}{A_2^2 - A_3A_5} + \frac{2A_4(A_2^2 - A_3A_5)}{A_2(A_2A_4 - A_3A_6)} + A_4\right) + \alpha_2, \\ \det(J(e_2)) &= \alpha_2 + \alpha_2\alpha_1\left(A_2\frac{A_3A_6 - A_2A_4}{A_2^2 - A_3A_5} + \frac{2A_4(A_2^2 - A_3A_5)}{A_2(A_2A_4 - A_3A_6)} + A_4\right). \end{aligned} \tag{15}$$

By analyzing the above judgment conditions of equation (14), $0 < \alpha_1 < (2/K)$ and $0 < \alpha_2 < 1$ can be obtained, where $K = A_2(A_3A_6 - A_2A_4 \ / \ A_2^2 - A_3A_5) + 2A_4(A_2^2 - A_3A_5)/A_2(A_2A_4 - A_3A_6) + A_4$. It can be known that adjustment parameters (α_1, α_2) are not related to the optimal decision $e_2(w^*, p_1^*)$ but are the main factors that affect the stability of e_2. Service value s affects not only α_1 and α_2 but also $e_2(w^*, p_1^*)$ and then affects the stability of system (9). When the decision parameters are not in this range ($0 < \alpha_1 < 2/K$, $0 < \alpha_2 < 1$), system (9) will be unstable at $e_2(w^*, p_1^*)$ and show bifurcation or chaos. When the decision-maker chooses the adjustment coefficients (α_1, α_2) in the stable region ($0 < \alpha_1 < (2/K)$, $0 < \alpha_2 < 1$), the equilibrium point $e_2(w^*, p_1^*)$ is stable. At this point, manufacturers and retailers in the supply chain can achieve maximum profits. From the point of view of management, managers should not only pay attention to their price adjustment parameters but focus on service value. Based on eigenvalues of the Jacobian matrix, the stability and bifurcation of system (9) will be studied in detail in the next section by numerical simulation. □

3.3. Complexity Dynamics Analysis and Numerical Simulation. Due to the existence of a large number of parameters, the complexity dynamics of system (9) will be studied intuitively by numerical simulation. Numerical values are assigned to the following letters: $a = 180, \theta_1 = 0.3$, $\theta_2 = 0.3$, $\theta_3 = 0.4$, $\rho_1 = 2.6$, $m_B = 3$, $m_T = 6$, $\gamma_1 = 1$, $v = 2$, $\eta = 5$, $\varphi = 0.2$, and $c = 4$. Thus, the Stackelberg equilibrium point can be expressed as $e_2 = (7.342, 15.2)$.

3.3.1. Complexity Dynamics with respect to α_i. In this section, the bifurcation diagram is a powerful tool to analyze the bifurcation phenomenon of system (9). Based on stability conditions equation (13), Figure 2 shows the 2D parameter bifurcation in the (α_1, α_2) plane, which shows the paths of system (9) to chaos. Different periods are represented by different colors: stable (green), period-2 (blue), period-3 (yellow), period-4 (Claret), period-5 (Cyan), period-6 (red), chaos (gray), and divergence (white). There are two ways to lead to chaos in system (9). The system enters chaos through periodic doubling bifurcation with α_1; when $0 < \alpha_2 < 1$, the system goes directly into chaos with α_2. When $0 < \alpha_1 < 0.065$, we can know that flip bifurcation will happen when α_1 increases. In short, it can be judged that the stability of the system is not independent of α_1 and α_2.

Figure 3 shows the bifurcation of prices (w, p_1, p_2) and the largest Lyapunov exponent (LLE) as α_1 increases with $\alpha_2 = 0.5$. In Figure 3(a), when $\alpha_1 < 0.065$, w, p_1, and p_2 do not fluctuate and system (9) is in a stable state. However, $\alpha_1 > 0.065$, w and p_2 show first the flip bifurcation. Due to limit, rational expectation has no effect on adaptive price expectation, and p_1 does not show fluctuation. The LLE with respect to α_1 shown in Figure 3(b) is a powerful tool to identify the state of system (9). When $\alpha_1 = 0.065$, the LLE reaches the first zero, and w and p_2 show the bifurcation phenomenon. After it, period doubling bifurcation continues to occur, and the system goes into chaos when LLE is more than zero.

When α_1 is set to 0.04, Figure 4 gives the bifurcation diagram of prices (w, p_1, p_2) and LLE of system (9) for α_2 varying from 0 to 1.1. We can see that as long as the parameter is in the stability region ($\alpha_2 < 1$), the game will be stable at $w = 7.342$, $p_1 = 15.2$, and $p_2 = 22.26$. In this situation, manufacturers and retailers can obtain Stackelberg game's optimal profit. When $\alpha_2 > 1$, the system directly goes

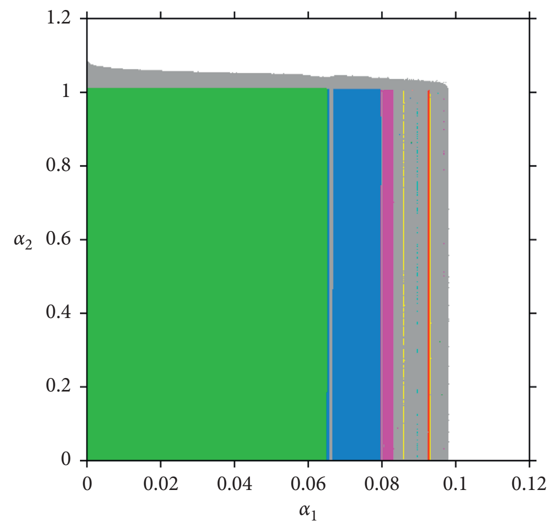


FIGURE 2: 2D bifurcation diagram with respect to α_1 and α_2.

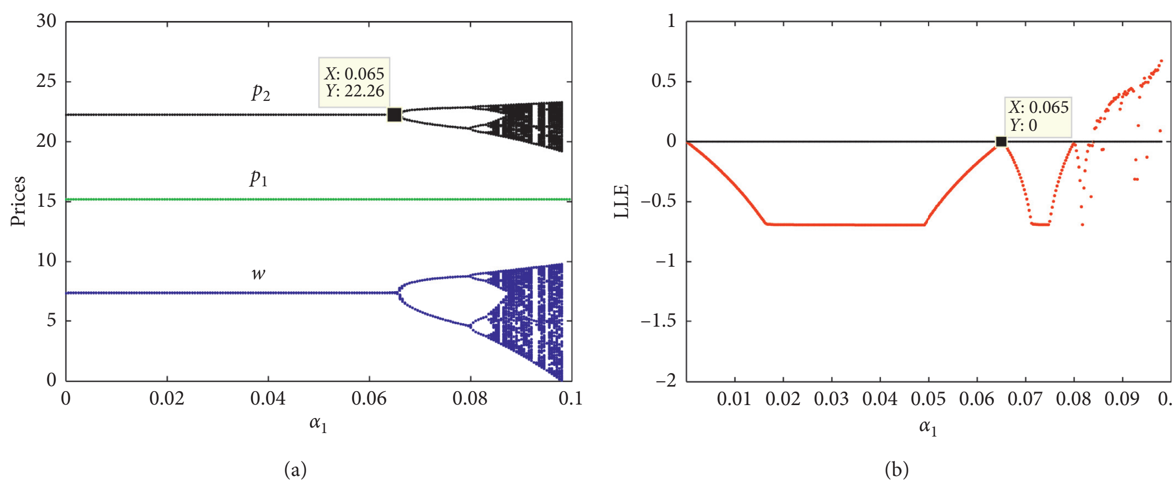


FIGURE 3: The behavior of dynamic system (9) with respect to α_1 when $\alpha_2 = 0.5$. (a) The bifurcation diagram. (b) The LLE diagram.

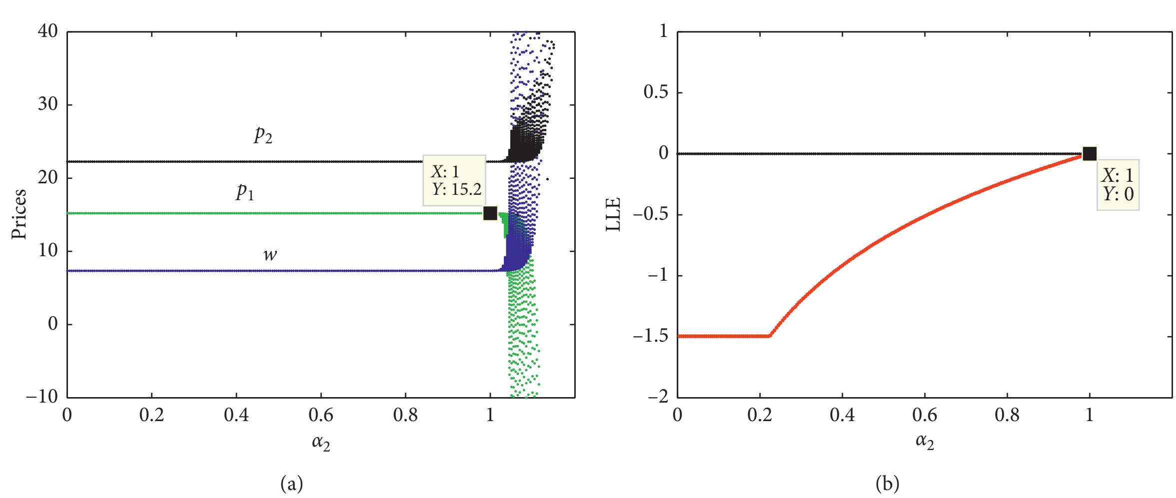


FIGURE 4: The behavior of dynamic system (9) with respect to α_2 when $\alpha_1 = 0.04$. (a) The wave shape bifurcation diagram. (b) The LLE diagram.

into the chaotic state without period doubling bifurcation; at this moment, the LLE is zero in Figure 4(b). Obviously, the influence of α_2 on the system dynamic behavior is different from that of α_1 on the system dynamic behavior.

Figure 5 is the 3D diagram for the chaos of system (9) corresponding to Figure 3(a). Red point represents the attractor when $\alpha_1 = 0.04$ and $\alpha_2 = 0.5$, which indicates that the trajectory of the system is fixed. In Figure 5(b), the blue curve is the chaotic attractor of the system, when $\alpha_1 = 0.094$ and $\alpha_2 = 0.5$, which vividly indicate the complexity and uncertainty of the system in chaotic state. Figure 6 shows the attractor of system (9) with respect to $\alpha_1 = 0.04$ and $\alpha_2 = 1.05$. In the chaotic state, w, p_1, and p_2 are in disorder.

Besides, when $\alpha_1 = 0.094$ and $\alpha_2 = 0.5$ or $\alpha_1 = 0.04$ and $\alpha_2 = 1.05$, chaotic system (9) also exhibits strong sensitivity to initial values. Here, fixing $p_1 = 14$ and $p_2 = 20$, Figure 7(a) shows the sensitivity to initial value in stable state, when w is changed from 7 to 7.001. We can find that, at the beginning of iterations, there is a little difference, but after 5 iterations, the difference gradually reduces to zero. Conversely, in chaos, Figure 7(b) shows that small difference in initial values can cause a huge deviation after 10 iterations, which warns decision-makers to be cautious in choosing initial values when making decisions.

3.3.2. Complexity Dynamics with respect to s. When making price decisions, decision-makers should consider the impact of service value on optimal decision-making, as well as the impact of service value on the dynamic system. Figure 8 indicates the range of service values. It can be seen that w decreases with increase in s, but w must be above zero, which is in line with the actual situation of the market. Besides, p_1 must be higher than w. Thus, it can be known that $s \in (1.66, 2.42)$.

Based on stability judgment conditions in equation (14), Figure 9 shows the 3D stable region with respect to s. When the value of (α_1, α_2, s) is in this region, system (9) is stable; otherwise, the system would not be stable. In Figure 9(b), increase in s improves the range of α_1. Figure 10 shows the stability region composed of (α_1, α_2) with s fixed different values. We can see that the stable region is least when $s = 2.2$ and becomes larger when $s = 2.35$ and 2.38. It is worth noting that s has no effect on the region of α_2. The above analysis shows that the larger the s is, the larger the stable region of system (9) will be.

Next, the combined effects of s α_i on system's complexity are discussed. A 2D bifurcation diagram with respect to s and α_1, when $\alpha_2 = 0.5$, is shown in Figure 11(a). Green represents the stable region consisting of (s, α_1). The range of α_1 increases significantly and then decreases with s increasing. For a given s belongs to $(1.66, 2.20)$, the system will experience a stable, series of period doubling bifurcations and fall into chaos with α_1 increasing. If s belongs to $(1.66, 2.20)$, the system will directly overflow. Figure 11(b) shows the 2D bifurcation diagram with respect to s and α_2 when $\alpha_1 = 0.04$. If given s belongs to $(1.66, 1.694)$, the system goes into the period doubling region and shows period doubling bifurcation or chaos with α_2 varying in $(0, 1)$. If the given s belongs to $(1.694, 2.42)$ and $\alpha_1 \in (0, 1)$, the system is in a stable state.

By comparing Figure 11(a) with Figure 11(b), it is found that service value s has little effect on α_2. Besides, the retailer should reasonably choose the service value when providing services to customers; otherwise, the system will be in a chaotic state, which is not conducive to the retailer to get maximize profits.

3.3.3. Impact of α_i and s on Profits. As the aim of enterprise in the market is to earn profit, the manufacturer and retailer have to pay attention to the result that whether they can get more profits or reduce losses by adjusting α_1, α_2, and s. In this section, the influence of α_1, α_2, and s on profits will be researched.

The bifurcation diagram of profits is shown in Figure 12 with α_1 varying from 0 to 0.1 and $\alpha_2 = 0.5$. In a stable state $(\alpha_1 < 0.065)$, the manufacturer and retailer can get stable returns and $\prod_m > \prod_r$. If $\alpha_1 > 0.065$, profits show the bifurcation and chaos phenomenon with α_1 increasing, which is consistent with Figure 3(a). Figure 13 shows the evolution diagram of the average profit with α_1. It can be known that, in the periodic doubling bifurcation, the average profit of the manufacture and retailer decreases and shows a floating trend in chaotic state.

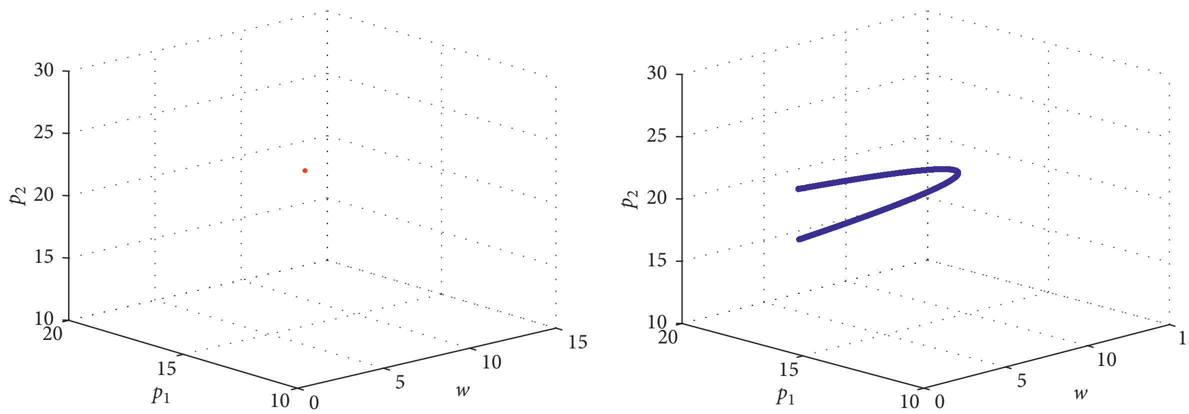
Figure 14 shows wave-shape chaos diagrams with respect to α_2 when $\alpha_1 = 0.04$. As α_2 increases $(0 < \alpha_2 < 1)$, system (9) remains stable. Once $\alpha_2 > 1$, system (9) will go into a fluctuant state, which causes a significant decline in profit.

Figure 15 shows the disordered evolution of system (9) as $\alpha_1 = 0.094$ and $\alpha_2 = 0.5$. It can be found that the profit of system (9) changes irregularly in chaotic state, which is difficult for the manufacturer and retailer to predict future profits. In actual operation, decision-makers should avoid the appearance of this phenomenon.

Figure 16 shows the bifurcation diagram of $\prod_r$ and $\prod_m$ with respect to s as $\alpha_1 = 0.04$ and $\alpha_2 = 0.5$. Obviously, the change of s has an impact on the dynamic evolution of system (9) and the profits of the manufacturer and retailer. It is shown in Figure 16 that when s is small $(s < 1.8)$, system (9) is in chaotic state. In this scenario, $\prod_r$ and $\prod_m$ are difficult to be measured. Further increase in s will lead to the appearance of period-4 state $(1.8 < s < 1.848)$, period-2 state $(1.848 < s < 1.967)$, and stable state $(1.967 < s)$. We can see that in stable state, increasing s is beneficial to the manufacturer and retailer. As $s > 2.155$, $\prod_r$ is greater than $\prod_m$. Table 2 shows the change of $\prod_m$, $\prod_r$, and $\prod_T$ with respect to s, where $\prod_T$ is equivalent to $\prod_m$ plus $\prod_r$. It can be found that the total profit of supply chain increases with s increasing.

Next, the combined effect of α_1, α_2, and s on the profits of the manufacturer and retailer is to be explored in two situations.

Situation 1. System (9) falls into chaos with respect to α_1 and s.



(a) (b)

Figure 5: Chaos attractor of the dynamic system (9) with respect to α_1 and $\alpha_2 = 0.5$. (a) $\alpha_1 = 0.04$. (b) $\alpha_1 = 0.094$.

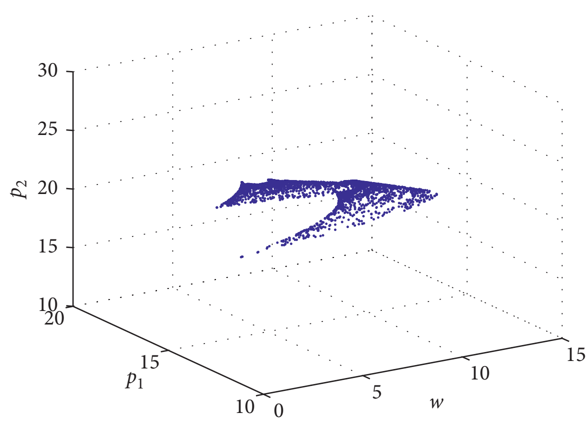
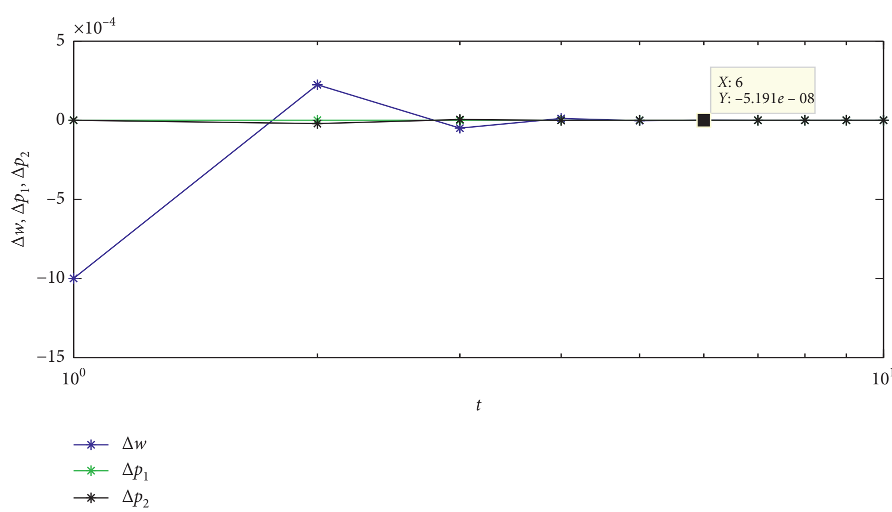
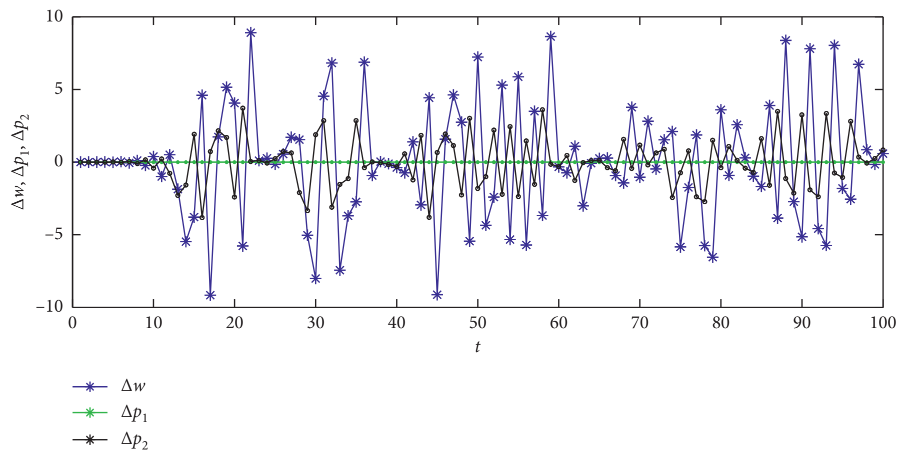


Figure 6: Chaos attractor of the dynamic system (9) with respect to $\alpha_1 = 0.04$ and $\alpha_2 = 1.05$.



(a)

Figure 7: Continued.



(b)

FIGURE 7: The sensitivity to initial value when $(w, p_1, p_2) = (w = 7, p_1 = 14, p_2 = 20)$ and $(w = 7.001, p_1 = 14, p_2 = 20)$. (a) $\alpha_1 = 0.04$ and $\alpha_2 = 0.5$. (b) $\alpha_1 = 0.094$ and $\alpha_2 = 0.5$.

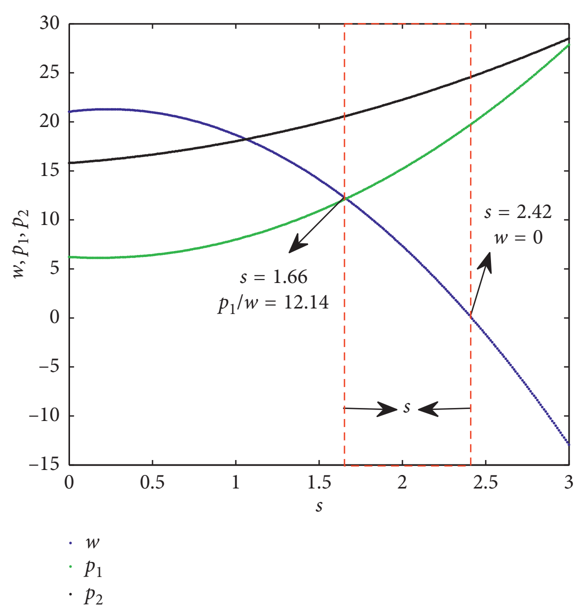


FIGURE 8: Nash equilibrium (w, p_1, p_2) with respect to s.

Figures 17 and 18 show the variation of $\prod_m$ and $\prod_r$ with α_1 and s. We can know that the smaller the service value is, the more easily the profit of the manufacturer and retailer fluctuates with α_1 increasing. On the contrary, the larger the service value, the chaotic phenomenon of system (9) will be delayed with α_1 increasing. The profits of the manufacturer and retailer will not be easily fluctuated. Meanwhile, the manufacturer and retailer can obtain stable profits. But too large α_1 will also cause the system to go into chaos.

Situation 2. System (9) falls into chaos with respect to α_2 and s.

As shown in Figures 19 and 20, as long as α_2 is less than 1, no matter how α_2 and s change, the profits of manufacturer and retailer will not fluctuate dramatically and the profit of manufacturer will slightly change with s increasing. However, the profit of retailer will increase with s increasing. Once α_2 is greater than 1, the profits of manufacturer and retailer will decline sharply.

With the variation of α_1, α_2, and s, system (9) probably loses stability and shows some complex behavior, meanwhile, which will lead to a decline in profits. Therefore, a management opinion given that manufacturer need to choose α_1 and α_2 carefully when making price decisions, in

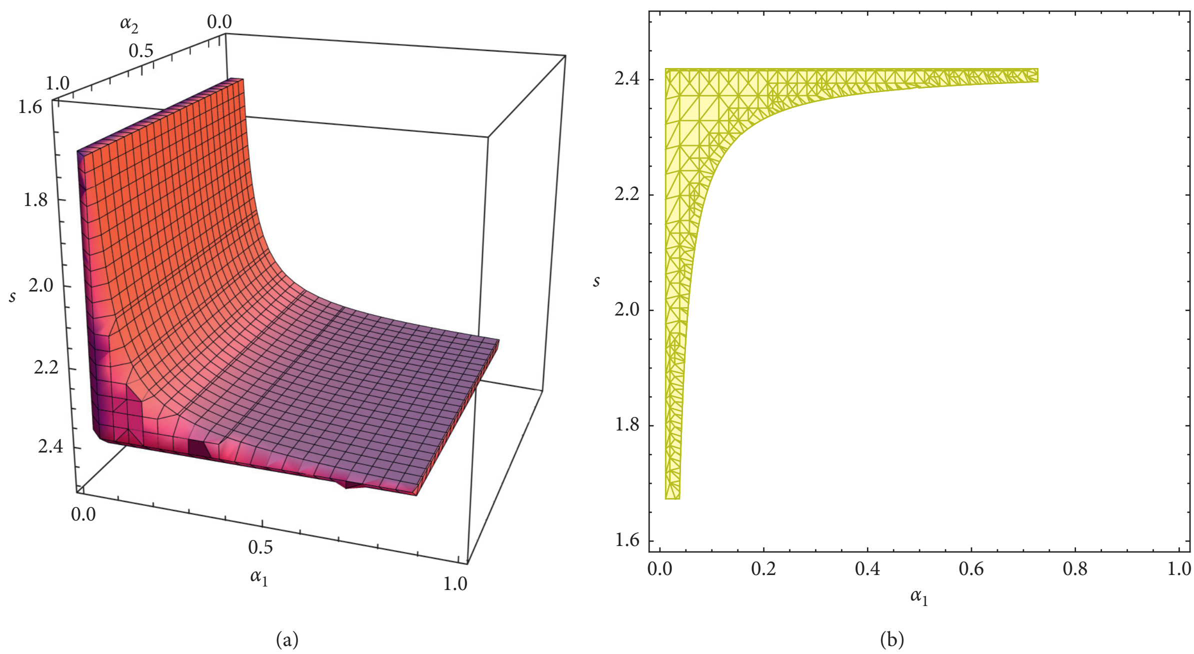


Figure 9: Stable region with respect to α_1, α_2, and s. (a) 3D stable region. (b) 2D stable region with $\alpha_2 = 0.5$.

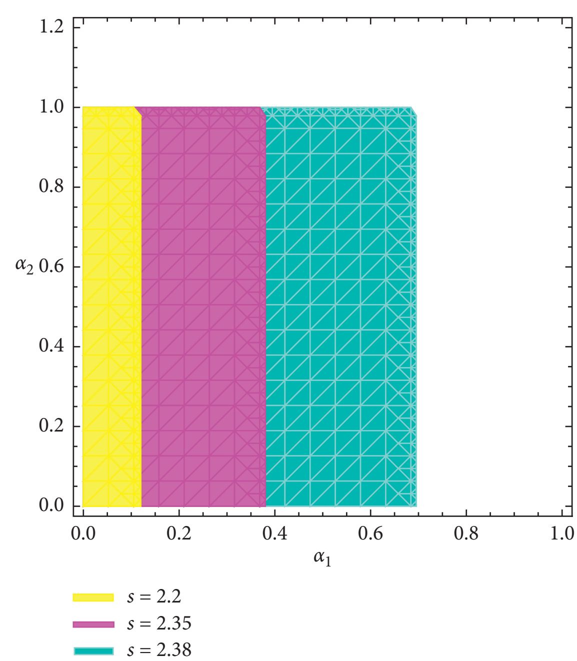


Figure 10: The stability region in the (α_1, α_2) plane with different s.

addition retailer need to cooperate with manufacturer to choose reasonable service value to ensure that the system is in a stable state and get maximize profits.

4. Model with Unit Profit Sharing (M^{ε})

4.1. Static Model. In this section, the manufacturer controls the profit from the integration channel. The retailer provides service value s for consumers from the integration channel and the traditional channel. Correspondingly, the manufacturer shares unit profit from the integration channel with the retailer. The manufacturer is the leader of the market, and the retailer is the follower.

Therefore, according to equations (1)–(3), the profit functions of the manufacturer and retailer can be described as follows:

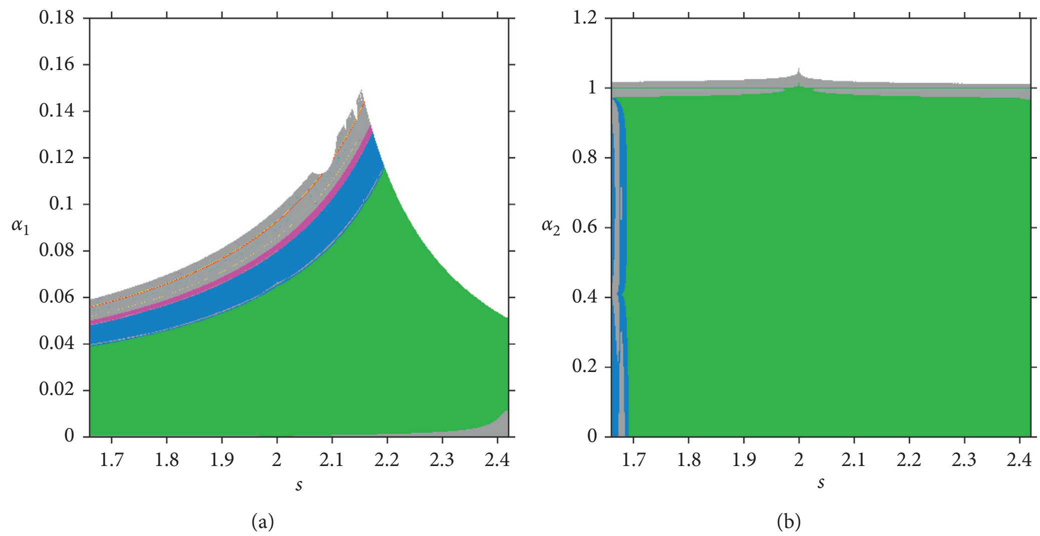


FIGURE 11: 2D bifurcation diagrams for periodic cycles. (a) 2D bifurcation with respect to α_1 and s. (b) 2D bifurcation with respect to α_2 and s.

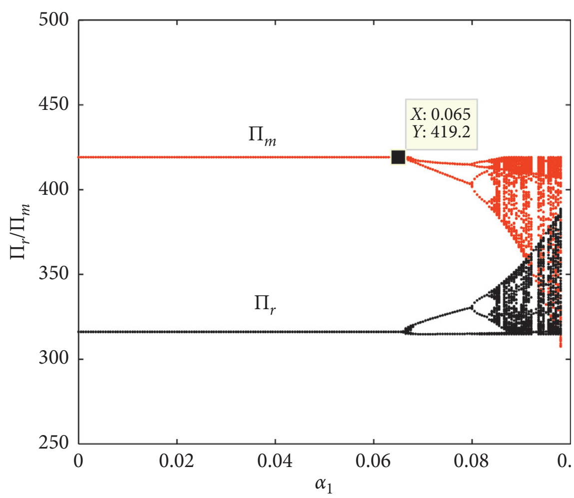


FIGURE 12: The bifurcation diagram of $\prod_r$ and $\prod_m$ with respect to α_1 as $\alpha_2 = 0.5$.

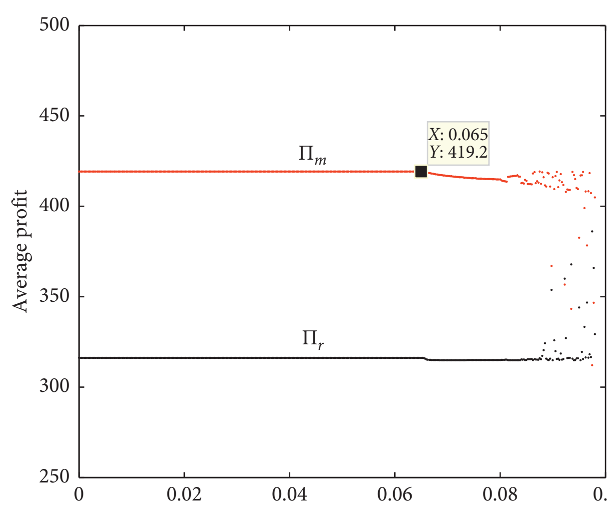


FIGURE 13: The average profit diagram with respect to α_1 and $\alpha_2 = 0.5$.

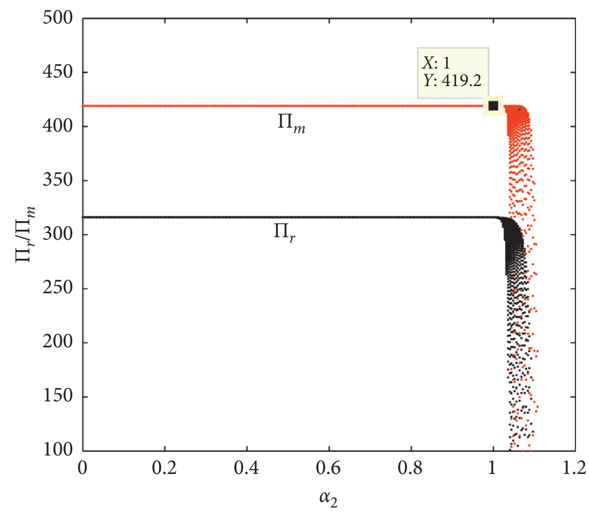


FIGURE 14: The wave-shape chaos diagram of $\prod_r$ and $\prod_m$ with respect to α_2 as $\alpha_1 = 0.04$.

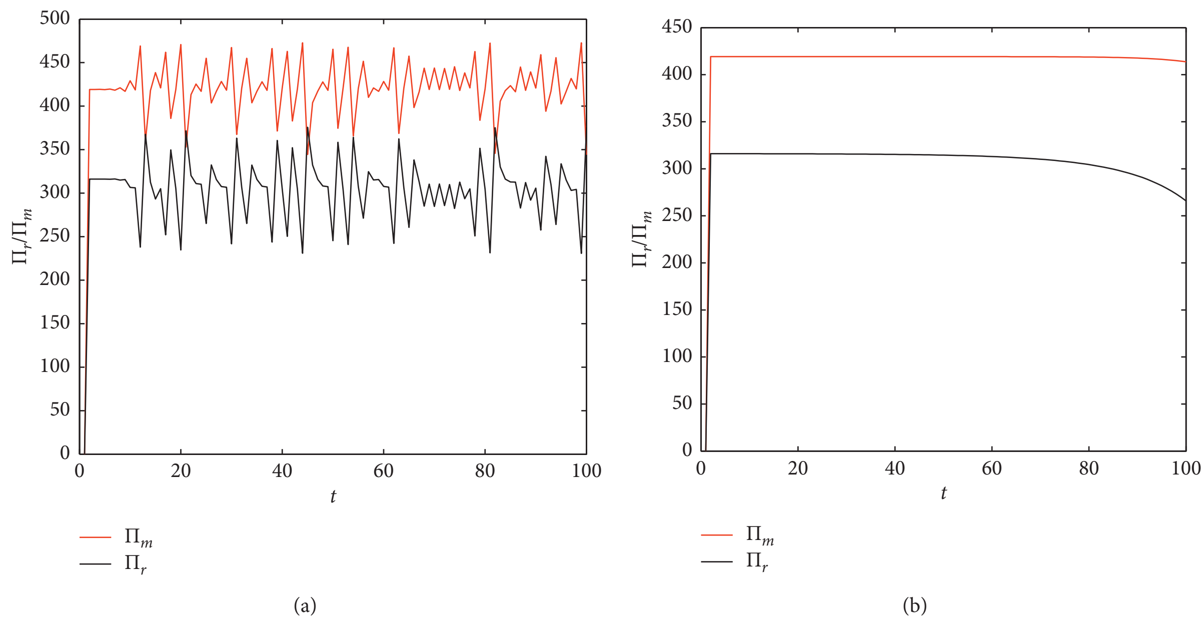


FIGURE 15: Time series of $\prod_r$ and $\prod_m$ with respect to α_1 and α_2. (a) $\alpha_1 = 0.094$ and $\alpha_2 = 0.5$. (b) $\alpha_1 = 0.04$ and $\alpha_2 = 1.05$.

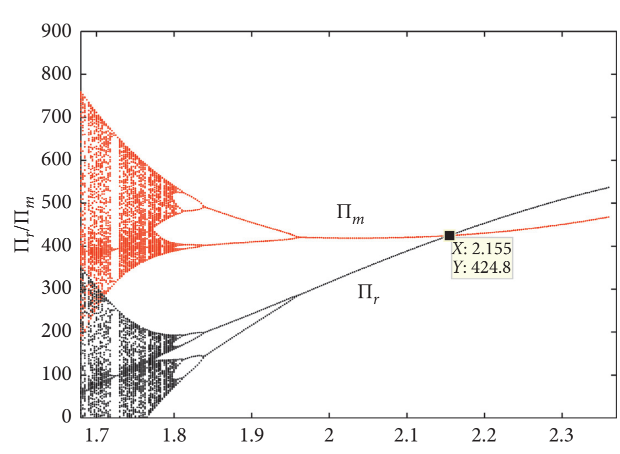


FIGURE 16: Profits change with s when $\alpha_1 = 0.04$ and $\alpha_2 = 0.5$.

Table 2: The profits of system (9) for s ($\alpha_1 = 0.06$ and $\alpha_2 = 0.5$).

	$s = 1.967$	$s = 2.092$	$s = 2.155$	$s = 2.275$	$s = 2.36$
$\prod_m$	420.4	420.1	424.8	444.5	468.1
$\prod_r$	291.2	383.4	424.8	496.0	536.7
$\prod_T$	711.6	803.5	849.6	940.5	1004.8

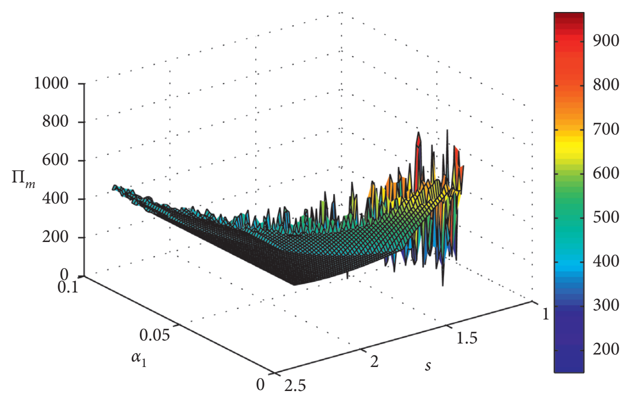


Figure 17: 3D profit diagram for the manufacturer with α_1 and s, as $\alpha_2 = 0.5$.

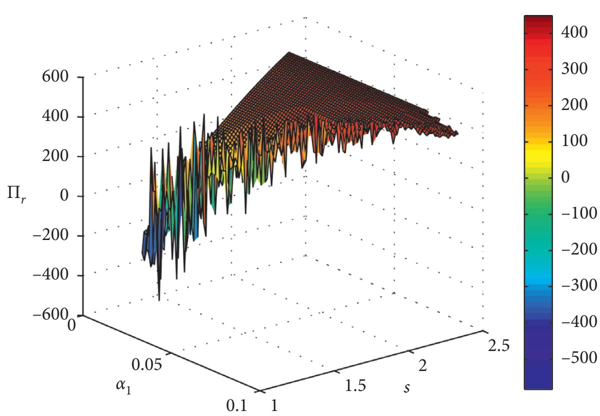


Figure 18: 3D profit diagram for the retailer with α_1 and s, as $\alpha_2 = 0.5$.

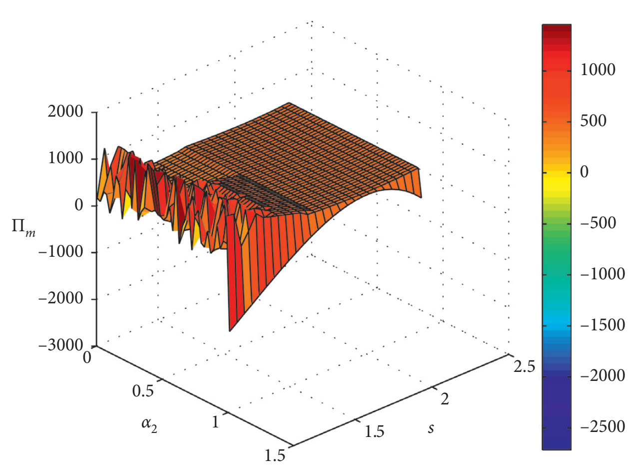


Figure 19: 3D profit diagram for the manufacturer with α_2 and s, as $\alpha_1 = 0.04$.

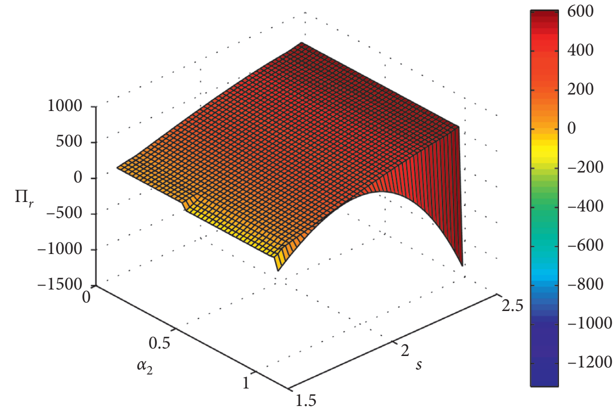


FIGURE 20: 3D profit diagram for the retailer with α_2 and s, as $\alpha_1 = 0.04$.

$$\begin{aligned}\max_{p_1,w}\prod_m^{\varepsilon} &= (p_1-c)D_O+(w-c)D_T+(p_1-c-\varepsilon)D_B\\ &= (p_1-c)(\theta_1 a-\rho_1 p_1+\gamma_1 p_2)\\ &\quad +(w-c)[\theta_3 a-m_T(p_2-s)+\gamma_1 p_1]\\ &\quad +(p_1-c-\varepsilon)[\theta_2 a-m_B(p_1-s)+\gamma_1 p_2]\\ &\quad \text{s.t. } c+\varepsilon<p_1, c<w,\end{aligned}\tag{16}$$

$$\begin{aligned}\max_{p_2}\prod_r^{\varepsilon} &= (p_2-w-c_v)D_T+\varepsilon D_B-\varphi c_s D_B\\ &= \left(p_2-w-\eta s^2\right)[\theta_3 a-m_T(p_2-s)+\gamma_1 p_1]\\ &\quad +\varepsilon[\theta_2 a-m_B(p_1-s)+\gamma_1 p_2]\\ &\quad -\varphi\eta s^2[\theta_2 a-m_B(p_1-s)+\gamma_1 p_2]\\ &\quad \text{s.t. } w+\eta s^2<p_2.\end{aligned}\tag{17}$$

To solve the Stackelberg equilibrium, we first find the optimal decision of the retailer. Given w and p_1, the retailer chooses p_2 to maximize. Setting $(\partial\prod_r^{\varepsilon}/\partial p_2)=0$,

$$p_2=\frac{\gamma_1 p_1}{2m_T}+\frac{w}{2}+\frac{s+\eta s^2}{2}+\frac{\varepsilon\gamma_1+a\theta_3-\varphi\eta\gamma_1 s^2}{2m_T}.\tag{18}$$

Submitting equation (18) into (16) and then taking the first-order partial derivatives of $\prod_m^{\varepsilon}$ with respect to p_1 and w can be shown as

$$\begin{cases}\dfrac{\partial\prod_m^{\varepsilon}}{\partial w}=\dfrac{3}{2}p_1\gamma_1-m_T w+\dfrac{a\theta_3+m_T s-\eta m_T s^2+\varphi\eta\gamma_1 s^2+m_T c-2c\gamma_1-2\gamma_1\varepsilon}{2}\\[2ex] \dfrac{\partial\prod_m^{\varepsilon}}{\partial p_1}=\left(-2m_B-2\rho_1+\dfrac{3\gamma_1^2}{m_T}\right)p_1+\dfrac{3\gamma_1 w}{2}-\dfrac{c\gamma_1}{2}+\dfrac{\gamma_1^2\varepsilon}{2m_T}+m_B(c+\varepsilon+s)\\[2ex] \quad +a\theta_1+a\theta_2-c\rho_1+\dfrac{\gamma_1\left(m_T s+\eta m_T s^2+a\theta_3-\varphi\eta\gamma_1 s^2\right)}{m_T}.\end{cases}\tag{19}$$

Setting $(\partial\prod_m^{\varepsilon}/\partial w)=0$ and $(\partial\prod_m^{\varepsilon}/\partial p_1)=0$, the solution of manufacturer can be obtained as

$$\begin{cases}w^*=\dfrac{4B_1B_2-6B_3\gamma_1}{4B_2m_T+9\gamma_1^3},\\[2ex] p_1^*=\dfrac{-4B_3m_T-6B_1\gamma_1^2}{4B_2m_T+9\gamma_1^3},\end{cases}\tag{20}$$

where

$$B_1 = \frac{a\theta_3 + m_T s - \eta m_T s^2 + \varphi\eta\gamma_1 s^2 + m_T c - 2c\gamma_1 - 2\gamma_1\varepsilon}{2},$$

$$B_2 = -2m_B - 2\rho_1 + \frac{3\gamma_1^2}{m_T},$$

$$B_3 = -\frac{c\gamma_1}{2} + \frac{\gamma_1^2\varepsilon}{2m_T} + m_B(c + \varepsilon + s) + a\theta_1 + a\theta_2 - c\rho_1 + \frac{\gamma_1(m_T s + \eta m_T s^2 + a\theta_3 - \varphi\eta\gamma_1 s^2)}{m_T}. \quad (21)$$

The Hessian matrix is

$$H^\varepsilon = \begin{bmatrix} -m_T & \frac{3}{2}\gamma_1 \\ \frac{3\gamma_1}{2} & -2m_B - 2\rho_1 + \frac{3\gamma_1^2}{m_T} \end{bmatrix}. \quad (22)$$

As $\begin{vmatrix} -m_T & (3/2)\gamma_1 \\ (3/2)\gamma_1 & -2m_B - 2\rho_1 + (3\gamma_1^2/m_T) \end{vmatrix} = 2m_B m_T + 2\rho_1 m_T - 3\gamma_1^2 - (9/4)\gamma_1^2 > 16\gamma_1^2 - (9/4)\gamma_1^2 > 0$, the Hessian matrix (w^*, p_1^*) is the optimal solution of the manufacturer.

Substituting equation (20) into (18), we obtain

$$p_2^* = \frac{-4B_3 m_T\gamma_1 - 6B_1\gamma_1^3}{8B_2 m_T^2 + 18m_T\gamma_1^3} + \frac{4B_1B_2 - 6B_3\gamma_1}{8B_2 m_T + 18\gamma_1^3} + \frac{s + \eta s^2}{2} + \frac{\varepsilon\gamma_1 + a\theta_3 - \varphi\eta\gamma_1 s^2}{2m_T}. \quad (23)$$

Substituting equations (20) and (23) into (16) and (17), the optimal profit functions of manufacturer and retailer can be described as follows:

$$\begin{cases} \prod_m^{\varepsilon *} = (p_1^* - c)(\theta_1 a - \rho_1 p_1^* + \gamma_1 p_2^*) + (w^* - c)[\theta_3 a - m_T(p_2^* - s) + \gamma_1 p_1^*] \\ +(p_1^* - c - \varepsilon)[\theta_2 a - m_B(p_1^* - s) + \gamma_1 p_2^*], \\ \prod_r^{\varepsilon *} = (p_2^* - w^* - \eta s^2)[\theta_3 a - m_T(p_2^* - v) + \gamma_1 p_1^*] \\ -\varphi\eta s^2[\theta_2 a - m_B(p_1^* - s) + \gamma_1 p_2^*] + \varepsilon[\theta_2 a - m_B(p_1^* - s) + \gamma_1 p_2^*]. \end{cases} \quad (24)$$

4.2. Dynamic Model. In the changing market environment, we discuss that the situation of participants' dynamic decision and the influence of relevant parameters on the dynamic system are more in line with the actual market. Based on reality, this paper considers that the manufacturer employs different price adjustment strategies to make decisions of period $t+1$. In dynamic periodic decision, the manufacturer adopts the bounded rationality expectation to make the wholesale price decision: $w_{t+1} = w_t[1 + \beta_1(\partial\prod_m^\varepsilon(w_t, p_{1,t})/\partial w_t)]$ and make price decisions of integration channel and direct channel based on adaptive expectation: $p_{1,t+1} = \beta_2 p_{1,t} + (1-\beta_2)p_1^*$.

Therefore, the dynamic process of the price game can be described as

$$\begin{aligned} w_{t+1} &= w_t + \beta_1 w_t\left(\frac{3}{2}p_{1,t}\gamma_1 - m_T w_t + \frac{a\theta_3 + m_T s - \eta m_T s^2 + \varphi\eta\gamma_1 s^2 + m_T c - 2c\gamma_1 - 2\gamma_1\varepsilon}{2}\right), \\ p_{1,t+1} &= \beta_2 p_{1,t} + (1-\beta_2)\frac{-4B_3 m_T - 6B_1\gamma_1^2}{4B_2 m_T + 9\gamma_1^3}. \end{aligned} \quad (25)$$

Here, β_1 is the limited rational adjustment parameter and $\beta_2\,(0 < \beta_2 < 1)$ is the adaptive adjustment parameter.

In system (25), the manufacturer first makes the decisions: w_t and $p_{1,t}$ by β_1 and β_2, and the retailer are followers; his decision $p_{2,t+1}$ is directly related to w_{t+1} and $p_{1,t+1}$ as

$$p_{2,t+1} = \frac{\gamma_1}{2m_T}p_{1,t+1} + \frac{1}{2}w_{t+1} + \frac{s + \eta s^2}{2} + \frac{\varepsilon\gamma_1 + a\theta_3 - \varphi\eta\gamma_1 s^2}{2m_T}. \quad (26)$$

4.2.1. Equilibrium Points and Local Stability. According to the theory of the fixed point, setting $w_{t+1} = w_t$ and $p_{1,t+1} = p_{1,t}$, there are two equilibrium points: e_1^ε and e_2^ε:

$$\begin{aligned} e_1^\varepsilon &= \left(0, \frac{-4m_T B_3 - 6B_1\gamma_1^2}{4m_T B_2 + 9\gamma_1^3}\right), \\ e_2^\varepsilon &= \left(\frac{4B_1B_2 - 6B_3\gamma_1}{4B_2 m_T + 9\gamma_1^3}, \frac{-4B_3 m_T - 6B_1\gamma_1^2}{4B_2 m_T + 9\gamma_1^3}\right). \end{aligned} \quad (27)$$

Correspondingly, the retailer's decisions under two equilibrium points are, respectively,

$$
\begin{aligned}
p_2^{e_1^\varepsilon} &= \frac{-2m_T B_3 \gamma_1 - 3B_1\gamma_1^3}{4m_T^2 B_2 + 9m_T\gamma_1^3} + \frac{s+\eta s^2}{2} \\
&\quad + \frac{\varepsilon\gamma_1 + a\theta_3 - \varphi\eta\gamma_1 s^2}{2m_T}, \\
p_2^{e_2^\varepsilon} &= \frac{-2m_T B_3 \gamma_1 - 3B_1\gamma_1^3}{4m_T^2 B_2 + 9m_T\gamma_1^3} + \frac{2B_1B_2 - 3B_3\gamma_1}{4B_2 m_T + 9\gamma_1^3} + \frac{s+\eta s^2}{2} \\
&\quad + \frac{\varepsilon\gamma_1 + a\theta_3 - \varphi\eta\gamma_1 s^2}{2m_T}.
\end{aligned}
\tag{28}
$$

Proposition 3. *Obviously, e_1^ε is the boundary equilibrium point, while e_2^ε is the Stackelberg equilibrium point.*

Proof. See Appendix C.

According to the analysis of equilibrium points in model M, we investigate the stability of e_2^ε by using Jury conditions:

$$
\begin{cases}
(g_1) = 1 + \operatorname{Tr}(J(e_2^\varepsilon)) + \operatorname{Det}(J(e_2^\varepsilon)) > 0, \\
(g_2) = 1 - \operatorname{tr}(J(e_2^\varepsilon)) + \det(J(e_2^\varepsilon)) > 0, \\
(g_2) = 1 - \det(J(e_2^\varepsilon)) > 0,
\end{cases}
\tag{29}
$$

where

$$
\begin{aligned}
\operatorname{Tr}(J(e_2^\varepsilon)) &= \beta_2 + 1 + \beta_1\left(\frac{-6B_3m_T\gamma_1 - 9B_1\gamma_1^3}{4B_2m_T + 9\gamma_1^3} - \frac{8m_TB_1B_2 - 12m_TB_3\gamma_1}{4B_2m_T + 9\gamma_1^3} + B_1\right), \\
\operatorname{Det}(J(e_2^\varepsilon)) &= \beta_2\left[1 + \beta_1\left(\frac{-6B_3m_T\gamma_1 - 9B_1\gamma_1^3}{4B_2m_T + 9\gamma_1^3} - \frac{8m_TB_1B_2 - 12m_TB_3\gamma_1}{4B_2m_T + 9\gamma_1^3} + B_1\right)\right].
\end{aligned}
\tag{30}
$$

By above stability judgment conditions, we can know $0 < \beta_1 < \vartheta$, $0 < \beta_2 < 1$, where $\vartheta = 4B_2m_T + 9\gamma_1^3 / -6B_3m_T\gamma_1 - 9B_1\gamma_1^3 - 8m_TB_1B_2 + 12m_TB_3\gamma_1 + B_1(4B_2m_T + 9\gamma_1^3)$. When the decision parameters are in this range $(0 < \beta_1 < \vartheta, 0 < \beta_2 < 1)$, system (25) will be stable at equilibrium point $e_2^\varepsilon(w^*, p_1^*)$. Due to the existence of a large number of parameters in system (25), the stability and bifurcation of the system will be studied intuitively in the next part. □

4.3. Complexity Dynamics Analysis and Numerical Simulation. In this section, the same parameters are chosen as in Section 3.3 furthermore, given $\varepsilon = 8$. Correspondingly, the Stackelberg equilibrium is $e_2^\varepsilon = (6.1663, 15.9983)$.

4.3.1. Complexity Dynamics with respect to β_i. First of all, we analyze the paths of system (25) going into chaos. Figure 21 shows the 2D parameter bifurcation in the (β_1, β_2) plane, where different colors represent different periods of system (25): stable (red), period-2 (yellow), period-3 (green), period-4 (blue), period-5 (cyan), period-6 (claret), chaos (gray), and divergence (white). It can be seen that system (25) can enter into chaos by two ways. In Path 1, we fix the value of β_2 $(0 < \beta_2 < 1)$. Beginning in stable state, system (25) goes into chaos through a series of period doubling bifurcations. In Path 2, given $\beta_1 \in (0, 0.054)$, change the value of β_2. It can be seen that system (25) goes directly into chaos from the stable period. We can know the paths of system (25) into chaos is similar to system (9), but a difference is that system (25) enters the bifurcation period and chaos earlier than system (9).

Next, we investigate dynamic evolution of system (25). Figure 22 shows the behavior of dynamic system (25) with respect to β_1 when $\beta_2 = 0.5$. w, p_1, and p_2 do not fluctuate in Figure 22(a) when $\beta_1 < 0.054$. Compared with Figure 4(a), w and p_2 are less than that in system (9). As $\beta_1 = 0.054$, the first flip bifurcation appears; meanwhile, the LLE showed in Figure 22(b) reaches the first zero. After it, with β_1 increasing, system (25) goes through period doubling bifurcation and goes into chaos with LLE > 0.

The dynamic evolution of system (25) with respect to β_2 is shown in Figure 23. As long as $\beta_2 < 1$, system (25) is always in the stable period. As $\beta_2 > 1$ and the LLE is zero in Figure 23(b), system (25) directly goes into wave chaos without period doubling bifurcation, which is different from the dynamic evolution of system (25) with β_1. Obviously, wave chaos of system (25) is weaker than that of system (9) in Figure 4.

Figure 24 shows time series of w, p_1, and p_2 with t when $\beta_1 = 0.08$ and $\beta_2 = 0.4$. We can see that w and p_2 show violent and disorderly fluctuations once system (25) becomes unstable. But, because retailer adopts adaptive expectation when deciding retail price, p_1 is not affected by bounded rationality adjustment parameter β_1. Figure 25 indicates the sensitivity to initial value of system (25) when $\beta_1 = 0.08$ and $\beta_2 = 0.4$. It reveals that, in a chaotic system, small difference in initial values can cause a huge deviation after 10 iterations, which is similar to Figure 7(b). In the unstable system, it is very difficult for decision-maker to make the next-stage decision. Therefore, managers should rationally adjust price decisions and choose the initial values reasonably to keep the system stable.

4.3.2. Influence of s and ε on the Stability of the System. In the process of cooperation, the manufacturer and retailer have to determine service value s and value of unit profit sharing ε because service value and unit profit sharing will

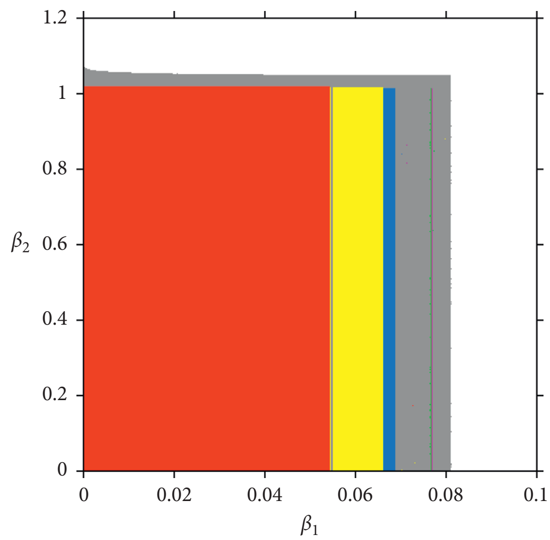


FIGURE 21: 2D parameter bifurcation in the (β_1, β_2) plane.

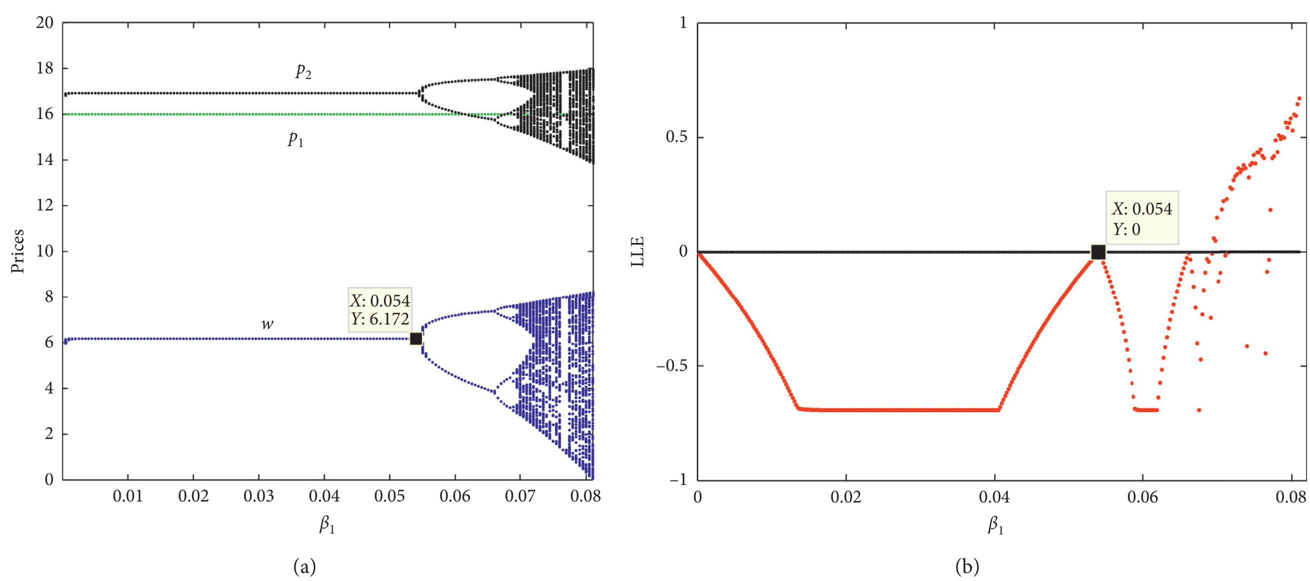


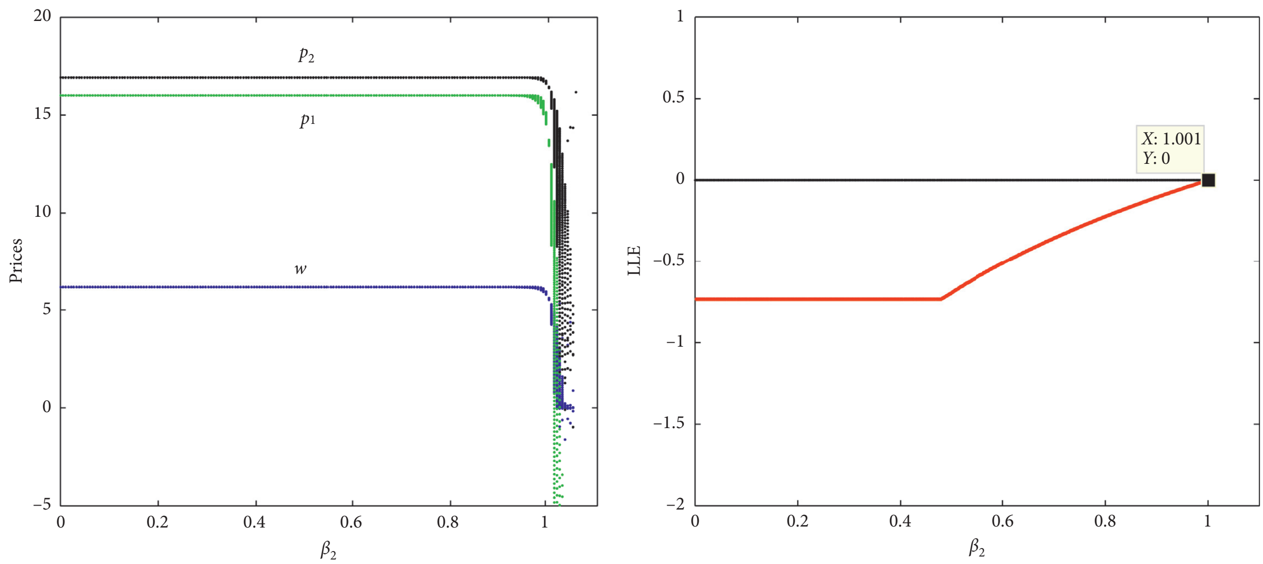
FIGURE 22: The behavior of dynamic system (25) with respect to β_1 when $\beta_2 = 0.5$. (a) The bifurcation diagram. (b) The LLE diagram.

affect the stability of system (25). According to the actual operation of the market, the ranges of s and ε are shown in Figures 26 and 27, respectively. To ensure that p_2 is greater than p_1, we can know $s > 1.62$. Meanwhile, in order to be meaningful, w must be greater than zero. Thus, s can be chosen in the range (1.62, 3.12). Similarly, only when $\prod_r^{\varepsilon} > \prod_r$, where $\prod_r$ represents the profits of retailers without cooperating with the manufacturer, the retailer be willing to cooperate with the manufacturer. In addition, as $\prod_r^{\varepsilon} > \prod_m^{\varepsilon}$, the manufacturer will terminate its cooperation with the retailer. Therefore, we can know that ε can be chosen in (2, 15.38).

Figure 28(a) shows the 3D stable region of the parameters (β_1, β_2, s) when $\varepsilon = 8$. If β_1, β_2, and s are in this 3D stable region, system (25) is stable. Combining Figure 28(b) and Table 3, we can find that s changing in (1.62, 3.12) has a significant effect on the stable region of the system. It can be concluded that if s is in (1.62, 3.12), the larger the service value s will be, the larger the stable region of system (25) will be, and service value s only affects the scope of β_1 but does not affect the scope of β_2. The conclusion is similar to that of system (9).

Observing Figure 29 and Table 3, we can see that the effect of ε on the stable region is similar to that of s. But the sensitivity of ε to the stable region is weaker than that of s.

Figure 30 shows 2D bifurcation diagrams for periodic cycles. Different colors represent different periods of system (25), which is the same as Figure 20. In Figure 30(a), the stable range of α_1 increases significantly and then decreases with s increasing. For a given s belongs to $(1.62, 2.42)$, system (25) will experience the stable period and a series of period doubling bifurcations and fall into chaos with β_1 increasing. If



(a)

(b)

FIGURE 23: The behavior of dynamic system (25) with respect to β_2 when $\beta_1 = 0.04$. (a) The bifurcation diagram. (b) The LLE diagram.

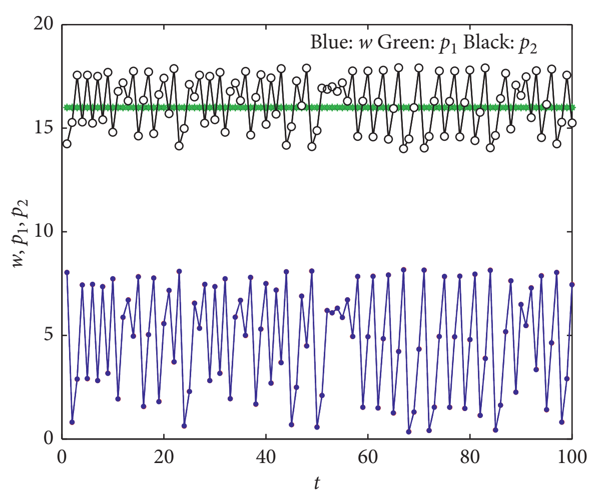


FIGURE 24: Time series of w, p_1, and p_2 with $\beta_1 = 0.08$ and $\beta_2 = 0.4$.

s belongs to $(2.42, 3.12)$, the system will directly overflow with β_1 increases. In Figure 30(b), if ε increases in $(2, 15.38)$, bifurcation and chaos will occur belatedly in system (25). Thus, improving ε is beneficial to the stability of system (25). The manufacturer can delay the occurrence of bifurcation and chaos of system (25) by adjusting ε.

4.3.3. Impact of β_i, s, and ε on Profits. Above all, we discuss the influence of β_i, s, and ε on the stability and complexity of system (25). Due to system (25) stability affecting the profits of manufacturer and retailer, next, the influence of β_i, s, and ε on profits will be investigated.

Figure 31(a) shows dynamic evolution of $\prod_m^{\varepsilon}$ and $\prod_r^{\varepsilon}$ with β_1; we can know that as $\beta_1 < 0.054$, the manufacturer and retailer can get stable returns. However, $\prod_m^{\varepsilon}$ and $\prod_r^{\varepsilon}$ show the bifurcation and chaos phenomenon with β_1 increasing. In Figure 31(b), in the bifurcation period, $\prod_m^{\varepsilon}$ decreases while $\prod_r^{\varepsilon}$ rises, which is different from system (9). As β_1 increases, the average profit shows a floating trend in chaotic state.

Figure 32 shows wave-shape chaos diagrams with respect to β_2 when $\beta_1 = 0.04$. As β_2 changes in $(0, 1)$, $\prod_m$ and $\prod_r$ remain stable. Once $\beta_2 > 1$, $\prod_m$ and $\prod_r$ will go into a fluctuant state, which causes a significant decline in profit. It can be clearly seen that the impact of β_1 on profits is significantly different from that of β_2 on profits. That is to say,

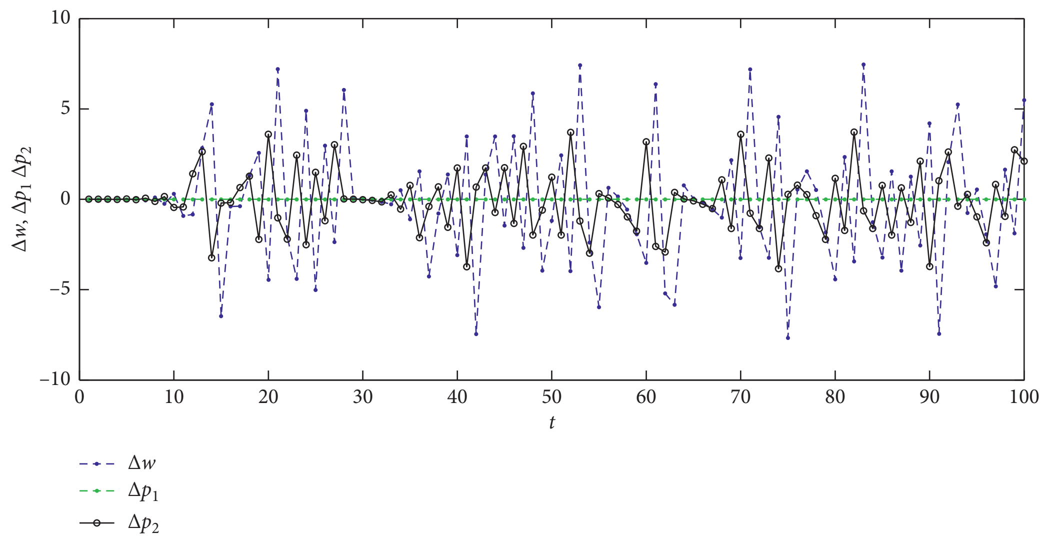


FIGURE 25: The sensitivity to initial value when $(w, p_1, p_2) = (w = 7,\ p_1 = 14,\ p_2 = 20)$ and $(w = 7.001,\ p_1 = 14,\ p_2 = 20)$.

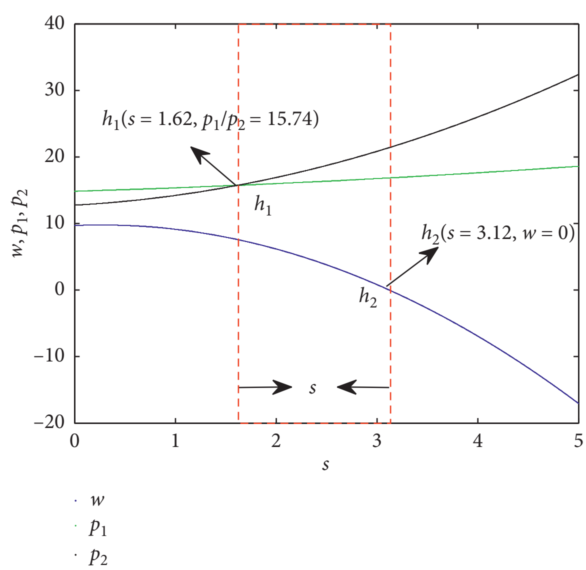


FIGURE 26: The Stackelberg equilibrium $(w, p_1$, and $p_2)$ with respect to s.

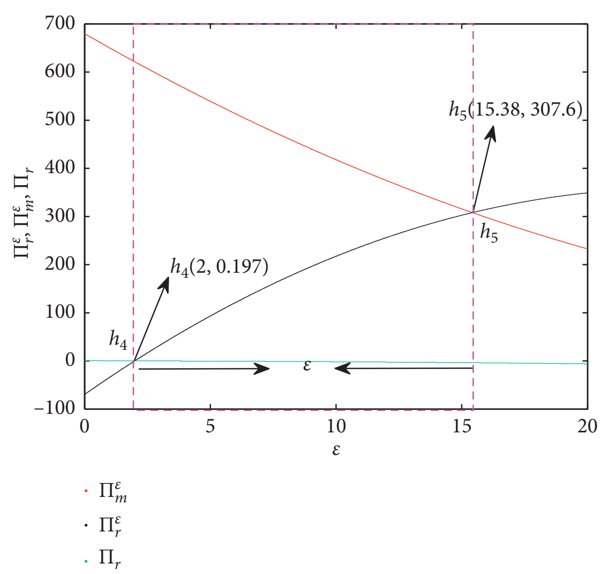


FIGURE 27: Profits of system $(\prod_r^\varepsilon, \prod_m^\varepsilon$, and $\prod_r)$ with respect to ε.

different price adjustment expectations have different effects on the profit of system (25).

Next, the combined effect of β_1, s, and ε on the profits of the manufacturer and retailer is to be explored in two situations.

Situation 3. System (25) falls into chaos with respect to β_1 and s.

Figure 33 shows the variation of $\prod_m$ and $\prod_r$ with β_1 and s. It indicates that, with s increasing, $\prod_m$ increases while $\prod_r$ decreases. We can know that smaller s and bigger β_1 can easily lead system (25) into chaotic state, causing $\prod_m$ and $\prod_r$ fluctuation. On the contrary, bigger s and smaller β_1 are helpful to keep system (25) stable and help the manufacturer and retailer to obtain maximum profits.

Situation 4. System (25) falls into chaos with respect to β_1 and ε.

As shown in Figure 34, $\prod_m$ decreases while $\prod_r$ increases with ε increasing. Meanwhile, it can be found that the larger ε is, the less likely the system (25) goes into bifurcation and chaos. When β_1 is less than a certain value, the system is in a stable state, and the profits of the manufacturer and retailer are also stable. In order to ensure the stability of system (25) and obtain stable profits, the manufacturer and retailer need to cooperate to make price decisions and service decisions.

5. Control of Complexity Dynamics

From the above numerical simulation and analysis, it can be seen that α_i, β_i, s, and ε affect the stability and complexity of the system. Once the system goes into chaos, the whole

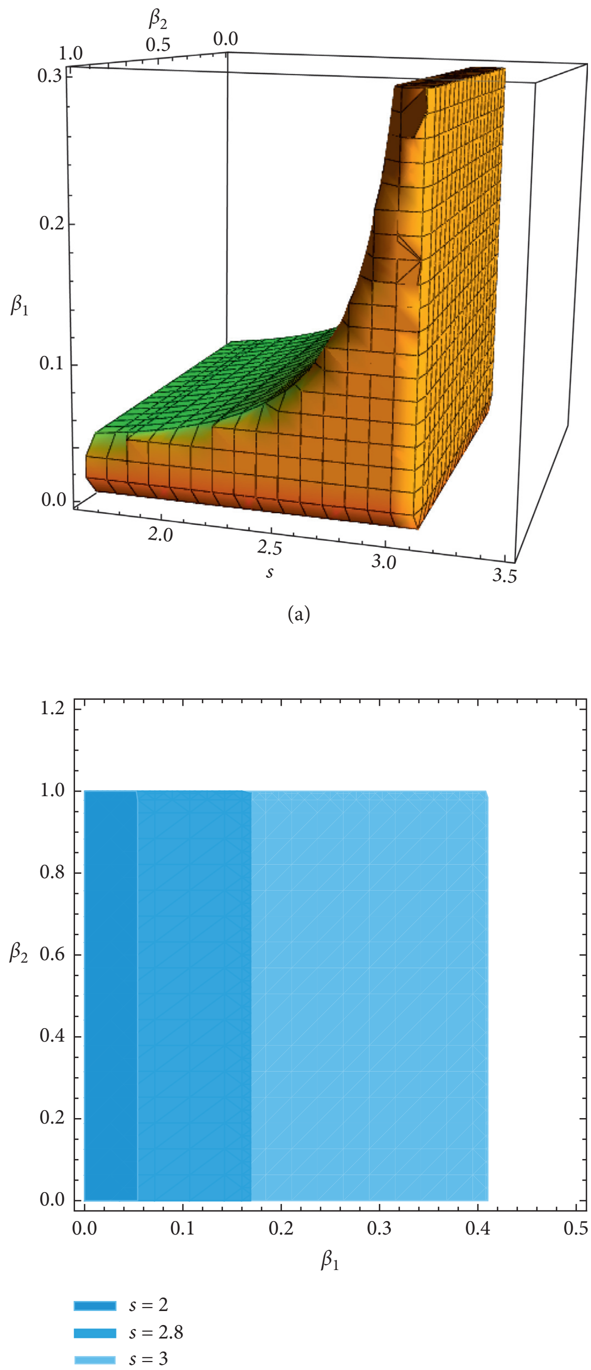


FIGURE 28: Stable region with respect to β_1, β_2, and s. (a) 3D stable region. (b) 2D stable region in the (β_1, β_2) plane.

market becomes disordered and unpredictable, and profits of the supply chain fluctuate or even decline sharply. In this state, it is difficult for the manufacturer and retailer to make next price decisions based on current profit. Thus, controlling chaos is beneficial to the whole supply chain.

In chaos control, some scholars have studied the control methods of the chaotic system [27, 32, 37]. According to the characteristics of this paper, this paper takes system (25) as

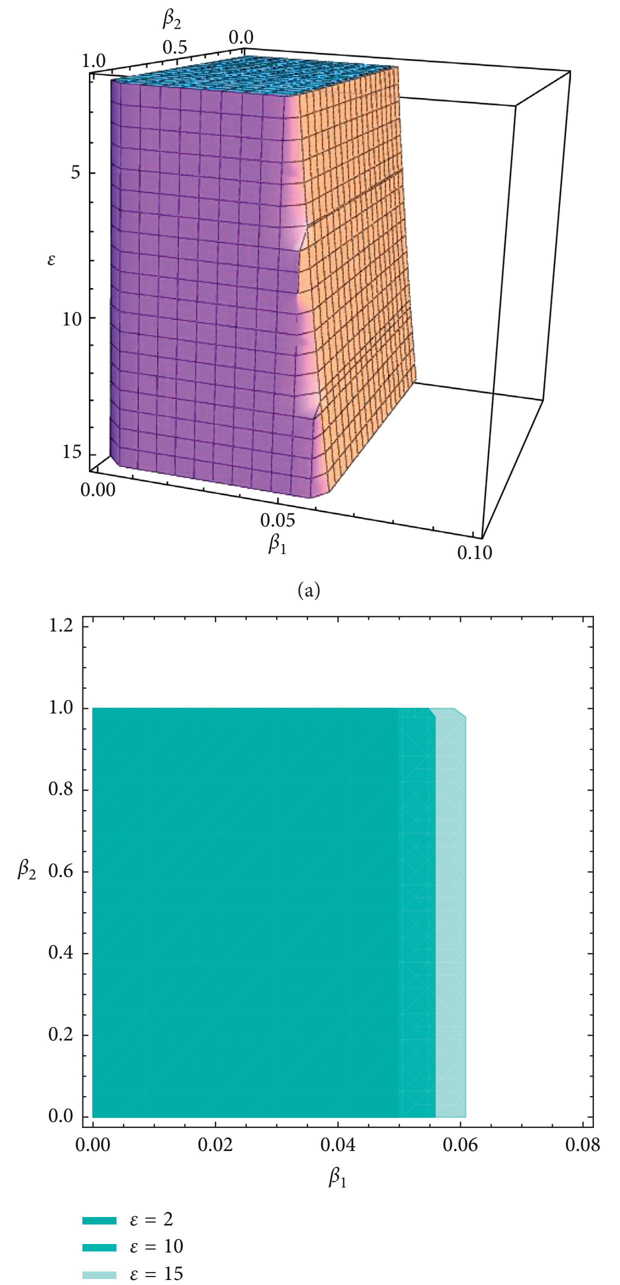


FIGURE 29: Stable region with respect to β_1, β_2 , and ε. (a) 3D stable region. (b) 2D stable region in the (β_1, β_2) plane.

TABLE 3: 2D stable region with respect to s and ε in the (β_1, β_2) plane.

s/ε	β_1	β_2
$s = 2.0$	(0, 0.0563)	(0, 1)
$s = 2.8$	(0, 0.1706)	(0, 1)
$s = 3.0$	(0, 0.4113)	(0, 1)
$\varepsilon = 2.0$	(0, 0.0498)	(0, 1)
$\varepsilon = 10$	(0, 0.0558)	(0, 1)
$\varepsilon = 15$	(0, 0.0611)	(0, 1)

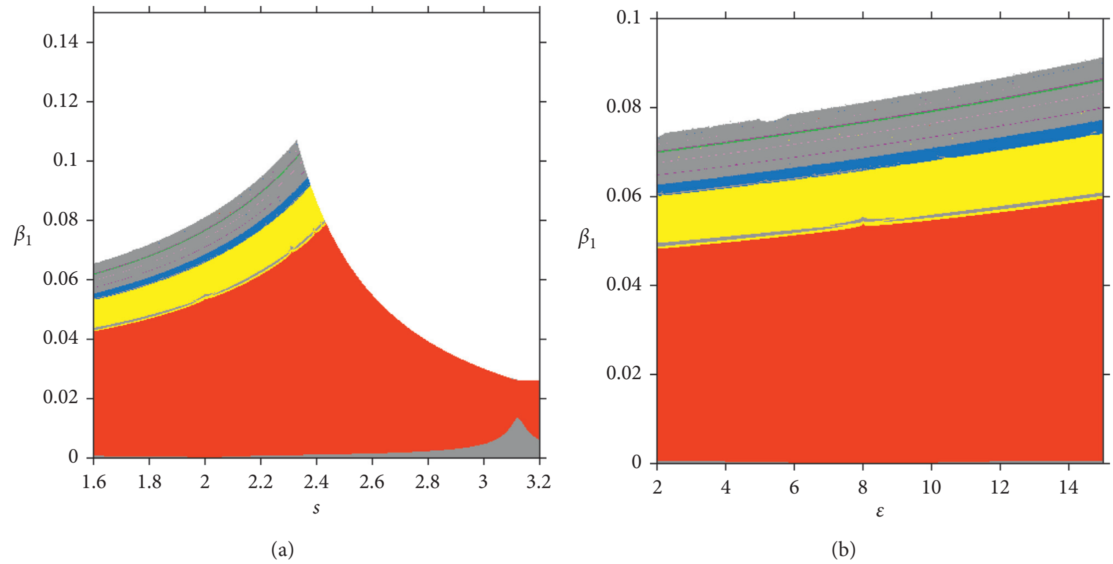


FIGURE 30: 2D bifurcation diagrams for periodic cycles. (a) 2D bifurcation with respect to β_1 and s. (b) 2D bifurcation with respect to β_2 and ε.

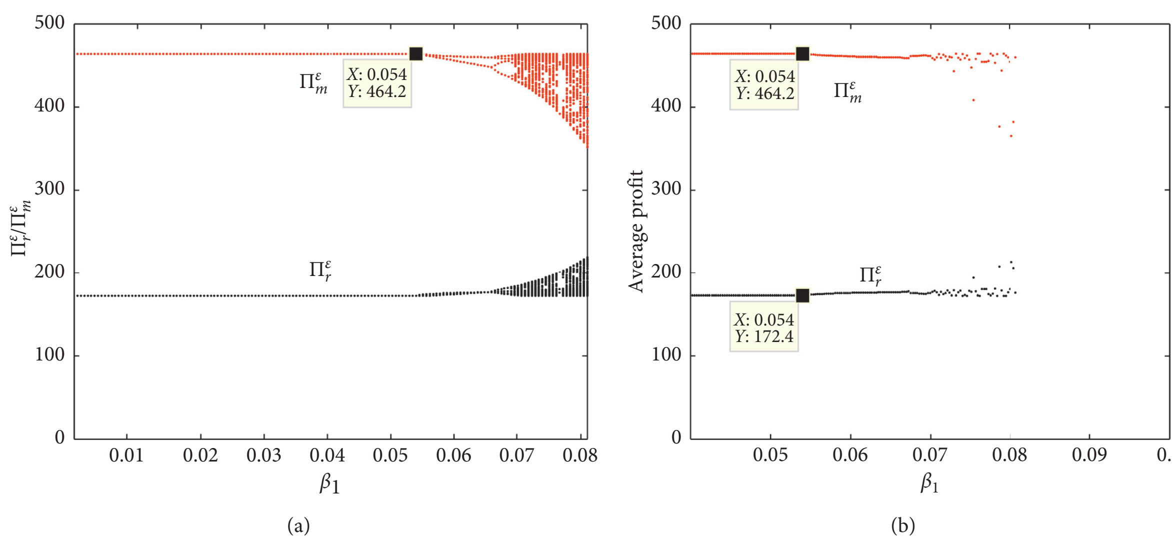


FIGURE 31: The bifurcation diagram and average profit diagram of $\prod_r$ and $\prod_m$ with respect to β_1 as $s = 2$ and $\varepsilon = 8$. (a) The bifurcation diagram. (b) The average profit diagram.

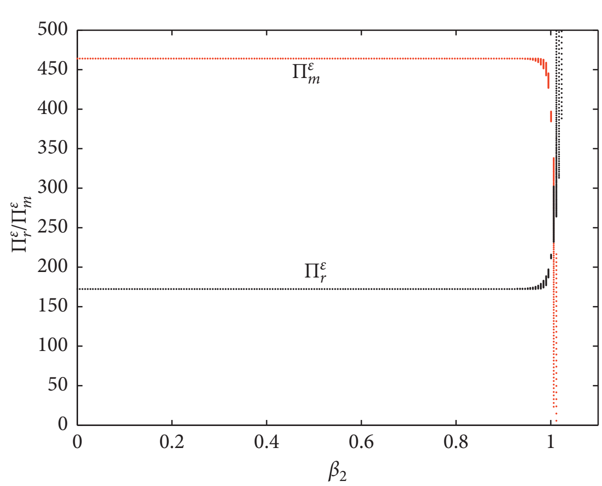


FIGURE 32: The bifurcation diagram of $\prod_r$ and $\prod_m$ with respect to β_2.

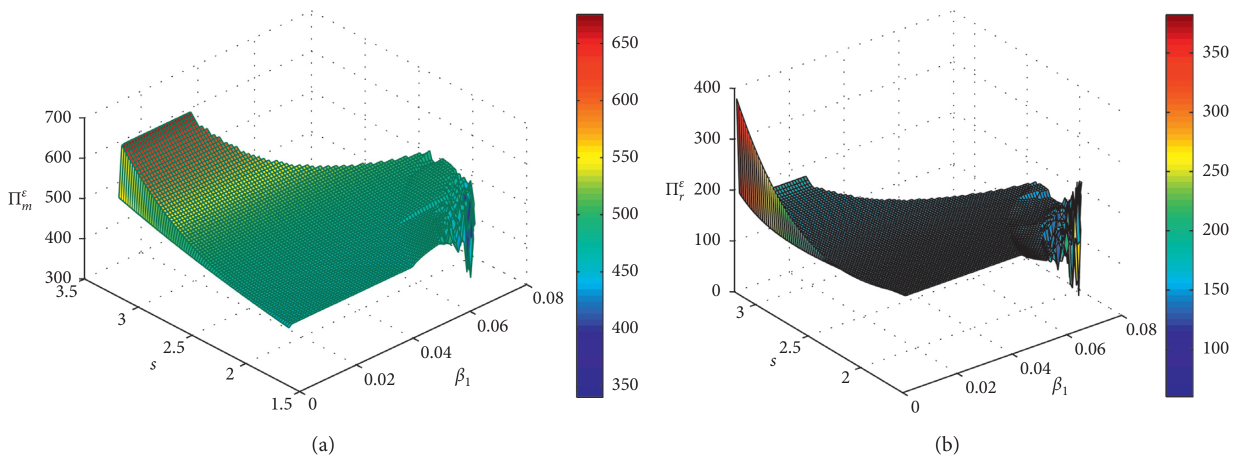


FIGURE 33: 3D profit diagrams of the manufacturer and retailer with β_1 and s, as $\beta_2 = 0.5$ and $\varepsilon = 8$. (a) 3D profit diagrams of the manufacturer. (b) 3D profit diagrams of the retailer.

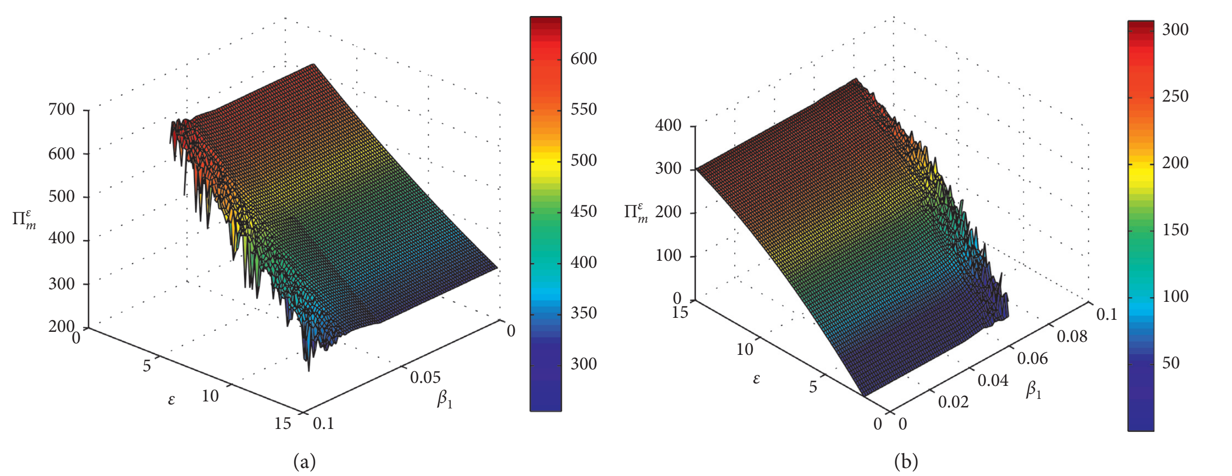


FIGURE 34: 3D profit diagrams of the manufacturer and retailer with β_1 and ε, as $\beta_2 = 0.5$ and $s = 2$. (a) 3D profit diagrams of the manufacturer. (b) 3D profit diagrams of the retailer.

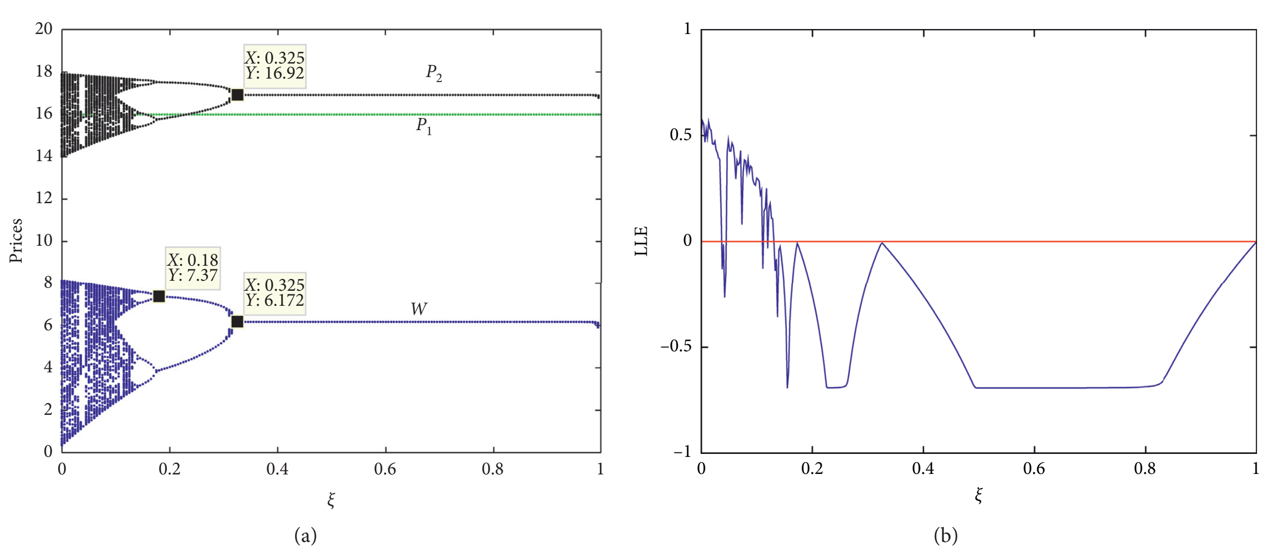


FIGURE 35: The price evolution process of system (32) with respect to ξ. (a) The bifurcation diagram. (b) The LLE diagram.

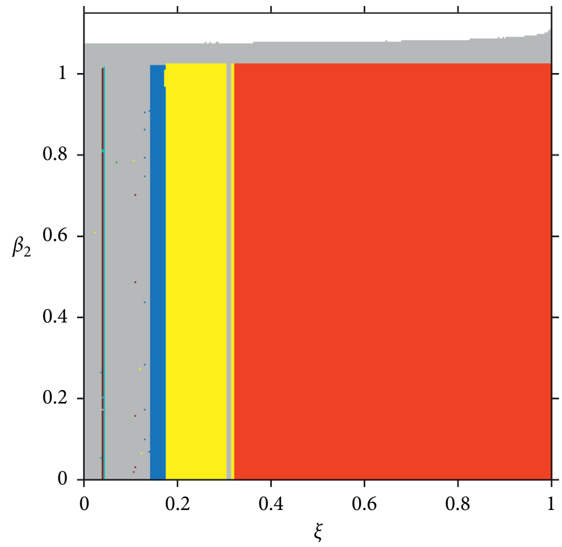


Figure 36: 2D bifurcation diagram with respect to β_2 and ξ.

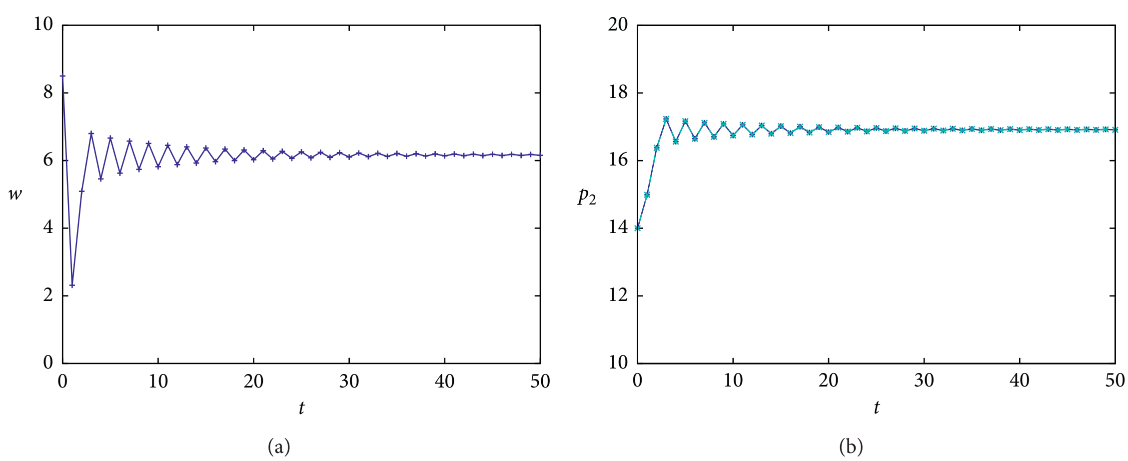


Figure 37: Initial value sensitivity of system (32) after being controlled as $\xi = 0.35$. (a) Initial value sensitivity of w. (b) Initial value sensitivity of p_2.

an example, and a chaos control method based on state feedback is adopted. Supposing system (25) is described as $w_{t+1} = T_1(w_t, p_{1,t})$, $p_{1,t+1} = T_2(p_{1,t})$. Then, the control system can be obtained as follows:

$$\begin{cases} w_{t+1} = (1-\xi)T_1\left(w_t, p_{1,t}\right) + \xi w_t, \\ p_{1,t+1} = T_2\left(p_{1,t}\right). \end{cases} \quad (31)$$

Namely,

$$\begin{cases} w_{t+1} = (1-\xi)\left(w_t + \beta_1 w_t\left(\frac{3}{2}p_1\gamma_1 - m_T w_t + \frac{a\theta_3 + m_T v - \eta m_T v^2 + \varphi\eta\gamma_1 v^2 + m_T c - 2c\gamma_1 - 2\gamma_1\varepsilon}{2}\right)\right) + \xi w_t, \\ p_{1,t+1} = \beta_2 p_{1,t} + (1-\beta_2)\frac{-4F_3 m_T - 6F_1\gamma_1^2}{4F_2 m_T + 9\gamma_1^3}, \end{cases} \quad (32)$$

where ξ is a feedback control parameter $(0 < \xi < 1)$. When $\xi = 0$, system (32) is in chaotic state.

The price evolution process of system (32) with respect to ξ is shown in Figure 35. When $\xi > 0.18$, in Figure 35(a), system (32) gets rid of chaos and four-period bifurcation and enters into two-period bifurcation state. Continuing to improve ξ to 0.325, system (32) goes into the stable state. In Figure 35(b), when $\xi > 0.325$, the LLE $(\text{LLE} < 0)$ confirms that the chaos of system has been controlled effectively.

Figure 36 shows 2D bifurcation diagram with respect to β_2 and ξ. With ξ increasing, system (32) experiences chaos and double period bifurcation and goes into stable state. When β_2 and ξ are in the red area, it is advantageous for the manufacturer and retailer to achieve business goals. The sensitivity of the system compared with Figure 25 can also be suppressed effectively in Figure 37.

6. Conclusions

In this paper, based on channel integration and service cooperation, we build two dynamic game models: one without unit profit allocation (M) and the other one with unit profit allocation (M^{ε}). In model M, first, we investigate the influence of adjusting parameters on the evolution of dynamic models and analyse the complex characteristics of the dynamic model. Second, we analyzed the influence of service value on the stability and complexity of the dynamic system. Finally, the combined effect of adjusting parameters and service value on the profit evolution of the dynamic model is explored. In model M^{ε}, we do similar research as model M and analyze and compare model M^{ε} with model M. Based on adaptive feedback, the dynamic game model is effectively controlled. The results show the following:

(1) The dynamic system shows bifurcation and chaos with adjustment parameters $(\alpha_1 \text{ and } \beta_1)$ increasing, and the prices will fluctuate violently. Increase in adjustment parameters $(\alpha_2 \text{ and } \beta_2)$ will lead the system directly into wave chaos without bifurcation. The manufacturer can avoid occurrence of chaos phenomenon by reasonable price decisions.

(2) Increasing service value s and profit distribution law ε will increase the stable region of the system. The larger distribution law will delay the system going into chaos.

(3) In the two models, the effect of service value s on profit is different. In model M, the profits of the manufacturer and retailer increase with service value s. In model M^{ε}, the manufacturer's profit increases while the retailer's profit decreases.

(4) When the system is in stable state, the manufacturer and retailer can get steady and persistent profits; once the system goes into chaos, their profits will suffer losses. Thus, keeping the relevant parameters in a certain range is profitable for the manufacturer and retailer to maintain the stability of the system.

However, this article does not take into account the behavior factors of the decision-makers, such as fairness concerns and altruistic preference. In the real market, these factors often affect the evolution and complexity of the dynamic system and profit of decision-makers. These problems will be studied in our future research.

Appendix

A. Proof of Proposition 1

To solve the Stackelberg equilibrium, we first consider the retailer's optimal decision. Given w and p_1, the retailer chooses p_2 to maximize

$$\begin{aligned} \text{Max}\prod_r (p_2) &= (p_2 - w)D_T + (p_1 - w)D_B \\ &\quad - \eta s^2 D_T - \varphi\eta s^2 D_B \\ \text{s.t. } & w + \varphi\eta s^2 < p_1, c < w. \end{aligned} \tag{A.1}$$

The solution can be solved by first-order equations $(\partial \prod_r (p_2)/\partial p_2) = 0$:

$$\begin{aligned} p_2 &= \frac{\gamma_1}{m_T} p_1 + \frac{m_T - \gamma_1}{2m_T} w \\ &\quad + \frac{\theta_3 a + m_T s + m_T \eta s^2 - \gamma_1 \varphi \eta s^2}{2m_T} \\ \text{s.t. } & w + \eta s^2 < p_2. \end{aligned} \tag{A.2}$$

Submitting equation (A.2) into equation (4) and then taking the first-order partial derivatives of equation (4) with respect to p_1 and w can be shown as

$$\begin{cases} \dfrac{\partial \prod_m (w, p_1)}{\partial w} = \left(-m_B + \dfrac{\gamma_1}{2} + \dfrac{\gamma_1^2}{2m_T}\right) p_1 + \left(-m_T + 2\gamma_1 - \dfrac{\gamma_1^2}{m_T}\right) w + m_B s + m_T s \\ -A_1 (m_T - \gamma_1) + \dfrac{c}{2}\left(m_T - 3\gamma_1 + \dfrac{2\gamma_1^2}{m_T}\right) + a\theta_2 + a\theta_3 \dfrac{\partial \prod_m (w, p_1)}{\partial p_1} \\ = \dfrac{-2m_B m_T + m_T \gamma_1 + \gamma_1^2}{2m_T} w + \dfrac{2\gamma_1^2 - 2m_T \rho_1}{m_T} p_1 + \dfrac{A_1 m_T \gamma_1 + a m_T \theta_1 + c(m_B m_T - 2\gamma_1^2 + m_T \rho_1)}{m_T}. \end{cases} \tag{A.3}$$

Taking the second-order derivatives, we can calculate the Hessian matrix as follows:

$$H^1 = \begin{bmatrix} -m_T + 2\gamma_1 - \dfrac{\gamma_1^2}{m_T} & -m_B + \dfrac{\gamma_1}{2} + \dfrac{\gamma_1^2}{2m_T} \\ -m_B + \dfrac{\gamma_1}{2} + \dfrac{\gamma_1^2}{2m_T} & \dfrac{2\gamma_1^2}{m_T} - 2\rho_1 \end{bmatrix}. \quad (A.4)$$

Since $m_B > n_1\gamma_1$, $m_T > n_2\gamma_1$, and $\rho_1 > n_3\gamma_1$ ($n_i > 2$, $i = 1, 2, 3$), $\begin{vmatrix} -m_T + 2\gamma_1 - (\gamma_1^2/m_T) & -m_B + (m_T\gamma_1 + \gamma_1^2/2m_T) \\ -m_B + (m_T\gamma_1 + \gamma_1^2/2m_T) & (2\gamma_1^2/m_T) - 2\rho_1 \end{vmatrix} > (3/2)\gamma_1^2 - (25/64)\gamma_1^2 > 0$. Because the Hessian matrix H^1 is negative definite. Setting $(\partial\prod_m (w, p_1)/\partial w) = 0$ and $(\partial\prod_m (w, p_1)/\partial p_1) = 0$, the optimal solution of the manufacturer can be obtained as

$$\begin{cases} w^* = \dfrac{A_5A_4 - A_2A_6}{B_2^2 - B_3B_5}, \\ p_1^* = \dfrac{A_3A_6 - A_2A_4}{A_2^2 - A_3A_5}. \end{cases} \quad (A.5)$$

Substituting equation (A.5) into (A.2), we obtain

$$p_2^* = \frac{\gamma_1 (A_3A_6 - A_2A_4)}{m_T (A_2^2 - A_3A_5)} + \frac{(m_T - \gamma_1)(A_5A_4 - A_2A_6)}{2m_T (A_2^2 - A_3A_5)} + A_1. \quad (A.6)$$

B. Proof of Proposition 2

The Jacobian matrix at the equilibrium points e_1 is

$$J(e_1) = \begin{bmatrix} 1 + \alpha_1\left(\dfrac{A_2A_3A_6 - A_2^2A_4}{A_2^2 - A_3A_5} + A_4\right) & 0 \\ 0 & \alpha_2 \end{bmatrix}. \quad (B.1)$$

Correspondingly, let us define the characteristic polynomial of $J(e_1)$: $f(\lambda) = \lambda^2 - \lambda \mathrm{tr}(J(e_1)) + \det(J(e_1))$. Its characteristic values satisfy

$$\begin{vmatrix} \lambda - \left(1 + \alpha_1\left(\dfrac{A_2A_3A_6 - A_2^2A_4}{A_2^2 - A_3A_5} + A_4\right)\right) & 0 \\ 0 & \lambda - \alpha_2 \end{vmatrix} = 0. \quad (B.2)$$

It can be deduced as $\lambda_1 = \alpha_2$ and $\lambda_2 = 1 + (A_3\alpha_1 (A_2A_6 - A_4A_5)/A_2^2 - A_3A_5)$, since $0 < \alpha_1$, $(A_3\alpha_1 (A_2A_6 - A_4A_5)/A_2^2 - A_3A_5) > 0$, and it is obvious that $\lambda_2 > 1$; hence, the equilibrium point e_1 is unstable.

C. Proof of Proposition 3

The Jacobian matrix of system (25) can be expressed as follows:

$$J(e_i^\varepsilon) = \begin{pmatrix} 1 + \beta_1\left(\dfrac{3}{2}p_1\gamma_1 - 2m_Tw + B_1\right) & w + \dfrac{3}{2}\beta_1 w\gamma_1 \\ 0 & \beta_2 \end{pmatrix}, \quad i = 1, 2. \quad (C.1)$$

The Jacobian matrix at e_1^ε is $J(e_1^\varepsilon) = \begin{pmatrix} 1 + \beta_1 ((-6m_TB_3\gamma_1 - 9B_1\gamma_1^3/4m_TB_2 + 9\gamma_1^3) + B_1) & 0 \\ 0 & \beta_2 \end{pmatrix}$; correspondingly, let us define the characteristic polynomial of $J(e_1^\varepsilon)$ as

$$f(\lambda) = \lambda^2 - \lambda tr(J(e_1^\varepsilon)) + \det(J(e_1^\varepsilon)). \quad (C.2)$$

Its characteristic values satisfy

$$\begin{vmatrix} \lambda - \left(1 + \beta_1\left(\dfrac{-6m_TB_3\gamma_1 - 9B_1\gamma_1^3}{4m_TB_2 + 9\gamma_1^3} + B_1\right)\right) & 0 \\ 0 & \lambda - \beta_2 \end{vmatrix} = 0. \quad (C.3)$$

It can be deduced that $\lambda_1 = \beta_2$ and $\lambda_2 = 1 + \beta_1 ((-6m_TB_3\gamma_1 - 9B_1\gamma_1^3/4m_TB_2 + 9\gamma_1^3) + B_1)$, since $0 < \beta_2 < 1$, $p_1^* = (-4m_TB_3 - 6B_1\gamma_1^2/4m_TB_2 + 9\gamma_1^3) > 0$, and $B_1 > 0$. So, it is obvious that $\lambda_2 > 1$; hence, the equilibrium point e_1^ε is unstable and regarded as boundary equilibrium point.

Data Availability

No data were used to support this study.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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