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RESEARCH PAPER

Complex Dynamics for Airlines' Price Competition with Differentiation Strategy

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Abstract: To investigate the complex dynamics for airlines' price competition, this paper proposes a price competition model of airlines with differentiation strategy and with the theory of bifurcation of dynamical systems. The existence and stability of equilibrium points of the model are discussed according to dynamic stability criteria. The complex dynamics of this model in different market parameters are shown though numerical simulation. The simulation results show that the speed of price adjustment has a significant impact on the stability of the model, while the speed of price adjustment is larger than critical value, and the phenomenon of bifurcation and chaos will appear on the dynamic system. Compared with the Nash equilibrium profits, all airlines' profits are decreased obviously when chaos is occurred. Differentiation has an important impact on airlines' price and profits, it's helpful to have more competition advantage that to keep and strengthen the differentiation advantage against the competitors.

Key Words: air transportation; price competition; theory of bifurcation; airlines; complex dynamics

1 Introduction

For a long time, airlines in China have heavily relied on travel agents to sell their tickets, resulting in the control of air ticket prices falling behind the price loosening mechanism. Due to the lack of traffic right allocation standards, airlines in China have to adopt price strategies to compete with other transportation modes in order to increase their market share. Consequently, price wars always lead to certain chaos in the market and some major losses for the airlines themselves[1]. The air transport market in China is dominated by a few large airlines such as Air China, China Southern Airlines, and Eastern Airlines, which is a typical monopoly phenomenon. Under this situation, the price of one airline will inevitably influence the ticket pricing of its competitors and the structure of the entire market. Therefore, airlines should consider the corresponding actions of the competitors to ensure stability of the entire market when deciding ticket pricing strategies. In order to solve this problem, the game theory can be used as an effective approach.

In recent years, many researchers have studied the pricing and competition problems in the air transport market. Mou and Li[2] studied the sequential pricing problem with two airlines by non-cooperation game model. Lei and Zhou[3] set up a stackelberg game model of option pricing for air cargo and analyzed the airlines' optimal pricing decision. Rolf[4] analyzed the capacity option pricing in the air cargo industry with a two-stage model and a strategy of airline pricing. Xu *et al*.[5] studied the airlines' pricing dynamic problem under different seat allocation rules. Wang[6] investigated the airlines' pricing game model with complete and incomplete information separately; she analyzed the reasons of undesirable price wars between airlines. Xiao[7] studied the airlines' pricing problem by using the Hotelling model. Jing *et al*.[8] used the game theory to analyze the government controlled air ticket price policy. Other studies included general pricing strategies under revenue management, real time dynamic pricing, pricing under deterministic and stochastic demands, dynamic pricing with homogeneous products, and pricing problems for airline alliances[9–11].

While many studies both domestic and foreign have addressed and reached valuable conclusions on the airlines' price competition problem, some areas need to be further investigated. First, the majority of the papers assumed that airlines have perfect rationality in pricing decision-making, but in fact, airlines cannot get enough or complete information

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about the air transport market, so airlines' price competition can only be of a bounded rationality. Secondly, most papers assumed that airlines are homogeneous; however, considering the airline network, quality of service, and marketing channel, it is impossible for two airlines to provide the same products. Thirdly, many of the papers focused on the static game model of airlines' price competition. But when the bounded rationality of a decision is taken into consideration, airlines need a lot of time to do the pricing game repeatedly in order to gradually achieve market equilibrium.

Due to the three points mentioned above and the lack of elasticity of aviation demand in China[8], we adopt the average pricing model, and build the airlines' price competition game model with differentiation strategy and bounded rationality. By using the theory of bifurcation of dynamic systems we analyze the existence and stability of equilibrium points of the dynamic price competition model and tackle the airlines' dynamic behaviors under different market parameters through a numerical simulation.

2 Model description

This paper considers that only two airlines have repeated dynamic price competitions in the air transport market. Let $p_i(t)$, i=1, 2 represent the ticket price of the ith airline and $q_i(t)$ represent the passenger traffic volume at discrete periods t, t=0, 1, 2, ⋯. According to the function of consumer utility and demand by Dowrick and Raju, we can obtain the following market demand function:

$$\begin{aligned} q_1(t) &= a_1 - b_1 p_1(t) + \theta_1 p_2(t) \\ q_2(t) &= a_2 - b_2 p_2(t) + \theta_2 p_1(t) \end{aligned} \tag{1}$$

where a_i (i=1, 2) are positive parameters of the ith airline's market demand, and positive parameters b_i represent the price-sensitivity coefficient, which means the larger the value, the larger the price elasticity of demand. The cross-price elasticity coefficient, positive parameter θ_i, is the differential parameter representing the differentiation between two airlines. To be more specific, the differential parameter θ_1 represents the second airline's differentiation towards the first airline. The smaller the value of θ_1, the larger the differentiation between the two airlines is and the alternative is smaller. Distinguishingly, when θ_1=0, it denotes that the products of the two airlines are completely different. At this moment, the second airline's differentiation to the first airline is the biggest and the substitution is the smallest. When $0<\theta_i<b_i$ (i=1, 2), it means that the cross-price effect is lower than its own price effect on airlines. In this paper we let $a_1=a_2$, $b_1=b_2$, $\theta_1\neq\theta_2$ for convenient expression. Therefore, Eq. (1) becomes the following form:

$$\begin{aligned} q_1(t) &= a - b p_1(t) + \theta_1 p_2(t) \\ q_2(t) &= a - b p_2(t) + \theta_2 p_1(t) \end{aligned} \tag{2}$$

It is assumed that the cost function has the linear form of $C_i=c_i q_i$. With these assumptions, the profit of the ith airline at period t is given by:

$$\Pi_i(p_1(t), p_2(t)) = (p_i(t) - c_i)(a - bp_i(t) + \theta_i p_j(t)) \tag{3}$$

where i, j=1, 2, $i\neq j$. Taking the partial derivative of $\Pi_i(p_1, p_2)$ about p_i and the marginal profit for the ith airline at an arbitrary period t of the strategy space gives:

$$\frac{\partial \Pi_i(p_1, p_2)}{\partial p_i} = (a + bc_i) - 2bp_i(t) + \theta_i p_j(t) \tag{4}$$

This optimization price reaction decision problem has a unique solution in the form based on Eq. (4).

$$p_i(t) = \frac{(a + bc_i) + \theta_i p_j(t)}{2b} \tag{5}$$

While the information in the air transport market is completely rational, the ith airline can use Eq. (5) to decide its market price. Thus, Eq. (5) is usually called the "perfect decision".

As the airlines are bounded rationally in price decision-making, the price has to constantly be adjusted to achieve the market equilibrium state with many periods of price competition. It is assumed that both airlines use "myopic" adjustment mechanism. Thus airlines determine their price with the information of marginal profit maximization from the last period. The airline decides to increase (decrease) its market price at period (t+1) if it has estimated to have a positive (negative) marginal profit at period t. Thus, the dynamic adjustment mechanism can be modeled as

$$p_i(t+1) = p_i(t) + \alpha_i p_i(t) \frac{\partial \Pi_i(p_i(t), p_j(t))}{\partial p_i} \tag{6}$$

where α_i are positive parameters which represent the speed of price adjustment of the ith airline which is the reflection of the reaction speed of marginal profit.

Hence the airlines dynamic price competition game in this case is formed from combining Eqs. (4) and (6). Then the dynamic system of differentiation strategy and bounded rationality is described by:

$$\begin{cases} p_1(t+1) = p_1(t) + \alpha_1 p_1(t)\left[(a + bc_1) - 2bp_1(t) + \theta_1 p_2(t)\right] \\ p_2(t+1) = p_2(t) + \alpha_2 p_2(t)\left[(a + bc_2) - 2bp_2(t) + \theta_2 p_1(t)\right] \end{cases} \tag{7}$$

3 Analysis of equilibrium point and local stability

Because the airline dynamic price competition game is an economic model, we define the equilibrium points of game as nonnegative fixed points which define dynamic system (7) as:

$$\begin{cases} p_1(t)\left[(a + bc_1) - 2bp_1(t) + \theta_1 p_2(t)\right] = 0 \\ p_2(t)\left[(a + bc_2) - 2bp_2(t) + \theta_2 p_1(t)\right] = 0 \end{cases} \tag{8}$$

By setting $p_i(t+1)=p_i(t)$ in Eq. (7), we can have at most four fixed points $E_0=(0, 0)$, $E_1=(0, (a+bc_2)/2b)$, $E_2=((a+bc_1)/2b, 0)$, and $E^* = (p_1^*, p_2^*)$, where,

$$p_1^* = \frac{2b(a + bc_1) + \theta_1(a + bc_2)}{4b^2 - \theta_1\theta_2},\ p_2^* = \frac{2b(a + bc_2) + \theta_2(a + bc_1)}{4b^2 - \theta_1\theta_2} \tag{9}$$

It is easy to verify that $p_i^* > 0$ according to the assumption of $0<\theta_i<b$ (i=1, 2) and $4b^2-\theta_1\theta_2>0$. The fixed points E_0, E_1, E_2

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