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Research on price Stackelberg game model with probabilistic selling based on complex system theory

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ABSTRACT

Probabilistic selling can expand the market and decrease uncertain demand. In this paper, we study a scenario that two manufacturers delegate a retailer to sell two substitute brand-products through traditional selling channel and probabilistic products through probabilistic selling channel; the customer has risk aversion behavior for probabilistic product. A non-cooperative dynamic price Stackelberg game model is developed based on limited rational expectation. The influences of parameters on the system stability are further analyzed; the phenomenon of flip bifurcation, chaos, and other complex phenomena are reported using bifurcation, attractor and power spectrum etc. The results show that the system stability could be robust with increase in customer's risk aversion and the probability of each product becoming to probability product, and frail with increase in price discount. The manufacturer may benefit from a larger proportion of its product becoming to probabilistic product. When the chaos occurs, the market becomes abnormal, irregular and unpredictable; the two manufacturers should determine their price adjustment speed according to the parameters' values, to ensure the up and downstream enterprises keep stable. The nonlinear feedback control method is used to control the system's chaos. The derived results have very important theoretical and practical values for the two manufacturers and the common retailer.

1. Introduction

The development of information technology (IT) and economic globalization is creating more efficient shopping environment for selling probabilistic products. In recent years, the probabilistic selling has been put forward and recently obtained great attention, which can be generated by retailers through mixing products from different suppliers [1]. Cai et al [2] studied the probabilistic selling considering Channel structure and supplier competition, and obtained that the probabilistic selling can expand the market and decrease uncertain demand. However, they neglected the effect of parameters on the participants' profits. Fay and Xie [3] developed a formal model considering buyer uncertainty which examined the purchase options, advance selling or probabilistic selling, and explored the differences via two different mechanisms homogenizing heterogeneous consumers and separating heterogeneous consumers. Anderson and Xie [4] developed a stylized model to analyze the pricing and market segmentation using opaque selling mechanisms.

Probabilistic selling can reduce the uncertainty demand which is noted by many scholars. Cheng [5] developed a quality-price game in a fully covered market where firms were uncertain about consumer tastes regarding quality. Banker et al. [6]

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investigated empirically and analytically the relationship between demand uncertainty and cost behavior, and obtained that the higher uncertain demand would lead the demand increasing. Chen et al. [7] investigated the long-term influences of demand uncertainty and market concentration on price instability in the hotel industry. Yang and Ng [8] established a flexible capacity strategy model with multiple market periods under investment constraints and demand uncertainty, and optimized the capacity, safety production, and the sales of each market period under different situations. Firms can benefit from creating buyer uncertainty by selling in advance [9,10]. Fay and Xie [1] studied the strategic effect of probabilistic selling and obtained that offering probabilistic products could reduce the seller's information disadvantage, increase profit and solve the mismatch between capacity and demand. Facing risks caused by uncertainties in end product demand and component availability, a scenario in an illustrative manufacturing company was developed for modeling demand and supply uncertainties [11]. Kwag and Kim [12] constructed a reliability model of the demand resource which was generalized by a multi-state model considering customers' behaviors. Askar [13] proposed a Cournot oligopoly game where quantity-setting firm used unknown nonlinear demand function and random cost function, analyzed its complete stability and bifurcation behaviors. Moreover, this idea of uncertainty was also applied in inventory [14], network design problem [15] and bullwhip effect [16].

Above literatures complemented extant research on uncertainty demand, the probabilistic selling or opaque selling can weaken the negative effect of uncertain demand. However, they studied the probabilistic selling or opaque selling under the static environment.

Literature on the channel structure, as well as competition between the suppliers was studied by many scholars. Tetteh et al. [17] developed four view Markov chain models to investigate how to control cost of inventory by analyzing the impact of speculation in a dual-supply chain. Dan et al. [18] analyzed price and service competition in the dual-channel supply chain which consists of a manufacturer and two retailers, investigated the influence of power structure on equilibrium price and service decisions, and proposes some competitive strategies for traditional retailer under e-commerce environment. Chiarella et al. [19] used a maximum likelihood approach on data to estimate a structural model. By using differential game theory, Sayadi and Makui [20] investigated the influence of dynamic brand and channel advertising on market expansion and market share in a dual channel supply chain, and showed that a higher compatibility of a product with online marketing, a higher advertising effort for the online channel by the manufacturer.

These literatures studied the different channel structure, as well as competition between the suppliers, analyzed the optimal solution in different conditions. But they did not consider the influence of the customer's risk preference on the system's decisions.

In our knowledge, there are few literatures using dynamics methodology to study the supply chains with probability selling. Rich dynamics characteristics in the economic and society system had been found, such as chaotic, or even hyper chaotic behavior. Ma and Tu [21] considered the macroeconomic model of money supply with time delays, discussed the effect of delay variation on system stability and Hopf bifurcation. Yang et al. [22] studied rich dynamics of a nonlinear economic model, found Chaotic and bubbling phenomena which clearly agreed with phenomena from technology bubbling. Ma and Li [23] constructed a dynamic bertrand–Stackelberg pricing model to analyze the influence of uncertain demand on the profit and complexity. Chiarella et al. [24] incorporated the adaptive behavior of agents with heterogeneous beliefs and establishes an evolutionary capital asset pricing model (ECAPM) within the mean-variance framework. Ma and Pu [25] studied the Cournot–Bertrand duopoly model, analyzed the stability of the fixed points, and recognized the chaotic behavior of the system.

We will study the dynamics characteristics of supply chains with probabilistic selling considering the customer has risk aversion behavior for probabilistic product. A new model will be developed to dynamic analyze the pricing and the stability of the supply chain with probabilistic selling. The mutual influence between variables and parameters and the dynamic phenomena will be analyzed through numerical simulation. The research is particularly vital and urgent to the practitioners because the development in new technology is making implementation of a probabilistic selling strategy much more efficient and practical.

In this paper, our primary aim is to propose a non-cooperative dynamic price Stackelberg game model with exogenous channel structure that involves manufacturer competition and the active role of a common retailer. Toward this aim, we will construct a non-cooperative dynamic price Stackelberg game model in which two manufacturers intend to sell their products to consumers who have heterogeneous preferences and risk preferences, and a common retailer is capable of generating the probabilistic product.

The remainder of this paper is organized as follows: In Section 2, we discuss the problems of consumer preferences and transaction process, and develop the dynamic price Stackelberg game model. Section 3 focuses on the stability of the dynamic price Stackelberg game model. The dynamic characteristics of the price Stackelberg game model are analyzed under different parameters change in Section 4. In last section, we outline some conclusions and relevant recommendations for future research.

2. The dynamic price Stackelberg game model

2.1. Assumptions

The following assumptions are made to develop our model in this paper.

(i) Two manufacturers (A and B) provide two substitute products (a and b), a common retailer (R) can sell the probabilistic product using probabilistic selling channel and traditional product using traditional selling channel. The two