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Complexity analysis of dynamic noncooperative game models for closed-loop supply chain with product recovery

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ABSTRACT

In this paper, we consider a closed-loop supply chain (CLSC) with product recovery, which is composed of one manufacturer and one retailer. The retailer is in charge of recollecting and the manufacturer is responsible for product recovery. The system can be regarded as a coupling dynamics of the forward and reverse supply chain. Under different decision criteria, two noncooperative game models: Stackelberg game model and peer-to-peer game model are developed. The dynamic phenomena, such as the bifurcation, chaos and sensitivity to initial values are analyzed through bifurcation diagrams and the largest Lyapunov exponent (LLE). The influences of decision parameters on the complex nonlinear dynamics behaviors of the two models are further analyzed by comparing parameter basin plots, and the results show that with the improvement of retailer's competitive position, the CLSC system will be more easier to enter into chaos.

1. Introduction

The continuous development of human activities and its economy, the vitality of protecting the environment is now central to policy makers as they have realized that the amount of resources and ecology are limited for human consumption. Government legislations were introduced in Europe, North America, Japan, China and other regions to protect the ecological environment and save resources. This prompted many corporations to reduce production costs and improve profits from used-products, and more companies joined in the closed-loop supply chain (CLSC) [1]. As it is both economically and environmentally sustainable, CLSC has been viewed as one of the most suitable strategies in the future [2,3].

CLSC can be regarded as an integration of the forward and reverse supply chains [2,4]. The forward supply chain (FSC) contains a series of activities resulting in the conversion of raw materials to finished products, and managers are trying to improve forward supply chain performances in areas such as demand management, procurement and order fulfillment. The reverse supply chain (RSC) is defined as the process of the collecting and recovery of used products.

In the past few years, CLSC has gained considerable attention in both the academia and practice. Pan et al. [5] formulated a dynamic programming model. They showed that the problem with only disposal or remanufacturing could be converted into a traditional capacitated lot sizing problem. Then it can be solved by a polynomial algorithm if the capacities are constant. A pseudo-polynomial algorithm was proposed for the problem with both capacitated disposal and remanufacturing. Yang et al. [6] developed a general CLSC network model, including raw material suppliers, manufacturers, retailers,

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consumers and recovery centers, to formulate and optimize the equilibrium state by using the theory of variational inequalities. Shi et al. [7] developed a CLSC system model to determine the production quantities of brand-new and remanufactured products, prices of products acquire and setting price respectively to get an overall maximization of profit. A numerical example illustrated the impacts of the uncertainties of demand and return of production plan selling and acquisition price of used products. Amin and Zhang [8] investigated a CLSC network including multiple plants, collection centers, demand markets, and products. A mixed-integer linear programming model was proposed that minimizes the total cost. They also extended the model to consider environmental factors by weighed sums and e-constraint methods and investigated the impact of demand and return uncertainties on the network configuration by stochastic programming.

The above literatures modeled the CLSC system from the view of optimization design, and the CLSC system also can be regarded as the game between the manufacturers and retailers under a certain market condition, so the system dynamics methodology is an important research perspective. Hammond and Beullens [9] expanded the work dealing with oligopolistic supply chains to the field of CLSC. They gave a CLSC network model consisting of manufacturers and consumer markets with perfect information. They pointed out CLSC equilibrium occurred when all players agreed on volumes shipped and prices charged. Vlachos et al. [10] gave a simulation model based on the principles of the system dynamics methodology to evaluate alternative long-term capacity planning policies using total supply chain profit as a measure of policy effectiveness. Georgiadis and Besiou [11] examined the impacts of ecological motivation and technological innovations on the long-term behaviors of a CLSC with recycling activities. They adopted system dynamics methodology applied to many environmental systems seeking long-term gains. Chen and Chang [12] dealed with a strategic issue of CLSC with remanufacturing by developing analytic models under cooperative and competitive settings to investigate the conditions under which an original equipment manufacturer (OEM) may take a cooperative approach by participating in remanufacturing. Their analysis revealed that the strategic decision depended critically on the costs of remanufacturing and the competition intensity. Gu et al. [13] and Wang et al. [14] studied the property of the equilibrium price of CLSC using the game theory method under retailers collecting mode and concluded the optimal strategy of a single stage. Guo and Ma [15] proposed a dynamic game model of CLSC system, which assumed that the node enterprises take the marginal utility maximization as the basis of decision-making. Through numerical simulation, the complex dynamic phenomena, such as bifurcations, chaos and continuous power spectrum of the model were analyzed.

Although CLSC has been widely studied, most models in the current literatures only consider one aspect of CLSC. New models need to be developed to consider the players' strategy choice on the stability of the system. In this paper, we propose two noncooperative game models under different decision criteria. The dynamic phenomena are analyzed through numerical simulation to analyze the influences of the decision parameters on the complex nonlinear dynamics behaviors.

The paper is organized as follows, the assumptions and notations are described in Section 2. In Section 3, we give a Stackelberg game model, and analyze its dynamic phenomena by numerical simulations. In Section 4, a peer-to-peer game model is proposed, and the dynamical behaviors are investigated. In Section 5, the influences of the decision parameters on the dynamic behaviors are analyzed by comparing parameter basin plots of the two models. Finally, conclusions are drawn in Section 6.

2. Model assumptions and notations

2.1. Assumptions

The following assumptions are made to develop the model for the CLSC system:

(i) The CLSC consists of a manufacturer and a retailer as shown in Fig. 1. The retailer collects waste products from consumers and returns the manufacturer. The manufacturer transfers payments to the retailer. The retailer sells products to consumers. The CLSC system can be seen as an integration of the forward and reverse supply chain. The manufacturer and the retailer are independent decision makers, and their goal is to maximize returns in discrete time period as $t = 0, 1, 2, \ldots$.

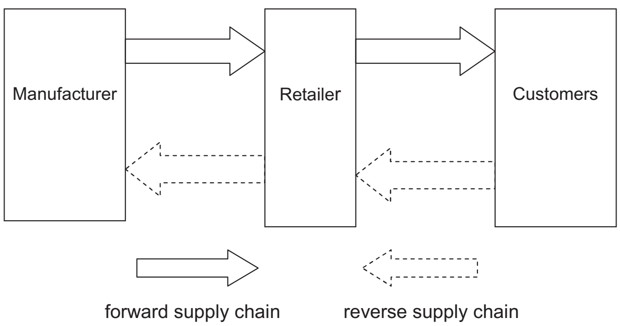

Fig. 1. The CLSC system.