Differential game model of joint emission reduction strategies and contract design in a dual-channel supply chain

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ABSTRACT

Joint emission reduction is widely used in low-carbon supply chain practices. It consists of the manufacturer's emission reduction and the retailer's advertising campaign. In this paper, we present a differential game that involves one manufacturer and one retailer in a dual-channel supply chain under low-carbon environment. We analyze the optimal equilibrium strategies in centralized and decentralized dual-channel supply chains, and compare the results of the single channel and dual-channel supply chains. We also discuss how the cooperative advertising contract and the cooperative advertising and emission reduction cost sharing contract affect the optimal strategies and coordination of dual-channel supply chains. Our results suggest that the emission reduction level trajectory is monotonic, whereas the goodwill trajectory changes direction once at most. Wholesale price and the degree of customer loyalty to the retail channel exert a significant influence on optimal strategies. Manufacturer's profit and emission reduction effort are higher and retailer's profit and advertising effort are lower in a dual-channel supply chain than in a single channel supply chain. The cooperative advertising and emission reduction cost sharing contract is more efficient than the cooperative advertising contract under certain conditions, and a high low-carbon and brand preference of consumers indicates a greater likelihood that the supply chain members will adopt the contract. The results can provide a theoretical basis for supply chain members to make optimal decisions and choose the appropriate contract in a dual-channel supply chain under low-carbon environment.

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1. Introduction

In recent years, under immense pressure from the energy crisis and climate change, people have started to explore sustainable economic development with low pollution and consumption, and various UN conventions and environmental regulations have been successively issued. In June 1992, more than 150 countries signed the United Nations Framework Convention on Climate Change, which was supplemented by the Kyoto Protocol in 1997 (www.kyotoprotocol.com). With the aim of reducing carbon emission and slowing down the progress of climate change, the follow-up scheme after the expiration of the first stage of the Kyoto Protocol was further discussed at the Copenhagen Climate Change Conference in 2009. In particular, the Chinese government explicitly promised at the Copenhagen Conference that the unit CO_2 emission of China in 2005 would decrease by 40%–45% in 2020 (cop23.unfccc.int/).

In such economic environment, manufacturing enterprises have begun to implement low-carbon management strategies and improve emission reduction technologies. At the same time, many retailers adopt advertising strategies to enhance consumers' low-carbon awareness and encourage their purchase of low-carbon products. Manufacturers' emission reduction and retailers' advertising campaign are referred to as joint emission reduction (Xu et al., 2016). Our study is based on one of the largest home appliance manufacturers in the world, Gree Electronic Appliances. In 2014, Gree presented the brand slogan "making the sky bluer and the earth greener" and formed strategic alliances with large appliance retailers, such as Gome and Suning. Under such alliances, Gree mainly utilizes new energy to develop environment-friendly products, whereas retailers such as Gome and Suning are mainly responsible for promoting the energy-saving products to ensure immediate market acceptance (http://www.gree.com.cn/).

Furthermore, the extensive application of internet technology has greatly changed traditional consumption patterns. With consumers' increasing acceptance of low-carbon products, many manufacturers, such as Lenovo, IBM and Sony, have begun selling low-carbon products directly to consumers through online channels (www.sys2011.com, www.ehaier.com). This is called the dual-channel supply chain, in which the manufacturer adopts both the retail channel and the online channel to sell its products. In this way, the online channel can help the manufacturer to enlarge market needs. However, for the retailer, the manufacturer is not only the supplier but also the competitor, thus, the channel conflict remains (Chen et al., 2012). Therefore, choosing the appropriate joint emission reduction strategies and coordination mechanisms becomes much more complex in a dual-channel structure and is of great practical significance for both the manufacturers and the retailers.

In game theory, differential games are a group of problems related to the modeling and analysis of conflict in the context of a dynamical system. More specifically, a state variable or variables evolve over time according to a differential equation (Dockner et al., 2000). The operational production of the manufacturer is usually multi-period rather than single period. Thus, conducting research from the long-run and dynamic perspectives is much more realistic. Accordingly, the present study explores the joint emission reduction strategies and coordination contracts in a dual-channel supply chain by using differential game model.

Some related literature examines the manufacturer and the retailer's joint emission reduction strategies in the single channel supply chain (Wang and Zhao, 2014; Xu et al., 2016). Studies such as Carrillo et al. (2014) and Li et al. (2016) also investigated dual-channel supply chain management under low-carbon environment. However, little research introduces the joint emission reduction problems into the dual-channel supply chain framework and considers the characteristics of the dynamics of emission reduction improvement activity. On the basis of observations and analysis, this study intends to answer the following questions:

(1) How do emission reduction level trajectory and goodwill trajectory change over time?
(2) How do wholesale price and the degree of customer loyalty to the retail channel affect optimal decisions in the dual-channel and single channel supply chains?
(3) How do the cooperative advertising (CA) contract and the cooperative advertising and emission reduction cost sharing (CA-ERCS) contract affect the optimal strategies and coordination of dual-channel supply chains?

The main contribution of this work is mainly embodied in the following aspects. First, this paper is the first to use differential game model to study the long-term decision problems in a dual-channel supply chain under low-carbon environment. Second, emission reduction level and advertising effort are both goodwill-building factors that positively affect goodwill; previous literature considers only the influence of advertising effort on goodwill. Third, this paper compares a CA contract with a CA-ERCS contract in a dual-channel context, whereas previous studies do not consider the channel conflict between direct and retail channels. This paper aims to provide a theoretical basis for the formulation of joint emission reduction strategies and the design of cooperation contracts in a dual-channel supply chain.

The remainder of this paper is organized as follows. Section 2 provides a literature review. Section 3 introduces the assumptions, notations, and the basic model. Section 4 analyzes the theoretical results of centralized and decentralized dual-channel supply chains, and compares the strategies of single-channel and dual-channel supply chains. The decentralized dual-channel supply chain is coordinated in Section 5. Numerical analysis is performed to gain more managerial insights in Section 6. Conclusions are drawn in Section 7.

2. Literature review

The related literature spans three streams: consumers' low-carbon preference, carbon emission reduction decisions under low-carbon environment, and contract coordination in low-carbon supply chains.

2.1. Consumers' low-carbon preference

With the development of the low-carbon economy, the environmental awareness of consumers has assumed a significant role in the management of low-carbon supply chains. Many scholars have conducted empirical research and theoretical analysis on consumers' low-carbon preference (Corbett and Klassen, 2006; Linton et al., 2007; Ibanez and Grolleau, 2008; Jacobs et al., 2010). Chitra (2007) explains that consumers become especially willing to pay more for low-carbon products when their low-carbon environmental awareness is strong. Liu et al. (2012) focus on the impact of consumers' environmental awareness on key supply chain players and find that retailers and manufacturers with superior eco-friendly operations will benefit as consumers' environmental awareness increases. Zhang et al. (2015) establish a multi-product newsvendor model to study the influences of consumers' low-carbon awareness on order quantity and channel coordination. In our paper, we also assume that consumers maintain a low-carbon preference and further investigate its impact on joint emission reduction strategies and contract design in a dual-channel supply chain.

2.2. Emission reduction decisions under low-carbon environment

In recent years, a growing number of scholars have become increasingly concerned about the study of emission reduction decisions under low-carbon environment (Upham et al., 2011; Absi et al., 2013; Zhao et al., 2014; Xu et al., 2016). The key distinctive features of the previous literature is the demand function, which relates market demand with supply chain members' pricing and emission reduction. The demand function strongly depends on the difference between static and dynamic model formulations. Thus, distinguishing the factors in the following discussion is appropriate.

2.2.1. Demand functions of static games
In the static model, Yalabik and Fairchild (2011) and Choudhary et al. (2015) investigate a firm that is facing regulatory penalties and reduced market demand due to carbon emissions, and explore the optimal emission reduction and pricing strategies. Sengupta (2012) discusses a manufacturer's pricing and investment behavior with environmentally conscious consumers. Results indicate that when companies realize that consumers are environmentally sensitive, they disclose their environmental performance directly to improve market response. Wang et al. (2016) develop a game model to analyze the manufacturer's emission reduction decisions in both the retailer-dominant and the power-balanced cases. Similar to the literature, our paper also considers price and emission reduction sensitive demand. By contrast, the above studies mainly center on a single manufacturer's emission reduction decisions and rarely explores the joint emission reduction behaviors among supply chain members.

Research on emission reduction problems in a dual-channel supply chain under low-carbon environment is limited. Carrillo