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The role of co-opetition in low carbon manufacturing

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ABSTRACT

Low carbon manufacturing has become a strategic objective for many developed and developing economies. This study examines the role of co-opetition in achieving this objective. We investigate the pricing and emissions reduction policies for two rival manufacturers with different emission reduction efficiencies under the cap-and-trade policy. We assume that the product demand is price and emission sensitive. Based on non-cooperative and cooperative games, the optimal solutions for the two manufacturers are derived in the purely competitive and co-opetitive market environments respectively. Through the discussion and numerical analysis, we uncovered that in both pure competition and co-opetition models, the two manufacturers' optimal prices depend on the unit price of carbon emission trading. In addition, higher emission reduction efficiency leads to lower optimal unit carbon emissions and higher profit in both the pure competition and co-petition models. Interestingly, compared to pure competition, co-opetition will lead to more profit and less total carbon emissions. However, the improvement in economic and environmental performance is based on higher product prices and unit carbon emissions.

1. Introduction

Decades of research has demonstrated that the fossil fuel leads to a higher carbon dioxide and greenhouse gases in the atmosphere which poses threats and challenges to human lives (Chen & Hao, 2015; Tang & Zhou, 2012). The recent economic recovery of many industrialized countries and the continuing industrialization of emerging economies have contributed to further global carbon emissions. Across different industry sectors, the manufacturing industry is often the single largest contributor to carbon emissions in many developed and developing economies (Fysikopoulos, Pastras, Alexopoulos, & Chryssolouris, 2014). Carbon footprint, historically defined as the total set of greenhouse gas emissions caused by an organization, event, product or person, has become a key evaluation factor when companies choose suppliers or customers make a purchase decision. For example, Walmart, Tesco, Hewlett Packard, and Patagonia require their suppliers to complete the carbon footprint certification and to guide customers to consider carbon footprint index rather than just the price and quality (Sundarakani, De Souza, Goh, Wagner, & Manikandan, 2010). Faced with novel realities, new generation of manufacturing process technologies has emerged (Chryssolouris, Papakostas, & Mavrikios, 2008; Fysikopoulos, Pastras, Vlachou, & Chryssolouris, 2014). Low carbon manufacturing defined as the manufacturing process that produces low carbon emission intensity through the effective and efficient use of energy and resources during the process (Chryssolouris, 2013; Tridech & Cheng, 2011). It has therefore become an important area of public policy and scholarly enquiry set against the background of increasing political and societal concerns about carbon emissions.

One response from regulatory and policy makers is to introduce various carbon emissions reduction policies such as mandatory carbon emission capacity and carbon emission taxes. In addition, many governments have also supplemented traditional "command and control" with emission trade schemes through which creating financial incentives for companies to invest in green innovations (Aidt & Dutta, 2004; Chaabane, Ramudhin, & Paquet, 2012; Lukas & Welling, 2014; Stavins, 2008). Among these schemes, cap-and-trade is one of the most influential regulatory policies, which provides the manufacturing sector a flexible market mechanism and a viable carbon emission reduction method. Manufacturers are motivated to reduce their carbon emissions level by improving energy efficiency of production process through green technology investment. While this policy may play a key role in achieving low carbon manufacturing, it will certainly affect firms' decisions at both strategic and operational levels.

In similar vein, the general public has also become increasingly sensitive to environmental issues. Buying low carbon products has become an irreversible trend. More importantly, this trend is no longer simply the choice of a few eco-conscious consumers,

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but has now shifted into the mainstream market (Fraj & Martinez, 2007; Kanchanapibul, Lacka, Wang, & Chan, 2014; Tsen, Phang, Hasan, & Buncha, 2006). For example, Echeverría, Moreira, Sepúlveda, and Wittwer (2014) indicated that consumers are willing to pay a premium price to products with carbon footprint. Consequently, carbon emission attribute of products has become an important factor influencing purchasing decisions and product demands. The growing number of environmental consciousness consumers gives manufacturing firms an economic incentive to invest in green technologies and to achieve low carbon manufacturing. At least, the emission sensitive demand should be considered when making the product pricing and emission reduction decisions.

From manufacturers' perspective, there is increasing realization of the importance of carbon emissions reduction. One important strategic response from the manufacturing sector is cooperation between autonomous firms such as supply chain collaboration, strategic alliances, and eco-industrial parks, focusing on inter-organizational interactions to reduce carbon emissions and other negative environmental effects (Kolk & Pinkse, 2004; Theißen & Spinler, 2014; Tudor, Adam, & Bates, 2007). The cooperation between competing firms for low carbon manufacturing is closely associated to the notion of co-opetition introduced by Brandenburger and Nalebuff (1996), which refers to the interdependence that entails competing and collaborating elements, with rivalry as well as collaborative mechanisms to maximize individual profits. Although the benefits of environmental collaboration have been widely discussed in the literature, to the best of our knowledge, no research has examined the role of co-opetition in low carbon manufacturing. Our research aims to fill this gap in the literature by examining the following key questions:

(1) Under the cap-and-trade policy, what effect does the manufacturers' carbon emission reduction efficiency have on their optimal prices, optimal green technology investments, and maximum profits?
(2) How to develop a pricing policy and green technology investment strategy to help manufacturers to maximize their economic benefit while minimizing the negative environmental impact?
(3) What effect does the purely competitive and co-opetitive relationships have on low carbon manufacturing?

To answer these questions, we consider two competing manufacturers with different emission reduction efficiencies under the cap-and-trade policy. They produce a same product and sell to end-users with a deterministic demand which is influenced by their own and competing manufacturer's prices and unit carbon emissions. Using the non-cooperative and cooperative games, our analysis attempts to derive the optimal pricing policies and green technology investment decisions for the two manufacturers in purely competitive and co-opetitive environments respectively. We also examine the effect of emission reduction efficiency and unit price of carbon emission trading on the manufacturers' optimal policies and maximum profits. Through a comparison of the optimal solutions between the purely competitive scenario and the co-opetitive scenario, this research intends to understand the role that co-opetition has in low carbon manufacturing.

The rest of this paper is organized as follows. A survey of related literature is presented in Section 2. Section 3 provides the model formulation and assumptions. In Sections 4 and 5, we investigate the pricing and emission reduction policies for two competing manufacturers in a purely competitive scenario and a co-opetitive scenario respectively. In Section 6, we focus on the effect of emission reduction efficiency on the two competing manufacturers' optimal decisions. The numerical examples presented in Section 7 analyse the effect of co-opetition on the optimal policies, total carbon emissions and maximum profits. Finally, we conclude our research findings and highlight possible future work in Section 8.

2. Literature review

The literature reviewed here primarily relates to three streams of research: (i) effect of cap-and-trade policy on firms' decisions, (ii) models with price and emission sensitive demand, and (iii) the impact of cooperation on environmental and organizational performances.

The first relevant stream of literature looks into impact of cap-and-trade policy on green operations and supply chain management. Among the earlier works, Dobos (2005) studied the effect of cap-and-trade policy on firms' decision and then obtained the optimal production quantity. Letmathe and Balakrishnan (2005) constructed two models with mandatory carbon emissions capacity, carbon emissions tax and cap-and-trade policies. They obtained the optimal product structure and production quantity, and then analysed the effects of cap, tax and trade price on optimal structure and optimal product quantity. Rong and Lahdelma (2007) developed a production model of a thermal power plant under cap-and-trade policy, and the optimal production quantity was obtained using stochastic optimization methods. More recently, Hua, Cheng, and Wang (2011) studied a firm's optimal order quantity under deterministic demand with cap-and-trade. They analysed the effects of carbon cap-and-trade policy on optimal order quantity, total carbon emissions and total cost. Bouchery, Ghaffari, and Jemai (2012) expanded the traditional EOQ model to multi-objective decision model and obtained optimal order quantity under carbon emissions constraint. In addition, they discussed the effect of carbon emissions policies on optimal order quantity. Song and Leng (2012) investigated the single-period newsvendor problem with carbon emissions policies and analysed the effect of different emissions policies on firm's order quantity. Their findings indicate that the optimal condition increase profits and reduce carbon emissions. Zhang and Xu (2013) studied a multi-item production firm which faced a stochastic demand and obtained the optimal product quantity. Their research also discussed the impact of carbon cap and trade price on optimal policy and profits. Similarly, Rosic and Jammernegg (2013) studied a single retailer with dual sourcing model and obtained the optimal order quantity and optimal order sourcing under cap-and-trade and carbon tax. Benjaafar, Li, and Daskin (2013) illustrated the impact of operation decisions on carbon emissions through a series of models. Their findings demonstrate that adjustments to the ordering policy can significantly reduce emissions without considerably increasing cost whereas the choice of pollution control mechanisms e.g. cap-and-trade can achieve the same emission reduction but incurring substantial differing costs. Toptal, Özlü, and Konur (2014) studied a single manufacturer's joint decisions on inventory replenishment and emission reduction investment under condition of carbon cap, tax and cap-and-trade policies. Although the literature on firms' optimal decisions under cap-and-trade policy is rich as illustrated above, most of them do not take price and emission sensitive demand into consideration.

Among the few studies that consider price and emission sensitive demand, Arora and Gangopadhyay (1995), Bansal and Gangopadhyay (2003) found that when a product has low-carbon attribute, consumers are willing to pay additional prices for the product. As a result, the manufacturer is willing to win customers by reducing carbon emissions. Other studies such as Geffen and Rothenberg (2000), Innes (2006), Laroche, Bergeron, and Guido (2001), Liu, Anderson, and Cruz (2012), Zhu and Sarkis (2007) and Zhang, Wang, and You (2015) also demonstrated that carbon emission reduction strategy is influenced by customer environmental