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Manufacturing/remanufacturing decisions for a capital-constrained manufacturer considering carbon emission cap and trade

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ABSTRACT

This paper examines manufacturer manufacturing/remanufacturing planning issues in which a downward substitution strategy is applied between new and remanufactured products and presents three mathematical models to determine the optimal production quantities of a new and remanufactured product that maximize the total profits when considering capital and/or carbon emission constraints. These models include sales revenues, manufacturing/remanufacturing costs and revenue from or cost of carbon credit trading. Finally, four numerical examples are provided to explore the comparison results for the optimal manufacturing/remanufacturing decisions, total profits and carbon emissions as well as to analyze the impact of parameters under different constraints, such as the initial capital, carbon cap and carbon price on the optimal production policies. The results indicate that the capital constraint can encourage the manufacturer to remanufacture used products at a higher quality level and significantly reduce carbon emissions. However, the carbon emission constraint can always encourage the capital-constrained manufacturer to produce more remanufactured products to achieve maximum profit. In addition, it is found that the manufacturer need more capital to achieve the maximum profit when the carbon emission constraint is considered. Furthermore, when the capital constraint is considered, the carbon emission constraint will have more distinct influences on the production policies of the manufacturer. Finally, the results proposed in this paper provide applicable suggestions to manufacturers and policy-makers.

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1. Introduction

With the rapid development of the market economy, environmental protection (especially the emission of greenhouse gases) has attracted increasing attention in recent years. Many countries have promulgated a number of carbon emission regulation policies, such as mandatory carbon emissions capacity levels, carbon taxes, and carbon emission cap and trade to help impose restrictions on the emissions of carbon dioxide and other greenhouse gases. Among them, the carbon emission cap and trade is regarded as one of the widely implemented programs based on eco-economic theory (Dales, 1968). For example, the Kyoto Protocol, which went into effect in 2005, established emissions caps for each country and allowed emissions trading (Chang et al., 2015). Furthermore, the carbon cap and trade mechanism is more effective in carbon emission reduction. (Stavins, 2008; Liu et al., 2015a,b). Early in 2013, global carbon emissions trading volume has attained 54.9 billion dollars (Zhang et al., 2014). Under the carbon trade mechanism, firms are assigned a carbon emission cap for a certain period, in which they choose to purchase or sell the carbon permits through the carbon market according to their own actual carbon emissions levels, e.g., the European Climate Exchange and Chicago Climate Exchange (Zhang and Xu, 2013; Toptal et al., 2014; He et al., 2015).

Remanufacturing is usually more environment friendly than traditional manufacturing since the process involves recycling used products in lieu of the input of raw materials (Gungor and Gupta, 1999; Ilgin and Gupta, 2010). However, remanufacturing can offer considerable economic benefits for enterprises (Li et al., 2013). For example, Xerox, which implemented a series of sustainable actions, earned over $80 million through cost savings from remanufacturing (Maslennikova and Foley, 2000). Hence, in a more carbon-constrained circumstance, the manufacturers, who are engaged in

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both manufacturing and remanufacturing, make decisions on the production quantities of new and remanufactured products with the consideration of both the production costs and carbon emission costs.

However, as the key resource, capital constraints have always existed, especially for small- and medium-sized manufacturers. On the one hand, due to the capital constraint, manufacturers may not be able to achieve the optimal planned production quantity (Kirca and Koksalan, 1996); on the other hand, it may result in the waste of other resources (Milaneza and Bührs, 2009; Srinivasa Raghavan and Mishra, 2011); therefore, capital constraint poses difficulties in achieving optimal profits for manufacturers. This issue leads to some interesting research questions: how can optimal manufacturing/remanufacturing decisions for capital-constrained manufacturers be made to maximize profits while considering carbon emission constraints? How do carbon emission caps and carbon prices affect manufacturing/remanufacturing decisions given capital constraints? Moreover, will the manufacturers' own capital have different levels of influence on production decisions due to the existence of carbon emission constraints?

This paper addresses the issues of manufacturing/remanufacturing decisions in a capital-constrained manufacturer considering carbon trading in a single period. The manufacturer, as a monopolist firm, produces new and remanufactured products to meet the stochastic market demand. In most studies, new and remanufactured products are not distinguishable and are thus sold for the same price to the same market. However, it is observed in practice that the remanufactured products are often offered at a lower price because of possible downgrading. It is then rational that the new and remanufactured products are segmented to different markets. Examples of such products include photocopiers, tires and personal computers (Ferrer, 1997; Ayres et al., 1997; Maslennikova and Foley, 2000). In addition, the manufacturer would apply a downward substitution strategy to avoid losses from back orders and customer goodwill for the remanufactured products. That is to say, the demand for remanufactured products can also be satisfied by new products but not vice versa. Therefore, like Pelin Bayındır et al., 2003, Inderfurth (2004), Piñeyro and Viera (2010), Ferrer and Swaminathan (2010), and Ahiska and Kurtul (2014), this paper studies manufacturing/remanufacturing problems under the circumstances described above, i.e., the segmented markets and one-way substitution strategy for new and remanufactured products. Based on these above issues, a benchmark model is formulated that only considers stochastic demands and product substitution for the following three models with carbon emission and/or capital constraints.

The remainder of this paper is organized as follows. Section 2 is devoted to a review of the related literature. In Section 3, the case study is described in detail and the basic assumption is proposed. The model formulation is presented in Section 4, and to analyze the effects of capital and carbon emission constraints and related parameters, such as initial capital, carbon price and carbon caps, on the optimal manufacturing/remanufacturing decisions, the total profits and carbon emissions, numerical examples are presented in Section 5. Conclusions and future research directions are presented in Section 6.

2. Literature review

As mentioned above, many studies have focused on issues related to production decisions in a hybrid remanufacturing/manufacturing system. With the promotion of low carbon production, there is growing interest in the effects of carbon emission constraints on manufacturing and remanufacturing decisions. A brief review of the previous literature that is related to this paper is conducted with regard to supply chain management and manufacturing and remanufacturing decisions with carbon emission constraints. At the strategic level, Sundarakani et al. (2010) and Lee (2011) consider it necessary to focus on the carbon footprint of the supply chain operation phase by establishing the model of a carbon footprint; many researchers have studied a series of decisions of reverse logistics and closed-loop supply chains while taking carbon emission constraints into account (Kannan et al., 2012; Chaabane et al., 2012; Wang et al., 2013; Fahimnia et al., 2013; Li et al., 2014; Zhang et al., 2015; Bazan et al., 2015). At the tactical level, there are several papers on traditional production decisions that consider carbon emission constraints (Fang et al., 2011; Song and Leng, 2012; Absi et al., 2013; Zhang and Xu, 2013; Chen et al., 2013; Gong and Zhou, 2013; He et al., 2015; Du et al., 2016).

However, only a few studies analyze the impact of carbon emission constraints on production decisions for remanufacturing. Considering the highly variable quality of used products, Yang et al. (2015) studied an acquisition and remanufacturing problem in a multi-product remanufacturing system under carbon emissions regulations. Chang et al. (2015) constructed two profit-maximization models to make optimal manufacturing/remanufacturing decisions under a carbon cap and trade mechanism. Unlike the previous literature, based on three different carbon emission regulation policies (mandatory carbon emissions capacity, carbon tax, carbon emission cap and trade), Liu et al. (2015a, 2015b) proposed optimization models to determine the optimal remanufacturing quantity and explored how the different carbon emission policies affect remanufacturing decision-making. Yenipazarli (2016) studied the effects of emissions taxes on the optimal production and pricing decisions of an enterprise that is engaged in manufacturing and remanufacturing using a leader-follower Stackelberg game model and analyzed the different impacts on tactical decisions between emissions taxes and emissions trading policies. Tornese et al. (2016) characterized the carbon equivalent emissions associated with pallet remanufacturing operations for two repositioning scenarios, such as cross-docking and take-back; Miao et al. (2016) addressed the problems of optimal pricing and manufacturing/remanufacturing decisions of the manufacturer with trade-ins under carbon regulations.

To the best of our knowledge, there is little information available in the literature about the influences of carbon emission constraints on the manufacturing/remanufacturing decisions with a one-way substitution strategy. In addition, the above literature assumed that the capital is always sufficient when the manufacturers/remanufacturers make production decisions under carbon emission constraints that do not conform to the actual situation. Therefore, in this paper, one of the major contributions is to study the effects of carbon constraints on the production decisions for a hybrid remanufacturing/manufacturing system that considers capital constraints.

In the field of manufacturing/remanufacturing decisions and supply chain decisions considering capital constraint, Buzacott and Zhang (2004) studied the relationship between production decisions and financing decisions in the process of multi-stage production operation for a capital-constrained enterprise. Xu and Birge (2004) explored the impact of capital constraints on production decisions in a stochastic demand market by analyzing the relationship between production decisions and capital structure. Based on the previous literature, Xu and Birge (2008) constructed a newsvendor model to study the optimal production decision under capital constraint and management incentive. Dada and Hu (2008) and Lai et al. (2009) study the impacts of capital constraint on purchase decision-making and the allocation of supply chain

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