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Effects of carbon permits allocation methods on remanufacturing production decisions

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ABSTRACT

Grandfathering and benchmarking are two typical free carbon permits allocation methods used in the carbon cap-and-trade mechanism. These emission regulations would generate carbon cost and hence make the firm's manufacturing and remanufacturing production decisions more complex. In this paper, we developed two models to contrastively evaluate the effectiveness of grandfathering and benchmarking methods on motivating the monopolist manufacturer to adopt low carbon remanufacturing practice in two periods. In the first period, the manufacturer produces completely new products without restrictions of carbon emission, while in the second period, the manufacturer can use collected returns derived from the first period to produce remanufactured products with carbon emission constrained by grandfathering or benchmarking regulation. We further analyzed the impact of carbon price, carbon emission saving per remanufactured product, and technology improvement on the production decisions. Our results indicate that the benchmarking method can more effectively motivate the manufacturer to adopt the low carbon remanufacturing production than the grandfathering method. We also find that the carbon price and carbon emission saving per remanufactured product would also affect the manufacturer's remanufacturing production decision.

1. Introduction

Carbon emission control becomes an increasing challenge in recent years, and many countries have attempted to curb carbon emission compulsively through enacting legislation. The carbon cap-and-trade mechanism (CCT-mechanism) is one such effective legislation employed around the world to control carbon emission (Perdan and Azapagic, 2011). The CCT-mechanism is used to allocated a quota of free carbon emission (carbon cap) to a firm by an external regulatory body, e.g., European Climate Exchange and Chicago Climate Exchange, and the firm can buy or sell carbon credit on a trading market of carbon emission, (Zhang and Xu, 2013). The CCT-mechanism is a very successful innovation in the environmental policy. One of the key issues in the CCT-mechanism is how to allocate free carbon emission permits. There are two typical methods to realize such allocation that has been adopted globally, grandfathering and benchmarking (Edwards and Hutton, 2001; Jensen and Rasmussen, 2000; Neuhoff et al., 2006). Grandfathering is used to allocate free permits in proportion to the firm's historic emissions in a base year, while benchmarking is employed to allocate free carbon permits are allocated according to an emissions target based on the regulator's judgment of the best-practice for an industry (Edwards and Hutton, 2001). In China, most of pilot emission trading markets in Beijing, Shanghai, Shenzhen and other big cities adopt grandfathering and benchmarking to distribute free carbon permits, which motivates us to mainly focus on these two allocation methods in this study.

Carbon emissions and energy consumption across the production lifecycle stages is highly product dependent (Sutherland et al., 2008). Under the legal and regulatory framework established by the CCT-mechanism, manufacturers have to adjust their production planning and seek low carbon production to reduce carbon emission. Remanufacturing has proved to be an eco-efficiency and low carbon production way. Remanufacturing process can not only make fully utilizes the additional value of the used productions, reduces disposal, but also saves energy, water and raw materials for production, therefore reduces carbon emission accordingly (Sutherland et al., 2008; Kerr and Ryan, 2001). In the UK,

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remanufacturing is estimated to contribute to 10 million tons of carbon dioxide reduction every year (Yenipazarli, 2016). The U.S. government continues to act on increasing the remanufacturing activity and maximizing the remanufacturing sector (Yenipazarli, 2016). With growing concerns over carbon and environmental problems in recent years, the Chinese government has also introduced recycling subsidy policies to commit to the environmental protection by accelerating the recycling, reusing and remanufacturing.

Given the wide attention on carbon permits allocation methods of CCT-mechanism and eco-efficiency of remanufacturing, it draws our great interest that how the production decisions of manufacturing and remanufacturing change under grandfathering and benchmarking regulations. Which method is more effective, grandfathering or benchmarking, on encouraging firms to engage in low carbon remanufacturing and quelling the carbon emissions? Specifically, if we refer to an AT(BT)-manufacturer as a manufacturer has advanced (backward) technology and generates less (more) carbon emission per unit new product, How are the production decisions of an AT(BT)-manufacturer affected by the carbon-related factors, e.g., carbon price in the carbon market and the carbon emission saving per remanufactured product? To answer these questions, we consider a manufacturer who only makes new product (product made up of so-called virgin materials) in the first period. In the second period, the government regulates carbon cap and trade scheme using either grandfathering or benchmarking method to allocate free carbon permits to the manufacturer. Then the manufacturer, who starts offering a mixed product of new and remanufactured product in period 2, determines optimal product decisions of new and remanufactured products to maximize its profit.

In this paper, we seek to extend the extant literature from two aspects. First, we assume free carbon cap allocated to the manufacturer is product-dependent and build models to compare the effectiveness of grandfathering and benchmarking methods. Second, we study the effect of two carbon permits allocation methods from the manufacturer's operational perspective. The results of this study provides practical implication to the manufacturer about how to maximize its profit by offering mixed new and remanufactured products under different free carbon permits allocation regulation. Besides, the regulator may also intervene the carbon price based on different carbon emission regulation to offer manufacturer incentives to implement low carbon remanufacturing.

The rest of the paper is organized as follows: After literature review in section 2, we propose two profit-maximization models for grandfathering and benchmarking methods, respectively, in section 3. Section 4 contrastively analyses the optimal production decisions of two carbon emission allocation methods, and discuss some properties that would be beneficial to implement carbon cap and trade policy. Numerical analysis for further insights is provided in section 5. The last section concludes our study by discussing the results and directing future research. Notation and some proofs are presented in Appendix.

2. Literature review

Carbon emission permit has become one of the most important research fields in recent years, various scholars have investigated the allocation of carbon emission permits from different perspectives. One of typical research focused by the researchers is contrastively evaluation the effectiveness of different carbon permits allocating methods, like auction, grandfathering and benchmarking, on carbon reduction of certain country, region and industry (Edwards and Hutton, 2001; Jensen and Rasmussen, 2000; Neuhoff et al., 2006; Morrell, 2007; Zhao et al., 2010, 2017; Zha et al., 2016). However, above studies from strategic perspective did not pay enough attention on supply chain operation.

Certainly, there is a considerable literature on supply chain management with low carbon policies. Rornese et al. (2016) focused on the carbon footprint associated with pallet remanufacturing. Zhang and Xu (2013) investigated the multi-item production planning problem with carbon cap and trade mechanism. Abdallah et al. (2012) developed a mixed integer program for the carbon-sensitive supply chain by taking into consideration carbon trading and green procurement. Chaabane et al. (2012) presented a generic mathematical model to assist decision makers in designing sustainable supply chains under carbon trading scheme. Considine and Larson (2012) examined fuel switching in electricity production following the introduction of the European Union's Emissions Trading System (EU ETS) for greenhouse gas emissions. Benjaafar et al. (2013) presented a series of models that illustrate how carbon footprint considerations could be incorporated into operational models decision-making with regard to procurement, production, and inventory management. Diabat et al. (2013) introduced a multiechelon multicommodity facility location problem with a trading price of carbon emissions and a cost of procurement. Gong and Zhou (2013) developed a quantitative production model with emissions trading to provide the firm with the optimal emissions trading, technology selection, and production strategies. Xia and Zhi (2014) considered the impact of carbon cutting and promotion related to carbon cutting on the product demand under the cap and trade system. Tseng and Hung (2014) proposed a model to evaluate carbon dioxide emissions and operational costs under different scenarios in an apparel manufacturing supply chain network. Chen et al. (2016) considered production planning models under carbon emission permits or carbon emission trading policies. Xu et al. (2017) studied the production and pricing problems in make-to-order supply chain regulated by cap-and-trade regulation. Ren et al. (2015) addressed the issue of allocating the carbon emission abatement target on product level in make-to-order supply chain consisting of a manufacturer and a retailer. Jiang and Chen (2016) investigated the production, pricing, carbon trading, and green technology investment strategies and the coordination of low carbon supply chain made up of a low carbon manufacturer and a retailer. Although extensive valuable researches have been carried out regarding the role of carbon emission policy, none of the above-mentioned papers have explored the effects of emissions regulation on production planning activities for remanufacturing.

Actually, the research that addresses operational issues in remanufacturing under an emissions regulation is scarce. However, the emission regulations would cause carbon cost and hence make the production decisions between new and remanufactured product more complex (Yenipazarli, 2016). Yang et al. (2016) studied an acquisition and remanufacturing problem in a market-driven multi-product remanufacturing system under carbon tax. Yenipazarli (2016) investigated the impact of emissions taxes on the optimal production and pricing decisions of a manufacturer using a leader-follower Stackelberg game model. Liu et al. (2015), Miao et al. (2016) and Bazan et al. (2017) also addressed the remanufacturing problem limited by carbon tax policy. However, the mechanism of carbon tax regulation is different from that of carbon cap-and-trade regulation. As far as we know, only a few papers studied remanufacturing decisions considering cap-and-trade regulation, which is most closely related to this study. Miao et al. (2016) addressed the problem of remanufacturing with trade-ins under the cap-and-trade