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Allocation of product-related carbon emission abatement target in a make-to-order supply chain

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ABSTRACT

This paper investigates the product-related carbon emission abatement target (PCEAT) allocation problem in a decentralized make-to-order supply chain, which is composed of a manufacturer and a retailer. The product-related carbon emissions here refer to the total emissions generated from the product manufacturing and retailing processes. To effectively reduce carbon emissions on the product level in the whole supply chain, a compulsory PCEAT is imposed on each unit of product. The problem is how to allocate the PCEAT between the manufacturer and the retailer, where the allocator can be either firm. We use Stackelberg game models to solve this problem by considering the following four scenarios: (1) the manufacturer is the leader and the allocator; (2) the manufacturer is the follower and the allocator; (3) the retailer is the follower and the allocator; and (4) the retailer is the leader and the allocator. Ignoring the carbon emission abatement limits of firms, it is found that if the leader is the allocator, the proportions of the PCEAT allocated to the two participators are determined by their marginal abatement costs. If the follower is the allocator, the PCEAT will be completely allocated to the leader. When the abatement limits of firms are taken into consideration, the firm constrained by the limit will undertake the portion of PCEAT up to its limit; while the other firm should undertake the remaining part. In any case, we find that it is always not bad to let the leader allocate the PCEAT.

1. Introduction

There is a wide consensus reached by practitioners and scholars that the current global warming is caused (to some extent) by the greenhouse gas (GHG) emissions from firm's activities (Bonan, 2008; Kumar, 2007). It is reported that 72% of GHG emissions results from household product consumptions (e.g., foods) (Hertwich & Peters, 2009). Since carbon emissions are the main part of GHG emissions, to counter the global warming, governments have enacted various policies and schemes on regulating carbon emissions (e.g. cap-and-trade, carbon tax, etc.) (Requate & Unold, 2003; Sullivan, 2010). In recent years, more and more customers have recognized the importance of environmental protection, and have attached greater value to green products. Under this circumstance, many progressive companies, such as Wal-Mart, Tesco and IBM, have paid much attention to green their products and their supply chain processes (Sundarakani, de Souza, Goh, Wagner, & Manikandan, 2010). Wal-Mart has set a goal to eliminate 20 million metric tons of GHG emissions from its supply chain by the end of 2015 (Walmart, 2010). Tesco has committed to reduce carbon emissions of the products in their supply chain by 30%, and try to help their customers reduce their own carbon footprints by 50% by 2020 (Trust, 2011). IBM has provided a carbon heat map to illustrate the carbon impact of a typical supply chain operations (Butner, Geuder, & Hittner, 2008). The achievements of carbon emission abatement targets of these companies will help them "green" their products and develop competitive advantages in the future.

The targets of the above mentioned companies can be interpreted as the "product-related carbon emission abatement target (PCEAT)". In the current paper, product-related carbon emissions refer to the emissions generated from the product manufacturing and retailing processes. As the main activities of the supply chain, manufacturing and retailing processes (especially the delivering and storing processes) produce the most emissions of the supply chain and there are many emission reducing opportunities in these processes. The emissions of the other stages account for a small

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part of the emissions produced in the whole life cycle. If we take all of them into consideration, it will make the problem very complex and may not get the solution. Therefore, the two main stages are chosen as representatives in the PCEAT allocation problem without considering the emissions generated from the other life cycle steps. It is clear that the PCEAT cannot be completely reached by any company on its own efforts. This should be done by all the members in the whole supply chain. The reason for this is that carbon emissions are generated from every process in product manufacturing and selling. The reduction of carbon emissions in one process cannot ensure the sufficient abatements of carbon emissions in the whole supply chain. Thus, to meet the PCEAT, all the members in the particular supply chain should cooperate to reduce the carbon emissions. This raises two important issues: (1) who should take the responsibility of allocating the PCEAT? (2) how to allocate the PCEAT between the firms in the supply chain? These two questions are what we attempt to answer in this paper.

We consider a decentralized make-to-order (MTO) supply chain consisting of a manufacturer and a retailer. The MTO mode is very popular in recent years due to the ever changing customer demands and the advancements in information technologies (Chen & Wan, 2005). Typical examples of MTO supply chain are Dell, Compaq, Gateway and others (Cattani, Dahan, & Schmidt, 2003). MTO supply is a good way to meet the customers' personalized requirements, avoid the blindness of production and reduce inventories and related costs (Rajagopalan, 2002). However, there is the conflict between a small response time to the customer and product customization. MTS (make to stock) has a quick response time to the customer while at the risk of high inventory and related cost. Many firms find it difficult to decide which products can be produced in MTO model and which products in MTS mode (Adan and Van der Wal, 1998; Soman, Van Donk, & Gaalman, 2007). There are many inspiring works on the issue of MTS and MTO (Choi, 2014; Soman et al., 2007). Since our primary focus is how to allocate the PCEAT between the manufacturer and the retailer, MTO case has a good realistic background and have the potential of deriving some clear management implications, thus we adopt the MTO case as the research base. We assume that a compulsory PCEAT is imposed on each unit of the product in the supply chain. This PCEAT may externally come from the government's regulations or internally come from the core enterprise's commitments (Caro, Corbett, Tan, & Zuidwijk, 2011). In practice, there are some possible methods to measure the carbon emissions caused by producing and retailing products, e.g. carbon label (Brenton, Edwards-Jones, & Jensen, 2009), which make the estimation and allocation of the PCEAT feasible in supply chains. This PCEAT can be allocated to the two firms by the allocator, who can be either the manufacturer (e.g., IBM) or the retailer (e.g., Wal-Mart, Tesco). Moreover, when the bargaining powers are taken into consideration, the leader and the follower in the supply chain should also be differentiated. Thus, to investigate the PCEAT allocation mechanism, we in this paper consider the following four scenarios by using Stackelberg game models: (1) the manufacturer is the leader and the allocator; (2) the manufacturer is the follower and the allocator; (3) the retailer is the follower and the allocator; and (4) the retailer is the leader and the allocator.

Generally, there exist limited potential carbon emission abatement spaces for firms in the supply chain due to limited carbon footprints in each firm. For ease of analysis, we first explore the PCEAT allocation mechanism without taking the carbon emission abatement limits of the two firms into account. Then we extend the investigation by considering these limits.

The rest of this paper is organized as follows. Section 2 reviews the related literature. In Section 3, without considering the firms' carbon abatement limits, the Stackelberg Game models of allocating the PCEAT between the members in the MTO supply chain are proposed. The computation process, results of the proposed models and some findings are presented in Section 4. In Section 5, we further investigate the issue of the PCEAT allocation by incorporating the carbon abatement limits of firms into the game models. Some numerical experiments are conducted in Section 6 to verify the results we get. All proofs are provided in the Appendix. Section 7 concludes this paper. All proofs are provided in the Appendix.

2. Literature review

In recent years, the research on carbon emissions constraints in operations management have received increasing attention, most of which focus on the level of individual firms (Nishitani, Kaneko, Fujii, & Komatsu, 2012; Zhou, Pan, Chen, & Yang, 2013). Since our work is devoted to carbon abatement target allocation in a supply chain, we here only review the most relevant studies. The related literature can be grouped into two categories: (1) supply chain operations optimization under carbon emission constrains; (2) carbon emission allowance, requirement and abatement target allocation.

2.1. Supply chain operations optimization under emission constrains

In the literature, various approaches have been proposed to reduce carbon emissions in supply chains by optimizing operational processes (e.g., supply chain design, product design, manufacturing, inventory control, logistics and distribution) under carbon emission constraints (Bonney & Jaber, 2011; Plambeck, 2012).

In supply chain design, Chaabane, Ramudhin, and Paquet (2011) present a multi-objective mixed-integer linear programming model to address this problem with considering economic and environmental factors. They apply their method to Canadian steel firm with emission limits and show that emission trading market is a possible way to reduce the carbon abatement cost. Elhedhli and Merrick (2012) integrate CO_2 emission concerns with a supply chain network design. Their numerical test shows that carbon emission costs will change the optimal design of the supply chain. El Saadany, Jaber, and Bonney (2011) propose a decision method that quantifies the different environmental quality factors in the form of cost to help managers to measure the environmental performance and improve the greeness of the supply chain while optimizing the whole profits. Zhang, Shah, Wassick, Helling, and van Egerschot (2014) develop a multi-objective optimization framework (considering three key performance indicators: total cost, total GHG emission, and total lead time) to optimize the design and planning of sustainable industrial supply chains, and their framework enlighten companies to improve the sustainability performance of their supply chain.

In supply chain and operations managements, Jaber, Glock, and El Saadany (2013) propose a vendor–buyer supply chain model which takes the different trading schemes of the EU emissions trading system (EU ETS) into consideration. Abdallah, Farhat, Diabat, and Kennedy (2012) argue that manufacturing firms should green their supply chains by combining carbon trading and environmental sourcing (i.e. green procurement) together. They conduct a mixed integer program to minimize the total cost by greening procurement in the supply chain. Chiu, Alsaffar, Okudan, and Haapala (2010) show that the costs and the carbon emissions can be reduced in product design in a bicycle supply chain. Tang and Zhou (2012) indicate that most carbon emissions in energy intensive industries are generated from manufacturing process. Benjaafar, Li, and Daskin (2010) examine the procurement and production planning by incorporating carbon constraints into the classical lot sizing model, and show that, in some cases, carbon