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Responsible production policies with substitution and carbon emissions trading

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ABSTRACT

This paper considers a production model involving a manufacturer that uses two different technologies, the green technology and the standard technology. The green product produced by the green technology can be used as a substitute for the traditional product produced by the standard technology, but not vice versa. Three models are considered. The first model concerns with product substitution only and serves as a benchmark model for the next two models, the carbon emission allowance model and the carbon emission trading model. The second model extends the product substitution model by imposing an upper limit on the total carbon emission allowance for each firm. The third model extends the second model to cater for carbon emission trading. For the carbon emission allowance model, analytical result shows that the optimal production quantity of any product depends on both its total carbon emission allowance quota and its unit carbon emission profit, and the effect of substitution improves the service level, the expected profit of the manufacturer, and the green of product mix. For the carbon emission trading model, analytical result shows that whenever the production quantity of any product is optimal, the marginal profit of production (i.e. the additional profit obtained by producing an extra item) should be equal to the unit price of carbon emission trading within the market. Moreover, the optimal policy of either model reduces the total amount of carbon emission, thus producing less pollution to the environment. Lastly, the optimal profits obtained by using the carbon emission trading model are larger than the corresponding optimal profits obtained by using the carbon emission allowance model.

1. Introduction

Production planning is a part of a supply chain network that has been extensively investigated in the past two to three decades (Li et al., 2011; Chen et al., 2012b). Originally, the objective of every company is to minimize production cost so as to increase its profit (Chen and Shen, 2012; Chen and Wang, 2015). However, in recent years, supply chain practitioners and researchers began to conduct research related to environmental issues, known as green supply chain management (Jin et al., 2014). New production technologies have been invented and adopted by some manufacturing firms in the United States and in the European Union in order to reduce the adverse effect of producing pollution to the environment (Chen and Hao, 2015). One of the earliest policy developments in controlling the emission of polluted air is the cap-and-trade policy (Keohane, 2009). The cap-and-trade policy aims at controlling pollution by providing incentives to firms which can accomplish a reduction in the emission of polluted air. The government of a country sets a limit, known as cap, on the quantity of pollution that can be emitted by each firm in a given period. If any firm does not use up its entire limit, it can sell its remaining quota to the outside market; if any firm needs additional quota, it can purchase the quota from the outside market (Toptal et al., 2014). Such a policy is claimed to be effective and efficient in controlling pollution level. In the latest decade, manufacturing firms start to have stronger sense of environmental responsibility. In a more carbon-constrained world, a sustainable supply chain should meet both economic and environmental objectives simultaneously, that is, improve profit and reduce negative environmental impact, e.g. carbon emissions. In order to improve profit, the manufacturer prefers to adopt standard technique to produce "standard product", but the unit carbon emission of standard product is high. In order to reduce carbon emissions, the manufacturer adopts green technique to produce

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"green product", but the unit cost of green product is high. In order to simultaneously improve profit and reduce carbon emissions, A mixture of green product and standard product will be a popular choice for many manufacturers.

Substitute goods is a concept in microeconomics which states that if the two goods satisfy the same needs of the individuals, the two goods can be replaced by one another (Chen et al., 2015). With the increasing awareness of environment protection, many industries start to develop or adopt new technologies to produce green product. A representative case is the manufacturers in the pulp and paper industry, which are primary polluters (Martin et al., 2000). The manufacturer in a Pulp and paper industry can adopt coal boilers or natural gas boilers to generate steam. The coal is cheaper than the natural gas, but the amount of carbon emissions generated by coal is more than that generated by gas. It is inevitable that the unit production cost increases when green technologies are adopted. However, the green technologies are more environmental friendly, and the green products are more demanding.

This paper considers a production planning model involving a manufacturer that uses two different technologies, the green technology and the standard technology. The green products are produced by the green technologies and the traditional products are produced by the standard technologies. One-way substitution is considered, i.e. the green product can be used as a substitute for the standard product, but not vice versa. In addition, for the emission trading, we focus on carbon emission trading which governs the level of the emission of carbon dioxide. We formulate three different models to study the effects of substitute goods and/or carbon emission trading on environmental responsibility. The first model concerns with product substitution only and serves as a benchmark model for the next two models, the carbon emission allowance model and the carbon emission trading model. The second model extends the product substitution model by imposing an upper limit on the total carbon emission allowance for the firm. The third model extends the second model to cater for carbon emission trading. In this model, the firm can buy any amount of carbon emission allowance quota from the market, or sell any amount of unused carbon emission allowance quota to the market.

The remainder of this paper is organized as follows. A survey of related literature is presented in Section 2. The model formulation and assumptions are presented in Section 3. In Section 4, we establish the benchmark case with no carbon emission constraint. In Sections 5 and 6, we discuss the manufacturer's optimal production policies in the presence of carbon emission allowance and carbon emission trading respectively. In Section 7, we conclude our findings and highlight possible future work.

2. Literature review

In this paper, we attempt to construct production models which consider substitution and carbon emission trading simultaneously. We first review the literature on supply chain models with substitution and then review the literature on models with carbon emission trading.

In the literature of supply models with product substitution, Mcgillivray and Silver (1978) was one of the pioneers who studied the inventory control systems for substitutable products. Analytic results were obtained for the limiting cases including the complete-substitutability and no-substitutability. However, costs related to substitution were not considered. Drezner et al. (1995) considered downward-substitutability between two products in an EOQ inventory setting. Analytic results were provided for the cases when two inventory systems were having no-substitution, full-substitution and partial-substitution. Khouja et al. (1996), Bassok et al. (1999) and Rao et al. (2004), respectively, proposed a model for substitutable products for inventory systems with stochastic demands. Grunani and Drezner (2000) considered deterministic hierarchical inventory models with substitution. Pineyro and Viera (2010) studied a lot-sizing problem with one-way substitution considering only the substitution of remanufactured products by new products, but not vice versa. Huang and Zhao (2011) considered multi-product competitive newsboy problem with partial product substitution with Nash equilibrium. There were many other production and inventory models discussed in Lang (2010). More recently, Chen et al. (2012a) investigated the manufacturer's pricing strategies in a two-echelon supply chain that comprises one manufacturer and two competing retailers, with warranty period-dependent and substitute demands. In addition, the authors discussed the effect of different pricing strategies of the manufacturer on supply chain decisions and profits. Previous researches have studied production substitution from different viewpoints, but the carbon emission trading policy and its impacts have not been discussed.

In the literature of production models with carbon emission trading, various researchers have attempted in investigating the effectiveness of the policy (Johnson and Heinen, 2004; Stranlund, 2007; Paksoy, 2010; Ramudhin et al. 2010). Further, in order to control carbon emission, the cap-and-trade policy has been claimed to be effective in reducing the air pollution (Subramanian et al., 2007; Murray et al., 2009; Diabat and Simchi-Levi, 2009; Shammin and Bullard, 2009; Ahn et al., 2010; Hahn and Stavins, 2011). More recently, Hua et al. (2011) considered the effect of carbon emission trading mechanisms in inventory management by means of EOQ models. Hong et al. (2012) studied the production planning model for manufacturers to determine their emission allowance and emission trading strategies. Chaabane et al. (2012) demonstrated that emission trading scheme should be enhanced and sustainability of a supply chain can be achieved in a cost-effective manner with the presence of efficient carbon management strategies. Yang et al. (2012) proposed a supply chain equilibrium model to determine optimal fuel, power, and emissions trading in the electric power industry. Song and Leng (2012) studied the impact of carbon emissions policies under classical newsvendor problem. Bouchery et al. (2012) incorporated sustainability components in classical inventory model and provided some insights on the effectiveness of regulatory policies to control carbon emissions. However, product substitutions were not considered in these papers.

As mentioned in the previous paragraphs, an integrated production model that considers product substitution under the cap-and trade policy is very rare. On the other hand, a mixture of green product and standard product and substitution between the mixed productions are popular choice from manufacturers' point of view. However, there is a gap in the literature to examine the impact of product substitution, a popular management practice, under the carbon trading policy. The main contributions of our work are as follows: our paper extends the existing literature by specifically proposing models that integrate substitution (i.e. the substitution of the traditional products by the green products) with the carbon emission allowance scheme and/or carbon emission trading scheme, and examining the impact of product substitution and carbon trading policy simultaneously on the manufacturer's responsible production policies and maximum expected profit.

3. Model descriptions and assumption

We consider a production model involving a manufacturer that uses two different technologies. The manufactured products are sold to the market with a stochastic demand. Product 1 is produced by green technique and is called "green product", product 2 is