Atmospheric Pollution Research xxx (2016) 1–10

HOSTED BY

ELSEVIER

Contents lists available at ScienceDirect

Atmospheric Pollution Research

journal homepage: http://www.journals.elsevier.com/locate/apr

Original article

Effects of emissions constraint on manufacturing/remanufacturing decisions considering capital constraint and financing

Yongjian Wang, Weida Chen *

School of Economics and Management, Southeast University, Nanjing, Jiangsu, 211189, PR China

ARTICLE INFO

Article history:
Received 17 August 2016
Received in revised form
21 November 2016
Accepted 22 November 2016
Available online xxx

Keywords:
Capital constraint
Financing
Manufacturing/remanufacturing decisions
Recovery rate
Emissions trading policy

ABSTRACT

Considering the different capital conditions (i.e. without capital constraint, with capital constraint, and with financing), this paper studies the manufacturing/remanufacturing decisions under emissions trading policy in a single period. Three mathematical models are developed to determine manufacturing/remanufacturing quantities that maximize total profits, which include sale revenue, revenue or expense of emissions trading, manufacturing/remanufacturing costs, and financing cost or interest revenue. Then, numerical example is provided to explore the comparison results on the optimal production quantities of new and remanufactured products, total profits and carbon emissions under different capital conditions and to analyze the impacts of parameters related to carbon emission, such as carbon price and carbon cap. The results indicate that, when capital constraint is considered, there always exists the quantity of recycled product is insufficient, but whether or not the other two conditions appear the insufficiency of recycled products mainly depends on recovery rate and carbon price; When financing is considered and the corresponding recovery rate is high enough, the increased recovery rate decreases the carbon emissions and increases the total profit; Considering capital constraint, the carbon price and carbon cap have greater influences on manufacturing/remanufacturing decisions, and the increased carbon cap can weaken the capital constraint and bring manufacturers more profit. Finally, the paper provides some applicable suggestions to manufacturers and policy-makers.

1. Introduction

Research has already shown that carbon emission is one of the main causes of global warming. Therefore, in order to control carbon emissions, many countries have enacted a serious of legislations or mechanisms, such as mandatory carbon emissions capacity, carbon tax, emissions trading. Compared with other carbon policies, emissions trading policy is more efficient to reduce the carbon emissions (Stavins, 2008; Hua et al., 2011). Actually, early in 1997, Kyoto Protocol aimed to set a carbon cap for each country and allow emissions trading, and the European Union Emission Trading System (EU-ETS), which is a cornerstone of European Union climate policy toward its Kyoto commitment and beyond, has grown to be the world largest carbon trading market (Zhang and Xu, 2013). And in China, the major emitters of greenhouse gases in the world, the emissions trading markets have been established in many cities, such as Beijing, Shanghai, Shenzhen, Tianjin and Chongqing, etc (Chang et al., 2015). In past two decades, many researchers have also focused on the issues of emissions trading, such as the design of emissions trading policy (Christos and Woodland, 2013), the allocation of initial emission cap (James and Chen, 2012), effects of the trade on total carbon emissions (Yu and Chen, 2016), comparison with other carbon policies, e.g. mandatory carbon emissions capacity and carbon tax, etc (Elkins and Baker, 2001; He et al., 2012; Jin et al., 2014).

Due to consuming all kinds of energies and fuels, manufacturing activities exhaust a large number of greenhouse gases. It can be predicted that emissions trading policy will increase the carbon emissions cost, which will urge manufacturers to pursue low-carbon production. Therefore, in addition to manufacturing, more and more manufacturers have committed to remanufacturing, which is usually more environment friendly than traditional manufacturing since it recycles old used products as the input of

* Corresponding author.
E-mail address: cwd@seu.edu.cn (W. Chen).

Peer review under responsibility of Turkish National Committee for Air Pollution Research and Control.

http://dx.doi.org/10.1016/j.apr.2016.11.006

raw materials (Gungor and Gupta, 1999; Ilgin and Gupta, 2010). In addition, remanufacturing can bring considerable economic benefits for the manufacturers (Li et al., 2013). For example, Xerox, which offered a series of sustainable services, earned over $80 million through the cost saving of remanufacturing (Maslennikova and Foley, 2000). Other successful examples include the remanufacturing systems of BMW, IBM and Kodak (Wei et al., 2011). From the perspective of economic benefits, there are many papers studied the coordination of new and remanufactured products to achieve maximum profit in a hybrid manufacturing/remanufacturing system (Ferrer and Swaminathan, 2006; Bayındır et al., 2007; Wang et al., 2011; Li et al., 2013; Ahiska and Kurtul, 2014).

However, considering carbon emissions constraint, more researchers focused on the supply chain management (Kannan et al., 2012; Chaabane et al., 2012; Benjaafar et al., 2013; Li et al., 2014; Zhang et al., 2015) and traditional manufacturing decision (Drake et al., 2010; Fang et al., 2011; Song and Leng, 2012; Absi et al., 2013; Chen et al., 2013). When remanufacturing is taken into account, manufacturers must make decisions on the production quantities of new product and/or remanufactured product with the consideration of both production cost and carbon emission cost.

In recent years, many papers have finished many studies related to remanufacturing decision considering carbon emissions constraint. Under carbon tax scheme, Yang et al. (2015) studied an acquisition and remanufacturing problem where the emission quantity depends on the quality of acquirable cores; Yenipazarli (2016) mainly studied the optimal manufacturing/remanufacturing and pricing decisions with carbon tax policy, and analyzed the different impacts on tactical decisions between carbon tax and emissions trading. Considering emissions trading policy, Fahimnia et al. (2013) analyzed the effect of carbon pricing on a closed-loop supply chain through comparing with a standard forward supply chain; Chang et al. (2015) studied a two-period problem to determine the optimal production quantities of new and remanufactured products; Miao et al. (2016) investigated optimal pricing and manufacturing/remanufacturing decisions of the manufacturer by introducing trade-ins. In addition, Liu et al. (2015) explore how different carbon emissions policies, such as mandatory carbon emissions capacity, carbon tax, carbon emission cap and trade, affect remanufacturing decision-making with limited information on demand distribution.

To the best of authors' knowledge, on the one hand, fewer papers study the effects of carbon emissions constraint on manufacturing/remanufacturing decisions; on the other hand, considering carbon emissions constraint (especially emissions trading policy), researchers ignore the capital constraint. However, in practice the production decisions are closely related to the financial situation, and even depend on it. Kirca and Koksalan (1996) studied how the finance condition changes production decisions through many simple examples. Therefore, it is not rational to assume that there is an unlimited amount of capital since capital usually turns out to be a constrained resource. Due to the lack of capital to cover the production and/or emissions costs, the original production planning may be not feasible at all, although it could be feasible from the point of view of production capacity and demand meeting. As a result, other resources have been underutilized for a period of time, which may lead to enormous losses of profit (Milaneza and Bührs, 2009; Srinivasa-Raghavan and Mishra, 2011). It is thus clear that capital availability is a significant factor that affects the feasibility of a production planning. In addition, emissions constraint may increase the production cost of the manufacturer, which accounts for some interesting research questions: How do they influence each other between emissions constraint and capital constraint? How does the financing activity change the manufacturing/remanufacturing decisions under emissions trading policy? How do carbon cap and carbon price affect manufacturing/remanufacturing decisions considering capital constraint?

Therefore, under the emissions trading policy, this paper studies the issue of the manufacturing/remanufacturing decisions of a capital-constrained manufacturer in a single period. Since the cost saving of remanufacturing, the study mainly focuses on making further research to investigate the effects of emissions constraint on manufacturing/remanufacturing decisions of a capital-constrained manufacturer. The paper differs from the above studies in the following aspects. First of all, this paper introduces the capital constraint to study the manufacturing/remanufacturing decisions under emissions trading policy. Meantime, considering the capital constraint, the paper analyzes the optimal manufacturing/remanufacturing decisions when financing is considered. In addition, we emphatically analyze the relationship between recovery rate and manufacturing/remanufacturing quantities, carbon emission quantity, total profit, financing quantity. Furthermore, the study investigates the impacts of the different parameters related to carbon emissions, such as carbon price and carbon cap, on the optimal manufacturing/remanufacturing decisions of the manufacturer. Finally, this paper gives manufacturers and the policy-makers some applicable suggestions according to our conclusions.

The remainder of this paper is organized as follows. Section 2 describes the problem in detail and proposes the basic assumption. The model formulation is presented in Section 3, and in order to analyze the effect of parameters related to carbon emissions, such as carbon price and carbon cap, on the optimal manufacturing/remanufacturing decisions and the total profits, the numerical example is presented in Section 4. The paper finally concludes this study and provides future research directions in Section 5.

2. Problem description and assumption

To study the optimal manufacturing/remanufacturing decisions of a capital-constrained manufacturer under emissions trading policy, three mathematical models are developed to investigate the optimal operational decisions based on different capital conditions.

On the operational side, this paper considers a monopolist manufacturer with capital constraint that produces new and remanufactured products simultaneously in a single period. It is observed in practice that the remanufactured products are often offered at a lower price because of the possible downgrading. Therefore, on the one hand, it is rational that the new and remanufactured products are segmented to different markets. Examples for such products include photocopiers, tires and personal computers (Ferrer, 1997; Ayres et al., 1997; Maslennikova and Foley, 2000). Then, the paper considers that, compared to remanufactured products, new products are sold to independent market at a higher price. On the other hand, the remanufactured products cannot be recycled to remanufacture, namely, new products are the sole source of returns and the recovery rate is$\rho, 0 \le \rho \le 1$. In addition, referring to Ferrer and Swaminathan (2006), it is assumed that the demand function of new and remanufactured products is$q_j = Q_j - p_j, j = m, r$, where Q_j is the potential market demands of new product and remanufactured product, q_m and q_r are the decision variables, *i.e.* production quantities that represent the actual market demands of new and remanufactured products, respectively, p_m and p_r are the selling prices of two products, and $p_m > p_r$. Furthermore, it is assumed that the production costs of new and remanufactured products are c_m, c_r, respectively, and $c_m > c_r$, which indicates that cost saving advantage of remanufacturing (Savaskan et al., 2004; Atasu et al., 2008). Without loss of generality, there