Computers and Operations Research 89 (2018) 253–268

Contents lists available at ScienceDirect

Computers and Operations Research

journal homepage: www.elsevier.com/locate/cor

Remanufacturing with trade-ins under carbon regulations

Zhaowei Miao[a], Huiqiang Mao[b], Ke Fu[c,*], Yu Wang[a]

[a] School of Management, Xiamen University, Xiamen, China
[b] Department of Management Sciences, City University of Hong Kong, Kowloon Tong, Hong Kong
[c] Lingnan College, Sun Yat-sen University, Guangzhou, China

ARTICLE INFO

Article history:
Received 9 November 2014
Revised 27 February 2016
Accepted 30 March 2016
Available online 7 April 2016

Keywords:
Sustainability
Remanufacturing
Trade-in
Carbon tax
Cap and trade
Subsidy

ABSTRACT

Observing prevalent concerns about the influence of carbon emissions on climate change, we address the problem of remanufacturing with trade-ins under carbon regulations. We analyze the optimal pricing and production decisions of the manufacturer under the carbon tax policy and the cap and trade program. The results show that the introduction of carbon regulations can promote sales of remanufactured products while reducing the demands of new products. However, the implementation of carbon regulations has negative impacts on the manufacturer's profits. Nevertheless, the manufacturer's profits can be improved through deliberately designed government subsidy schemes. We also demonstrate that the government has the incentive to propose such subsidy schemes because the total emissions can be reduced under well-designed regulations, but not at the cost of the manufacturer's profits.

1. Introduction

Environmentally and socially sustainable operations have sprung up as a heated interest in the operations management literature in the last decade. In a recent survey paper, Tang and Zhou [28] point out that "consumers and governments are pressuring firms to strike a balance between profitability and sustainability." Remanufacturing has played an increasingly important role in sustainable operations because of its significant value in recovering used products. Through replacing or reprocessing used components from used products to produce "new" ones, remanufacturing can reduce the use of natural resources and waste in the production process, which helps enhance the environmental performances of the firms. However, remanufacturing is usually coupled with the problem of recycling used products. The processing of these used products often leads to waste streams for consumers but expands values for the manufacturer by remanufacturing or refurbishing. Trade-in programs provide a feasible method to solve this problem. In a trade-in program, the government offers an additional subsidy to consumers to compensate for the "residual value" of their existing products when they purchase new products and return used ones. Such practices have been widely observed. For example, the Chinese government proposed a trade-in subsidy policy for household appliances and automobiles to encourage consumers to purchase more energy-efficient new appliances or automobiles with their existing low-efficient used ones being returned in 2012. According to this policy, the total amount of subsidies can reach about $43 billion.[1] In fact, trade-in programs have far more markets than are appreciated, ranging from golf clubs to CT scanners and also including bicycles, personal computers, and printers [25,24].

Although remanufacturing decisions have been discussed widely in the existent literature such as Ferrer et al. [7], Mitra [21], Atasu et al. [1], and Gong and Chao [9], there is rather limited research on the problem of remanufacturing with trade-in programs. The major difference between this problem and previous studies lies in the fact that the demand market of the former is constituted by *new consumers* and *replacement consumers*. In this case the purchases of new consumers are mainly determined by the manufacturer, while those of replacement consumers are also influenced by government subsidies. Remanufacturing and trade-in programs are closely related to carbon emissions that are becoming a common concern shared by governments, manufacturing firms, and many other stakeholders. In 2008 British Columbia first put carbon tax into practice in Canada, taking the bold step of introducing a broadly-based carbon tax to reduce carbon emissions [20]. In Europe many countries, such as Finland, Norway, Sweden, and Denmark, began to tax the emissions of carbon dioxide in

* Corresponding author.
E-mail address: fuke@mail.sysu.edu.cn (K. Fu).

[1] Based on public data from the State Council of China.

https://doi.org/10.1016/j.cor.2016.03.014
0305-0548/

the 1990s. With these governments' concerns about carbon emissions, some traditional operational problems are reconsidered in this context. Some important research includes Kroes et al. [14], Benjaafar et al. [3], Jira and Toffel [11], and Cachon [4]. These papers have made important steps to incorporate carbon concerns into operation management. However, despite its practical importance, remanufacturing with carbon regulations has not been considered by these studies.

Observing the prevailing applications of remanufacturing with trade-ins and the increasing importance of carbon emissions regulations, in this study, we consider remanufacturing with trade-ins under carbon emissions regulations. We intend to address a number of questions. For example, how does the manufacturer optimize its pricing and production decisions in this context? What are the influences of government regulations on the production decisions and profits of the manufacturer? By answering these questions we also provide useful managerial insights for both the manufacturers and the governments who are involved in trade-in programs and carbon emissions regulations. These insights may help both the manufacturers and the governments make informed decisions to achieve sustainability.

We consider remanufacturing and trade-in decisions of the firm under two types of commonly used carbon emissions regulations: carbon tax and "cap and trade" programs. The carbon tax policy mainly depends on the control of the government, while cap and trade also relies largely on the supply and demand relationship of the market. Due to the flexibility of the cap and trade mechanism, the European Union began the European Union emissions trading scheme in 2005 and covered the 27 countries of the European Union and three non-European Union members for now [27].

Through styled models we address the manufacturer's trade-in and remanufacturing decisions when the carbon emissions of the firm are limited and/or costly and reveal the influences these carbon regulations would have on the firm's optimal decisions and profits. Our results show that the firm's remanufacturing policy is determined by its remanufacturing cost and the government's subsidy when carbon regulations are absent. However in the presence of carbon emissions regulations, the remanufacturing policy is also dependent on the emissions cost, which is influenced by not only the firm itself but also the government's carbon instruments. Moreover, we find that the introduction of carbon regulations can boost the demands of remanufactured products under certain conditions even though they have negative effects on new products. In addition, generally the firm's profits are inevitably decreased under the carbon tax. However, the firm's profit loss due to emission costs can be compensated and even be more than offset by the compensation of government subsidies. We further demonstrate that the government has the incentive to implement such subsidy schemes because under certain conditions the subsidy can increase the firm's profits without increasing the firm's emission costs.

According to Tang and Zhou [28], firms have to pay more attention to the triple bottom-line dimensions—profit, people, and planet—when making their business decisions. This paper is closely related to the interface between the "profit" and the "planet" dimensions. In fact, the manufacturer needs to make pricing and production decisions to maximize its profit under the carbon regulations. In addition, the government also plays a significant role in these two dimensions because it has to consider the manufacturer's profitability and the environmental issues when developing subsidy schemes and carbon regulations.

The remainder of this paper is organized as follows: After Literature Review, we first formulate the demands and the base model in the third section. In Section 4, the models under the carbon tax and cap and trade are proposed and some main results about pricing policy, market demands and profits are also presented. In Section 5, we conclude the paper and offer some future research directions.

2. Literature review

In the sustainable operations management literature, this paper is related to three main streams of studies: remanufacturing, trade-ins, and carbon regulations. There is a large base of literature on remanufacturing. Atasu et al. [1] propose a complementary approach to consider several demand-related issues involving the existence of green segments, original equipment manufacturer competition, and product life-cycle effects. They provide the conditions that ensure the profitability of remanufacturing for a monopolist and demonstrate that the manufacturer can defend its market share via price discrimination where remanufacturing becomes an effective marketing strategy. Different from the marketing perspective, Ovchinnikov [23] is concerned with revenue and cost management of remanufactured products, and Geyer et al. [8] examine the economics of remanufacturing under limited component durability and finite product life cycle. Other studies also include the competition and cannibalization between new and remanufactured products [2,7], the match between demand and supply of remanufacturing [10], and product design with remanufacturing [29]. Some researchers employ the framework of multi-period dynamic production and inventory control problems to study remanufacturing (see, for example, [9] and the references therein). The aforementioned studies have provided significant contributions for understanding remanufacturing. Trade-in practices, however, have received limited attention. Rao et al. [24] incorporate key features of durable goods markets, such as the coexistence of new and used products markets and the cannibalization problem between them, heterogeneity of consumers, and the lemons problem in resale markets, to reveal the crucial role of trade-ins in durable goods markets. Kim et al. [13] focus on trade-in transactions and provide a model and empirical evidence on the preference of consumers for under- and overpayment. Some papers study trade-ins from the perspective of consumers; for example, Okada [22] incorporates mental accounting into the problem of trade-ins when consumers make product replacement decisions. Differently, Ray et al. [25] consider both trade-in rebates and remanufacturing in a durable products marketing. Assuming two distinct types of customers in the durable products market, the paper proposes the optimal pricing and trade-in strategies for such remanufacturable products and identifies the most favorable pricing strategy for the firm when faced with a particular market condition. In this paper we are also concerned with both trade-in and remanufacturing problems to identify different pricing and production strategies for different market conditions. However, the differences lie in the fact that we focus on joint decision-making concerning new and remanufactured products. On the other hand, in addition to the trade-in rebates as discussed in Ray et al. [25], we also explicitly consider the subsidies offered by the government. In this setting, we find that the firm's optimal pricing strategies and profits are not only affected by its own characteristics such as remanufacturing cost and emissions efficiency, but they also depend on the government's carbon regulations and subsidy schemes.

The last related stream of research is operations management under carbon regulations. This stream of research is relatively recent along with the heated global concerns on formulating or tightening regulations of carbon dioxide emissions to fight against climate change. Among these recent research works, Benjaafar et al. [3] have made an important contribution. Using relatively simple and widely used models, Benjaafar et al. [3] demonstrate how carbon emission concerns can be incorporated into operational decision making with regards to procurement, production, and