Journal of Cleaner Production xxx (2015) 1–14

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

Joint production and pricing decisions for multiple products with cap-and-trade and carbon tax regulations

Xiaoyan Xu [a, b], Xiaoping Xu [b], Ping He [a, *]

[a] School of Management, Zhejiang University, 866 Yuhangtang Road, Hangzhou, Zhejiang 310058, PR China
[b] School of Management, University of Science and Technology of China, 96 Jinzhai Road, Hefei, Anhui 230026, PR China

ARTICLE INFO

Article history:
Received 26 December 2014
Received in revised form
17 August 2015
Accepted 18 August 2015
Available online xxx

Keywords:
Cap-and-trade
Carbon tax
Production
Pricing
Social welfare

ABSTRACT

Cap-and-trade and carbon tax regulations are the two main low-carbon policies to curb carbon emissions. This paper studies the joint production and pricing problem of a manufacturing firm with multiple products under cap-and-trade and carbon tax regulations, and compares the effects of the two regulations on the total carbon emissions, the firm's profit and social welfare. The firm faces price-sensitive demands and the demands for these products are independent. Firstly, we find that the optimal number of products to be produced under cap-and-trade regulation (carbon tax regulation) is determined by the emission trading prices and the cap (tax rate). Secondly, we detect that the optimal cap (tax rate) is decreasing (increasing) or constant in the environmental damage coefficient. Finally, we discover that, the social welfare under carbon tax regulation is not less than that under cap-and-trade regulation, although there is neither one regulation always inducing more profit and having advantages in curbing carbon emissions than the other one.

1. Introduction

It is a global consensus that carbon emissions have directly led to global warming. Therefore, many regions and countries have enacted legislations or mechanisms to curb carbon emissions. Cap-and-trade and carbon tax regulations are the two main mechanisms to reduce carbon emissions in the world. Cap-and-trade regulation is one of the most effective market-based mechanisms to curb carbon emissions. Under this regulation, firms receive the emission credits (the maximal amount of credits is called “the cap”) from government agencies, and the emission credits can be traded through carbon trading market. Under carbon tax regulation, firms are charged for each unit of their carbon emissions at a fixed tax rate level. So, carbon tax regulation is a way of price adjustment to guide the behavior of the firms in the economic body. They needs to pay a fixed fee for each unit of CO_2 emitted, which indicates that carbon tax regulation is intended to indirectly curb the quantity of total carbon emissions, because under the stable tax rate, the firms may pay much for their overmuch carbon emissions (Pizer, 2002). However, cap-and-trade regulation is a way to directly control the quantity of total carbon emissions. The firms in the economic body are allocated free emission credits (the total amount of emission credits is fixed) and use the price of emission credits to economically allocate emission credits among the firms. Just as Wittneben (2009) says, cap-and-trade regulation has more certainty in curbing carbon emissions. Moreover, emission credits are limited resource so that the firms may be difficult to get emission credits which can induce the firms to emit less carbon emissions.

Many countries have imposed cap-and-trade or carbon tax regulation. For example, Europe has established European Union Emissions Trading Scheme (EU ETS), which is the largest emission trading market in the world. EU ETS covers almost 50% of the total carbon emission in European Union (Hintermann, 2010). British Columbia imposed carbon tax in 2008, which reduced 9.9% carbon emissions of the province. Australia also adopted carbon tax regulation in 2011 (Gale et al., 2013). For firms, carbon emissions are mainly generated in the production process. Thus the carbon emission regulations directly affect the firms' production decisions, especially for the firms with multiple products because the product portfolio is involved. It is generally accepted that large amounts of carbon emissions bring a lot of environmental problems, such as the increase of sea level and temperature. Carbon emissions can induce the increase of social cost, which damages the social welfare. Governments try to maximize social welfare by designing

* Corresponding author. Tel.: +86 571 88206827.
E-mail address: phe@zju.edu.cn (P. He).

http://dx.doi.org/10.1016/j.jclepro.2015.08.081
0959-6526/

suitable carbon emission regulations, e.g. the cap-and-trade or carbon tax.

Most manufacturing firms produce multiple products to satisfy various demands. For example, Baosteel Group Corporation produces 16 kinds of cement products such as HR steel sheet and CR steel sheet in the stainless steel[1]; Anhui Conch Cement Limited Company manufactures 11 kinds of cement products such as cement of sulfate resistant cement and special portland cement for nuclear generator plant.[2] These products are used in different industries so that their demands are independent. Carbon emissions are generated in production activities. Due to the difference of production technologies or raw materials in the production process, these products have different production costs and carbon emissions intensity (i.e., carbon emissions generated by producing unit product). To reduce carbon emissions of these products, Chinese government has established 7 carbon trading pilot over different cities, such as Tianjin and Shenzhen carbon trading markets. However, carbon tax regulation is a cost-effective policy in reducing carbon emissions, and is highly advocated by experts and international organizations (EEA, 1996; OECD, 1996; Zhang and Baranzini, 2004; Oreskes, 2011). Although carbon tax regulation is not imposed in China now, it is possible to impose this regulation in China in the near future.[3] To maximize profits, the firms need to determine the product portfolio under each of the two regulations. To maximize social welfare, the government should make the choice between cap-and-trade and carbon tax regulations, as well as determine the cap level or tax rate, respectively.

In this paper, we theoretically analyze the joint production and pricing problem of a manufacturing firm with multiple products under cap-and-trade and carbon tax regulations. We also discuss the government decisions to maximize social welfare. Firstly, we model the optimal production and pricing problem under cap-and-trade regulation as a two-step optimization problem. In the first step, we solve the optimal production and pricing decisions upon given total emissions, and based on which we in the second step solve the optimal production decisions under cap-and-trade regulation. In addition, we derive the optimal cap to maximize social welfare. Secondly, we search for the solutions of the optimal pricing and production quantities of each product under carbon tax regulation. Moreover, we also derive the optimal tax rate to maximize social welfare from the viewpoint of governments. Finally, we compare the firm's profit, the total carbon emissions and social welfare under the two regulations.

The remainder of this paper is organized as follows. The relevant literature is reviewed in Section 2. The basic model is established in Section 3. The main results of the joint production and pricing problem for multiple products under cap-and-trade regulation are presented in Section 4. The main results of the joint production and pricing problem for multiple products under carbon tax regulation are presented in Section 5. Two regulations are compared with respect to the optimal total emissions, the optimal profit and social welfare in Section 6. Numerical examples are given in Section 7 to illustrate some results of the paper. Section 8 concludes the paper and discusses the possible future research directions. All the proofs are presented in Appendix.

2. Literature review

Much of the literature investigates cap-and-trade and carbon tax regulations either at the macro or micro levels. Here we only review the studies highly related to our paper, which can be divided into three categories: the first category includes the studies analyzing cap-and-trade and carbon tax regulations at the macro level; the second category includes the studies about the firms' operational decisions under cap-and-trade and carbon tax regulations at the micro level; the last category explores the firm's production decisions and the government decisions under different environmental policies.

2.1. The macro analysis of cap-and-trade and carbon tax regulations

From a macro perspective, many papers have investigated the advantages and disadvantages, and the feasibility of cap-and-trade and carbon tax regulations. Theoretically, there is a broad equivalence in long-run efficiency between cap-and-trade and carbon tax regulations in the long run (Pezzey, 1992; Farrow, 1995).

In the view of advantages and disadvantages, Farinelli et al. (2005) compare different environmental policies including cap-and-trade and carbon tax regulations to explore the improvement of energy efficiency under these policies. They find that a carbon tax regulation with high tax rate reduces carbon emissions with a severe impact on the growth of GDP (Gross Domestic Product), and cap-and-trade regulation can induce the firms to adopt new technology which has higher energy efficiency. In order to achieve both the economic goal and emissions reductions, Wagner et al. (2009) propose a regulation-Clean Investment Budgets (CIBs)-in which carbon emission in the countries are limited to avoid global warming in excess of 2 °C and capital is invested in a low-carbon economic development to generate emission credits. The generated emission credits are the necessary resource for the firms to emit carbon emissions and can also be traded in the carbon trading market. They suggest that CIBs can reduce more carbon emissions than cap-and-trade regulation. After summarizing the survey of over fifty web articles and news about cap-and-trade and carbon tax regulations, Harrison and Smith (2009) argue that cap-and-trade regulation is business-friendly and can produce jobs.

From the perspective of the feasibility analysis, Green et al. (2007) show that imposing cap-and-trade regulation is highly problematic because fake emission credits can be sold in the market. Avi-Yonah and Uhlmann (2009) argue that carbon tax regulation is easier to implement than cap-and-trade regulation because cap-and-trade regulation faces the challenges of setting baselines of emission reduction targets. Wittneben (2009) further compares cap-and-trade and carbon tax regulations in 7 dimensions and finds that imposing carbon tax regulation can reduce carbon emissions more quickly with less cost. By using random utility theory, Liu et al. (2015) choose the data of 201 companies in China to explore the attributes (tax rate, tax relief measures and the revenue utilization) of carbon tax regulation. They find that the years of 2016–2020 may be possible to implement this policy in China.

The above studies discuss cap-and-trade and carbon tax regulations from different aspects, without considering the firm's production decisions and the social welfare under the two regulations. We use Stackelberg game to explore the firm's production decisions and the selection of cap-and-trade and carbon tax regulations, and find some managerial insights for both the firm and the government.

2.2. Firms' operational decisions under cap-and-trade and carbon tax regulations

The existing literature on the firms' operational decisions under cap-and-trade and carbon tax regulations contains the research on supply chain design, inventory management and production decisions at the micro level.

[1] http://www.baosteel.com/group/channels/1763.html.
[2] http://www.conch.cn/sm2111111158.asp.
[3] http://www.ccin.com.cn/ccin/news/2014/08/14/302127.shtml.

Please cite this article in press as: Xu, X., et al., Joint production and pricing decisions for multiple products with cap-and-trade and carbon tax regulations, Journal of Cleaner Production (2015), http://dx.doi.org/10.1016/j.jclepro.2015.08.081