Transportation Research Part E 97 (2017) 132–150

Contents lists available at ScienceDirect

Transportation Research Part E

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

Capacity and production planning with carbon emission constraints

Shuang Song [a], Kannan Govindan [b,*], Lei Xu [c,*], Peng Du [c], Xiaojiao Qiao [c]

[a] College of Science, Tianjin University of Technology, Tianjin 300384, PR China
[b] Center for Engineering Operations Management, Department of Technology and Innovation, University of Southern Denmark, Odense M 5230, Denmark
[c] School of Management, Tianjin University of Technology, Tianjin 300384, PR China

ARTICLE INFO

Article history:
Received 31 January 2016
Received in revised form 13 September 2016
Accepted 17 October 2016

Keywords:
Green supply chain management
Capacity expansion
Carbon emission
Production planning

ABSTRACT

This paper builds a two-stage, stochastic model to study capacity expansion problem in logistics under cap-and-trade and carbon tax regulations. The optimal capacity expansion and production decisions are obtained, and the effects of carbon emission regulations on capacity expansion are studied. Through analytical study and a real case numerical analysis, we find that the carbon tax exhibits different impacts on optimal capacity expansion decisions in low tax rate and high tax rate, and the volatility of capacity investment cost has a larger impact on optimal capacity expansion than that of production cost.

1. Introduction

Carbon emission regulations effectively curbed greenhouse gases (GHGs) globally on firm activities in the recent decades (Drake et al., 2015; Du et al., 2012; Hua et al., 2011; Hovelaque and Bironneau, 2015). Among many emission regulations, there are two basic regulations widely used to control carbon emission in many countries or regions: cap-and-trade and carbon tax policies (Drake et al., 2015; Jaber et al., 2013; Song and Leng, 2011). Since the Kyoto Protocol became effective, the cap-and-trade system was proposed and became a worldwide consensus (Du et al., 2012), with many carbon emission trading markets, like the European Union Emissions Trading Scheme (EU-ETS), Regional Greenhouse Gas Initiative (RGGI), and Japan's Voluntary Emissions Trading Scheme (JVETS) starting to trade in carbon credits. Meanwhile, carbon tax has also been adopted by many countries and regions. For example, the European Union, Australia and some countries in the Nordic region have adopted the carbon tax as a compliance requirement (Lee et al., 2015). These two regulations are both effective in reducing carbon emission. It was estimated that CO_2 was reduced by about 50–200 million tons as a result of the establishment of EU-ETS (Ellerman and Buchner, 2006). Empirical and simulation models also suggest that the carbon tax implemented by British Columbia has reduced emissions in the province by 5–15% (Murray and Rivers, 2015).

Inevitably, firms' economic and business activities, such as production, transportation, warehousing, are all responsible for producing carbon emission, and are, therefore, greatly influenced by carbon emission regulations. Under these regulations, firms face a dilemma: to maintain their original operations mode and technology and pay additional fees for their carbon emission, or to adopt more advanced technology to reduce carbon emission. To break loose from the dilemma, firms begin to explore various means to reduce carbon emission. A summary of carbon emission reduction studies from existing

* Corresponding authors.
E-mail addresses: kgov@iti.sdu.dk (K. Govindan), chully.xu@gmail.com (L. Xu).

http://dx.doi.org/10.1016/j.tre.2016.10.007
1366-5545/

literatures demonstrates three primary approaches: (i) determining delivery modes to reduce carbon emission on logistics, and ordering quantities to reduce on inventory (Tang et al., 2015; Hua et al., 2011; G. Chen et al., 2013; X. Chen et al., 2013; Hovelaque and Bironneau, 2015); (ii) introducing innovations in the physical process and replacing inefficient energy equipment and facilities (G. Chen et al., 2013; X. Chen et al., 2013; Drake et al., 2015); and (iii) examining the emission-dependent supply chain under carbon emission regulations (Benjaafar et al., 2013; Du et al., 2012; Jaber et al., 2013).

A firm's capacity refers to the maximum systematic level of value-added activity over a period of time (Slack et al., 1995), which is constrained by bottlenecks in the handling capability of all involved procedures, such as procurement, production, transportation, and warehousing. Hence, a firm has to expand the capacity of the bottleneck procedure in order to fulfill the demand. As a matter of fact, capacity expansion, especially based on technology innovations, is a fundamental problem for firms. This issue is studied extensively in literature with regard to production processes (Boyabatli and Toktay, 2011; Ravi and Li, 2008; Goyal and Netessine, 2007), transportation processes (Andre et al., 2009; Li and Zhang, 2015; Ahmed et al., 2003; Li and Tirupati, 1994), and warehousing processes (Huang, 2004; Cormier and Gunn, 1999; Caron et al., 2000; Molnár, 2005). However, there is still a research gap on how firms might expand their capacity, and employ original and new capacities to produce and deliver their products to downstream customers under the cap-and-trade and carbon tax regulations. To fill this gap, this study investigates a general capacity expansion problem; we pursue which capacity a firm may decide to utilize in the production and transportation process under two different kinds of carbon emission regulations. In particular, we examine the following three perspectives.

(1) We compare the market dependent cap-and-trade mechanism and the government-dominated carbon tax policy. Under the cap-and-trade system, firms can buy or sell their carbon credits in a carbon emission trading market to control their operations and to maximize their profits. In 2005, the first year of EU ETS's operation, 321 million allowances, with a value of US $7.9 billion, were traded. By 2011, the number of traded allowances had risen sharply to 7.9 billion, with a value of $147.9 billion.[1]. As a compliance requirement, carbon tax has major advantages over the general alternative of regulating emissions through conventional command and control policies (Pearce, 1991).
(2) We consider technology innovation. Firms can reduce their carbon emission by using innovative equipment or materials. For example, a possible way to reduce CO_2 emissions is through carbon capture and storage (CCS). CCS is a combination of technologies designed to prevent the release of CO_2 generated through conventional power generation and industrial production processes by injecting the CO_2 into suitable underground storage reservoirs.[2] In this paper, the firm invests a developed technology which can reduce the carbon emission to a large extent, such as CCS, to expand their capacity.
(3) We investigate capacity expansion and technology portfolios. For example, the "old" technology is based on the original capacity, and the "cleaner" technology, which generates less carbon emission than the "old" technology when producing unit product, is based on the new capacity. Therefore, technology is dependent on capacity. Since we try to unravel the firm's dilemma between reducing carbon emission and maintaining the ability to fulfill demand, we not only discuss which technology to choose when producing the product under the consideration of carbon emission, but also investigate when and how much to expand the capacity in order to fulfill the demand.

The remainder of this paper is organized as follows. In Section 2, we discuss the relevant literature. In Section 3, we describe our assumptions and model. Section 4 addresses the optimal capacity expansion decisions and capacity utilization under the cap-and-trade and carbon tax regulations. Our analysis of results and numerical study are presented in Section 5. Section 6 concludes the paper with a discussion of the implications and possible further extensions.

2. Literature review

Here we provide a brief discussion of related literatures under two important classifications, and the first considers capacity investment, in which part we focus on transportation capacity investment and production capacity investment. As for transportation capacity investment, Liu et al. (2015) study a logistics service integrator's service capacity decision with two opportunities due to demand update. Li and Zhang (2015) study two competing shipping forwarder's capacity decision problem, in which the forwarders are allowed to purchase capacity from each other after they purchase the initial capacity from the carrier. Their study finds that capacity cooperation leads to a win-win situation for both the carrier and forwarders. As for production capacity investment, Boyabatli and Toktay (2011) examine the impact of endogenous credit terms under capital market imperfections in a capacity investment setting; they propose a capacity investment and technology choice with a demand stochastic decision making method. Ravi and Li (2008) present a comprehensive analysis of a duopoly making capacity, production, and price decisions with demand uncertainty, providing the capacity strategies for both flexible and inflexible firms. Ahmed et al. (2003) address a multi-period investment model for the capacity expansion problem with uncertain demand and cost parameters. Goyal and Netessine (2007) study the impact of competition on technology choice

[1] For more detail, please refer to http://ec.europa.eu/clima/policies/ets/pre2013/index_en.htm.
[2] For more detail, please refer to http://www.climatetechwiki.org/technology/oxyfueling-cement-kilns.