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Production lot-sizing and carbon emissions under cap-and-trade and carbon tax regulations

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ABSTRACT

Cap-and-trade and carbon tax are two emission regulations widely used to curb the carbon emissions generated from firms. Based on economic order quantity (EOQ) model, this paper examines the production lot-sizing issues of a firm under these two regulations, respectively. The optimal lot-size and emissions under the two regulations are achieved. We then investigate the impacts of production and regulation parameters on the optimal lot-size and emissions. Furthermore, we compare the firm's optimal carbon emissions under the two regulations. It is found that under the cap-and-trade regulation, the firm's decisions of the optimal emissions as well as permits trading depend on the differentiated permits trading prices. If setup incurs the same cost as holding incurs per unit of generated emissions, both regulations always lead to the same optimal emissions (which is also equal to that without emission regulation). Otherwise, neither regulation always leads to lower emissions than the other does.

1. Introduction

There is an increasing consensus that the carbon emission generated from firms' activities is one of the main causes of global climate change. To curb the carbon emissions, many countries and regions enact various regulations on firms' activities. “Cap-and-trade (or emissions trading)” and carbon tax are two most popular regulations implemented in the world. Under the cap-and-trade regulation, firms initially receive a free amount of permits (“cap”) over a planning horizon (e.g., one year), and are allowed to trade the permits with other firms or government agencies through special markets (e.g., carbon market). The European Union's Emissions Trading System (EU ETS) is the first and biggest international scheme for permits trade. Up to 2010, the EU ETS covers 11,000 power stations and industrial plants in 30 countries (European Commission, 2013), and involves over 50% of all emissions in the European Union (Benjaafar et al., 2013). Advocated as an alternative cost-effective instrument for reducing emissions, carbon tax regulation is much easier to implement than cap-and-trade regulation is. Under carbon tax regulation, firms are charged for their carbon emissions at a constant tax rate level. A growing number of scholars (Avi-yonah and Uhlmann, 2009), politicians and economists (Inglis and Laffer, 2008) and business leaders (Pontin, 2010) advocate carbon tax regimes rather than cap-and-trade.

As we know, carbon emissions are generated in almost all activities of firms, e.g., procurement, production, inventory holding, order processing, transportation and some others (Hua et al., 2011; Chen et al., 2013). Generally, carbon emissions from different activities are generated in different ways. For example, emissions from procurement are generated only when a procurement activity is implemented, usually irrelevant to the procured quantity; while emissions from inventory holding depend on the inventory quantity and inventory time. In production process, if the production lot-size is too small (which is advocated by Just-In-Time production theory), lots of emissions are generated from frequent setups; otherwise, if the production lot-size is too large, lots of emissions are generated from inventory. In the presence of emission regulations, emission-related costs arise in terms of buying additional permits (under cap-and-trade regulation) or paying tax (under carbon tax regulation). These emission-related costs can be substantial (Drake et al., 2010), which induces carbon-intensive firms to take the emission-related costs into consideration when determining the production lot-size.

This paper addresses the issues of the production lot-sizing of a firm under cap-and-trade and carbon tax regulations based on EOQ model. Under each regulation, the optimal lot-size and emissions of the firm are characterized, and the impacts of production parameters and regulation parameters on the optimal lot-size and

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emissions are also investigated, respectively. Due to their different mechanisms, cap-and-trade and carbon tax regulations lead to different forms of emissions costs, and have different impacts on firms' operational decisions. The comparison of these two regulations may provide governments the guidance on determining the cap (under cap-and-trade regulation) or the tax rate level.

In the cap-and-trade regulation considered in this paper, the permits buying and selling prices of the firm can be different. To our best knowledge, most of the existing studies on operational decisions under the cap-and-trade regulation treat these two prices as the same. The only exception is Gong and Zhou (2013), who investigate the impact of emission trading on a manufacturer's technology choice and production planning by using differentiated permits buying and selling prices. Since the emission trade takes place in a carbon market and a firm can buy permits from or sell permits to agencies, the permits buying price and selling price of a firm could be different. Following Gong and Zhou (2013), we differentiate these two prices and assume that the firm's permits buying price is not smaller than the firm's permits selling price in the cap-and-trade regulation. The rationale for this price differentiation is well-documented in Gong and Zhou (2013). First, the trading prices of permits actually represent the cost and the revenue of buying and selling a unit of permits, respectively, which include transaction costs. Transaction costs in emissions trading can be significant and have been studied both empirically and theoretically (e.g., Stavins, 1995; Woerdman, 2001). Second, the bid–ask price spreads, often seen in various trading markets, are another cause of non-identical selling and buying prices. For instance, the ask and bid prices for ECX EUA (European Union Allowances: carbon credits issued under the EU ETS to CO_2-emitting installations) futures for December 2010 are €15.48 and €14.20 per metric ton (12:00 p.m., Aug. 14, 2010, Hong Kong Time), respectively (http://www.ecx.eu/market-data). This implies that the firm's permits buying price may be higher than the selling price in practice. Furthermore, we hold that if the buying price is smaller than the selling price, firms might raise profit by purely buying and selling carbon permits. This speculation in turn weakens the effect of carbon trading regulation on reducing firms' emissions. It is noteworthy that, the production lot-sizing issue with identical permits buying and selling prices is a special case of what is discussed in our paper.

The rest of this paper is organized as follows. In Section 2, related literature is reviewed. In Sections 3 and 4, the lot-sizing decisions under cap-and-trade and carbon tax regulations are explored, respectively. In Section 5, the two regulations are compared with respect to the optimal emissions. Section 6 concludes this paper.

2. Literature review

In recent years, the research on cap-and-trade and carbon tax regulations has received extensive attentions both in empirical and theoretical studies.

The first stream mainly discusses the concepts, advantages and disadvantages of cap-and-trade and carbon tax regulations at strategic levels based on empirical studies. Ekins and Barker (2001) provide a detailed survey of the literature on carbon tax and emissions trading as well as their implementations. They conclude that there is a general agreement that market-based instruments of carbon control will achieve a given level of emission reductions at lower cost. As indicated by Harrison and Smith (2009), the cap-and-trade regulation is business-friendly and can produce more jobs. However, carbon tax regulation is simpler and easier to implement than cap-and-trade regulation is, and the tax increases the revenue of government which can be used as the investment of carbon abatement (Baranzini et al., 2000). Theoretically, both cap-and-trade and carbon tax can achieve cost-effective emission reductions (Stavins, 2008), and there is a broad equivalence between emissions trading scheme and carbon tax regulation under some assumptions (Pezzey, 1992; Farrow, 1995).

The second stream examines the operational decisions of firms under emission regulations. Letmathe and Balakrishnan (2005) study the production mix and production quantities of a firm under several different environmental constraints, e.g., threshold values, penalties and taxes, and/or emissions trading. From the perspective of carbon abatement efficiency, Mandell (2008) shows that utilizing the two regulations (i.e., cap-and-trade and carbon tax) can be superior to adopting only one regulation (either cap-and-trade or a carbon tax). Benjaafar et al. (2013) introduce a series of simple and general models to illustrate how carbon footprint could be incorporated into operational decisions, where many observations and insights are obtained. Drake et al. (2010) study a two-stage decision problem of a firm under the two regulations (cap-and-trade and carbon tax). In the first stage, the firm chooses capacities under two technologies, “dirty” and “clean”. With the given technology, the firm in the second stage chooses production quantities to maximize its own profit. Hoen et al. (2014) examine the effect of different emission regulations (including voluntary targets) on transportation mode selection for a ‘carbon-aware’ company (either by choice or enforced by regulation) under stochastic demand. Jaber et al. (2013) study the coordination in a two-level supply chain in the EU ETS, where greenhouse gas emissions are generated in the manufacturing processes. Jin et al. (2013) investigate the impact of carbon policies on supply chain design and logistics of a major retailer, where three carbon policies are considered: carbon emission tax, inflexible cap and cap-and-trade.

The third stream is related to the estimation of emission costs and carbon accounting under carbon emission regulations. Tsai et al. (2012a) develop a mixed Activity-Based Costing (ABC) decision model for green airline fleet planning under emissions trading scheme. Ståhls et al. (2011) investigate the impacts of international commodity trade on carbon flows of forest industry in Finland, using a quantitative analysis method. The carbon flows are embodied in the traded forest. They show that in Finland, the direct impact of the forest industry is only a minor fraction of the total CO_2 emissions related to production, and almost all of the emissions are caused due to production of exports. Stechemesser and Guenther (2012) systematically review the literature related to carbon accounting. One can refer to Tsai et al. (2011, 2012b, 2013) and Mózner (2013) for other similar studies.

Close to our work, Van der Veen and Venugopal (2014) incorporate the cost of energy usage into EOQ model, and find that the economic and environmental performance of a firm can be synergy or trade-off, depending on the values of specific parameters of the emission regulations. Hua et al. (2011) investigate how firms react in inventory management under carbon emission regulation based on EOQ model. They derive the optimal order quantity, and examine the impacts of regulation parameters on the optimal decisions, carbon emissions and total costs. However, in their work, only the cap-and-trade regulation is discussed, and the permits buying and selling prices are assumed to be equal. Bonney and Jaber (2011) incorporate transportation cost and waste into EOQ model, and develop an environmental economic order quantity model, which results in a larger optimal ordering lot-size than that under the standard EOQ model. Arslan and Turkay (2010) revise the standard EOQ model by incorporating sustainability constraints. Various sustainability constraints, such as carbon tax, cap and trade, direct cap and carbon offset, are considered. They show that in most cases, the optimal ordering quantity with the presence of sustainability constraints is larger than that without the constraints. It is noteworthy that, in the above mentioned studies, the permits buying and selling prices are all assumed to be the same. One exception is Chen et al. (2013). They investigate the EOQ model under various