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Research article

Supply chain carbon footprinting and responsibility allocation under emission regulations

Jin-Xiao Chen [a,*], Jian Chen [b]

[a] Institute of Quantitative and Technical Economics, Chinese Academy of Social Sciences, Beijing 100732, China
[b] Department of Management Science and Engineering, School of Economics and Management, Tsinghua University, Beijing 100084, China

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ABSTRACT

Reduction of greenhouse gas emissions has become an enormous challenge for any single enterprise and its supply chain because of the increasing concern on global warming. This paper investigates carbon footprinting and responsibility allocation for supply chains involved in joint production. Our study is conducted from the perspective of a social planner who aims to achieve social value optimization. The carbon footprinting model is based on operational activities rather than on firms because joint production blurs the organizational boundaries of footprints. A general model is proposed for responsibility allocation among firms who seek to maximize individual profits. This study looks into ways for the decentralized supply chain to achieve centralized optimality of social value under two emission regulations. Given a balanced allocation for the entire supply chain, we examine the necessity of over-allocation to certain firms under specific situations and find opportunities for the firms to avoid over-allocation. The comparison of the two regulations reveals that setting an emission standard per unit of product will motivate firms to follow the standard and improve their emission efficiencies. Hence, a more efficient and promising policy is needed in contrast to existing regulations on total production.

1. Introduction

Global concerns over climate change continue to increase along with the acceleration of global warming. The Intergovernmental Panel on Climate Change shows that greenhouse gas (GHG) emissions around the world have increased by more than 80% from 1970 to 2010, while the huge threat to global ecosystem continues to rise. Reducing GHG emissions is a consensus of the international community under such enormous pressure. China and the United States, as the top two emitters of carbon dioxide, issued their joint announcement on climate change in November 2014. Both sides announced their respective actions and targets on emission abatement. Thereafter, the United Nations Climate Conference in Paris reached a new global agreement on 12 December 2015, in which all convention parties were committed to achieving a goal of zero net GHG emissions by the second half of this century.

As main actors of economic activities, firms face a number of challenges in taking responsibilities for climate change. Emission regulations and carbon trading mechanisms impose restrictions on business operations and drive firms to improve product designs. Regulatory uncertainty has also been inherent in climate change, and firms have called for a stable policy framework to scale up investments in clean technologies and properly develop a carbon market (Kolk and Mulder, 2011). Meanwhile, consumers and investors have paid more attention to firm performance with respect to carbon issues. Consumers may arrive at purchase decisions according to the business implications of climate change, while investors consider the influence of carbon management on long-term shareholder value (Lash and Wellington, 2007; Swarr, 2009).

Walmart and Tesco have initiated their management of global carbon footprints. By setting specific goals, these companies have committed to reduce emissions jointly with their suppliers. However, Accenture (2009) reveals that only 1 in 10 companies attempt to manage carbon footprints in their supply chains, and managers of 37% of these companies know little about the carbon footprints associated with their business. The situation is, however, improving, as revealed by the Carbon Disclosure Project (CDP) in 2010. Accordingly, in view of long-term business development, 44 CDP members and up to 710 of their suppliers exert efforts to reduce supply chain-wide emissions despite having been affected

* Corresponding author.
E-mail addresses: jincheng0830@126.com (J.-X. Chen), chenj@sem.tsinghua.edu.cn (J. Chen).

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by the recent financial crisis.

An important issue related to carbon footprinting is joint production, which arises commonly within supply chains. A product is the outcome of multiple operational processes, such as purchasing, manufacturing, and transportation. The decisions made by firms during the same process usually determine company strategies and influence others. For example, when a manufacturer changes the ordering quantity or updates the production facility to optimize operations, the supplier should adjust to this change by preplanning its supply. For carbon emissions, joint production means that multiple firms may influence emissions from a particular process. For instance, emissions from transportation led by third-party logistics firms can be influenced by the manufacturer that changes the storage site or shares with suppliers the demand information that may improve supplier operations and lessen the need for fast transportation. In addition, emissions from manufacturing processes are naturally related to suppliers who provide the materials for manufacturing. Huang et al. (2009a) report that the top 10 suppliers account for 30%–50% of the total emissions in a sector. For example, over 90% of emissions of Walmart should be attributed to its numerous suppliers. Similarly, suppliers face difficulties in allocating their emissions to multiple customers (CDP, 2011). Therefore, identifying which firms specifically contribute emissions to a particular process is impractical. In other words, the boundary for the attribution of footprints is vague among firms in a supply chain.

Life-cycle assessment (LCA), which is widely used for carbon footprinting in practice, aggregates emissions across multiple subsystems (processes/firms) to correctly estimate system-wide (supply chain-wide) emissions. An aggregate reporting purpose in LCA that is based on accurate estimation claims to avoid double counting of environmental impact, such as carbon footprints (Lenzen et al., 2007; Lenzen, 2008). Caro et al. (2013) show that in the presence of joint production, double counting is desirable for designing regulatory mechanisms or setting incentives to induce social value optimization. No double counting leads to underinvestment in emission abatement efforts because benefits must be split in that case. However, double counting naturally means that the social value is optimized at a loss of the interest of a supply chain and that firms should be able to afford high extra costs.

The purpose of this paper is to provide a framework for carbon footprinting and study the allocation of responsibilities for supply chain-wide footprints without double counting. Given that joint production blurs the organizational boundaries of carbon footprints, footprints cannot be simply assigned to individual firms and a responsibility allocation scheme is of necessity. Hence, analyzing operational activities that generate emissions within the scope of a supply chain is more explicit than directly pinning down individual firms. We investigate a more general structure of supply chains and build a general model for carbon footprinting and responsibility sharing in the presence of joint production.

Our study is conducted from the perspective of a social planner who aims to optimize social value. The allocation rule carried out by the social planner can be viewed as a compensation scheme to motivate firms to be jointly optimized. The impact of emission regulations on the supply chain is considered throughout this study. Two emission regulations are investigated, referred to as Regulations I and II hereafter. Regulation I is a carbon tax policy under which a firm is ordered by the social planner to purchase emission allowance, i.e., a sufficient amount of carbon quota, in advance for all possible emissions from its subsequent operations. Regulation II is a special type of cap-and-penalty, but the cap is set as an emission standard per unit of product. Under Regulation II, a firm obeying this standard can emanate its emissions free; otherwise the firm will pay for all emissions from its operations.

The contributions of this study are follows. First, this study determines whether the allocation of abatement costs instead of carbon footprints can prevent double counting from inducing the best effort level. Our study is based on the common condition that each activity within a supply chain is led by one, and only, one firm that is, just seen from the perspective of the social planner, required to pay for all the emissions from that activity. Second, this study analyzes the ways a decentralized supply chain can achieve centralized optimality of social value under Regulations I and II given a balanced allocation for the entire supply chain. We examine the necessity of over-allocation of abatement costs on certain activities and find opportunities for individual firms to avoid over-allocation, which could result in loss of interest among individual firms. Third, a comparison is made between Regulations I and II from a regulatory point of view. Setting an emission standard per unit of product, as proposed in Regulation II, is an effective policy to spur firms to follow the standard and improve emission efficiencies. This strategy is in contrast to existing regulations on total production under which the emission cost increases with production size.

The remainder of the paper is as follows. Section 2 provides a literature review of three associated areas. Section 3 describes the basic modeling framework in our study. Section 4 investigates supply chain carbon footprinting and responsibility allocation under Regulations I and II. Section 5 concludes.

2. Literature review

Our study is generally related to three areas of literature, namely, emission regulation and trading mechanism, sustainable supply chains, and carbon footprinting and responsibility sharing. Previous studies with their specific focuses may be associated with two or more areas. The following subsections review the research development in these areas and represent what our study draws on and differs from the literature.

2.1. Emission regulation and trading mechanism

Research in this subject mainly focuses on policy instrument and mechanism design. The main financial tools for emission regulations include *price* and *quantity*, e.g., carbon tax (price), upper limit and lower limit (quantity), or a mix of both (Weitzman, 1974). Many studies have discussed these two tools, e.g., Hepburn (2006) and Newell and Pizer (2008), and the derivative tools, e.g., Burtraw et al. (2010).

According to the Congressional Budget Office of the United States (2008), emission policies emphasized by governments and relevant organizations are categorized into four types: mandatory carbon emissions capacity (cap), carbon tax, cap-and-trade, and investment in the carbon offset. Other policy instruments include cap-and-penalty, command-and-control, and a mix of these schemes (He and Gao, 2011). Viewpoints from various studies show that determining which type is better is still a moot point (Newell and Pizer, 2008; Webster et al., 2010). Dissou and Karnizova (2016) conduct a multi-sector business cycle analysis on the stochastic effects of reducing emissions with carbon permits and carbon taxes for the US. Their study indicates that the origin of shocks is important for ranking these two policies. Tax and cap-and-trade, which drew much attention from early studies on pollution control (Klaus, 1993), have received increasing attention concerning carbon emission regulation. Metcalf and Weisbach (2009) provide an in-depth analysis on the design of carbon tax for the US. They also show that a well-designed carbon tax can capture about 80% of U.S. emissions by taxing only a few thousand taxpayers, and almost 90% with modest additional cost. The cap-and-trade system has