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The impact of carbon policies on supply chain design and logistics of a major retailer

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ABSTRACT

The energy used to move freight comprised about 17% of all the energy consumed in the United States in 2010. This percentage was an increase from 8.7% in 1970 even though fuel efficiency gradually improved over the period. One major reason of this phenomenon is that the longer supply chains of many industries caused by globalization increase freight movement. Various carbon policies have been discussed and even implemented for some industry sectors in the European Union to reduce carbon emissions. However, the emissions of surface transportation have not been well studied. This paper investigates three of the most common carbon policies: carbon emission tax, inflexible cap, and cap-and-trade. The impact on a company may include the redesign of its supply chains and different choices of transportation modes (truck, rail, or waterway). This paper proposes optimization models for major retailers, who make a huge contribution to freight movement, to design their supply chains under various carbon policies. The results from the models can help policy makers to predict the impact of policies on overall emissions in the freight transportation sector. The model may also be incorporated into the integrated assessment models for climate change analyses. Furthermore, a sensitivity analysis is conducted to study the impact of the policy parameters on carbon emissions and logistics cost. This research uses the supply chain of a major U.S. retailer (i.e., Wal-Mart) to demonstrate how to use the models and conduct the sensitivity analysis. In order to realize significant emission reduction, a redesign of supply chains of major retailers is necessary and will be triggered only by a high carbon tax rate, a high carbon price, or a very strict carbon cap, which all may involve high social and/or economic complexity. Numerical experiments show that different policies have different impacts on the costs and the effectiveness of emission reduction. How to choose policy parameters is critical to the effectiveness of a carbon policy. The different sensitivity also implies different challenges during the implementation of the policies, such as the high cost preventing retailers from accepting any carbon taxes and the difficulty of reaching an agreement on the carbon caps between retailers and policy makers.

1. Introduction

Transportation consumed 27.6 quadrillion Btu energy in the United States in 2011, which was 27.8% of the total energy consumed in the nation (Bureau of Transportation Statistics, 2012). The energy used to move freight comprised about 17% of all the energy consumed in the United States in 2010 (Davis et al., 2012). This percentage was an increase from 8.7% in 1970. Furthermore, most of the energy consumed in transportation (95.6%) in 2011 was from petroleum or natural gas, which was much higher than the industrial sector (53.4%), the residential sector (29.6%) and commercial sector (21.6%) (US DOE, 2012). Therefore, freight transportation also has a huge environmental impact compared to other energy demand sectors. Transportation activities (excluding international bunker fuels) accounted for 33 percent of CO_2 emissions from fossil fuel combustion in 2010 (EPA, 2012). From 1990 to 2010, transportation emissions rose by 17.5 percent in the US even though the efficiency of vehicles gradually improved (EPA, 2012). A similar phenomenon happened in the European Union (EU), where greenhouse gas emissions in other sectors decreased by15% between 1990 and 2007 but emissions from transport increased by 36% during the same period (European Commission, 2011a). One major reason why fuel consumption and carbon emissions have increased from freight transportation in the last several decades is that the supply chains of many industries have become highly globalized due to lower transportation and communication costs and lower labor costs in developing countries. Consequently, longer

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supply chains have increased freight movement, internationally and domestically.

The Intergovernmental Panel on Climate Change (IPCC) advised that global carbon emissions should be cut by at least 50% by 2050 (Parry et al., 2007). To meet the target, the emissions from transportation must be reduced. The EU has been a frontrunner in the world regarding carbon emission reduction, while the carbon policies in the US are mainly at the discussion stage though the US emits more CO_2 than the EU (Davis et al., 2012). The EU Emissions Trading System (ETS) was launched in 2005 and is a major pillar of EU climate policy. Under the EU ETS, large emitters are asked to monitor and report their CO_2 emissions annually. In the first phase of 2005–2007, ETS covered major energy activities, production and processing of ferrous metals, mineral industry and pulp, paper and board production (European Commission, 2008a). In 2012, ETS started to include the aviation sector and would like to ultimately include maritime transport and forestry (European Commission, 2008b). However, the huge number of individual cars adds complexities to the general transportation sector so that the EU may try to reduce emissions from surface transport through fuel suppliers and car manufacturers. The European Commission in 2007 proposed that transport fuel suppliers need to reduce carbon emissions per unit of energy by 1% a year from 2010 levels until 2020 (European Commission, 2011b). However, the high emissions and energy consumption in transportation may not be significantly reduced by the efficiency improvement of fuels and vehicles alone, as evidenced by history, if the pattern of transporting people and freight remains the same.

Although it is difficult to monitor individual passenger vehicles, it is possible to use various carbon policies to influence freight movement, which accounts for a large portion of the emissions in the transport sector. In order to predict the effectiveness of a carbon policy and to decide the right parameters for the policy, it is important to understand the response of freight shippers to carbon policies. A carbon policy's impact on a company may include the redesign of its supply chains, different choices of transportation modes (truck, rail, or waterway), and better logistics management (e.g., order size and frequency). The literature review in Section 2 shows that there are not enough studies on the impact of various carbon policies on supply chain design and mode choices though one paper does discuss ordering decisions under several carbon policies (Benjaafar et al., 2013).

This paper will investigate the impact of the three most common carbon policies in the literature on freight flows, especially on supply network design and mode choice for major retailers, whose product movements contribute to a significant part of freight transportation. Optimization models are proposed for the decision making of a major retailer under various carbon policies. A case study will be presented based on the assessment of the global supply chain of Wal-Mart, a major retailer in the United States based on publically obtained information. Wal-Mart was ranked the number one importing company in the United States in 2011 (UBM Global Trade, 2012). Wal-Mart imported a total of 710,000 TEUs (Twenty-foot Equivalent Units), followed by Target, another giant retailer in the States, with 472,400 TEUs. If we have a look at a typical Wal-Mart store on the east coast of the United States, most items are produced in Asia, cross the Pacific Ocean by steam ships, and travel through the continent by rail and/or trucks to reach the store. The long journey of a large amount of freight involves heavy energy consumption and carbon emissions. It is expected that the analysis developed in this paper can help to better understand how the suggested policies affect the overall supply network design and mode choice of retailers. It is believed that a good understanding of a retailer's response to various carbon policies will help policy makers to predict the impact of policies on overall emissions in the freight transportation sector. Furthermore, the IPCC is using the Integrated Assessment Models (IAMs) to understand future climate change under various socio-economic conditions. The models proposed in this paper could be incorporated into IAMs to predict the economic activities under various carbon policies and therefore facilitate what-if analyses. In addition to the above practical relevance, this paper contributes to the literature with models and analysis procedures that can be used to analyze freight transportation patterns under various carbon policies.

The objective of the paper is achieved by two specific means: 1) building optimization models for supply chain design and logistics operations of global retailers under various carbon policies and 2) conducting a sensitivity analysis to study the impact of the policy parameters on carbon emissions and logistics cost. Following the practice and other papers in the literature (Dinan, 2008; Houser, 2008; Diabat and Simichi-Levi, 2010; Benjaafar et al., 2013), this paper investigates the three most common carbon policies: carbon emission tax, inflexible cap, and cap-and-trade.

The remainder of the paper is organized as follows. Section 2 reviews the relevant literature. Section 3 provides optimization formulations of designing the supply chain network and choosing transportation modes for a global retailer under various carbon policies. Section 4 presents a comprehensive case study with sensitivity analysis on policy parameters. The case study demonstrates that the studied policies have different impacts on logistics cost and emission reduction. Section 4 also discusses the insights on the challenges during policy implementation based on the findings from the case study. Section 5 concludes the paper and provides future research directions.

2. Literature review

This paper is related to two streams of research in literature, the study of carbon policies and research on supply chain design, especially green supply chain design. Most work on carbon policies is at the macro-level of countries or regions, such as the study of the relationship among the annual coal consumption, total pollution and annual emissions goal in China (Liao et al., 2011). A similar model was built for the emission trading market in the United Kingdom (Cárdenas et al., 2011). There are several studies focusing on the impact of carbon policies on the manufacturing industry. Ho et al. (2008) studied the impact of carbon price policies on various US industries. Bassi et al. (2009) concluded that any price on carbon could significantly influence US energy-intensive manufacturers. Wansart et al. (2008) studied an automaker's decisions of product design and production under emission regulations in Germany. Anand et al. (2006) developed a system dynamic model to estimate CO_2 emissions from the cement industry in India. The transportation mode choice decision is typically the emphasis in many transportation-related studies. Developing more railroads and mitigating more traffic from highways to railroads were suggested to control emissions from passenger transportation in China (Han and Hayashi, 2008). Hoen et al. (2010) investigated the effect of two carbon policies, carbon tax and cap-and-trade, on the single transportation mode selection decision. They concluded that an emission cost for freight transport via a direct emission tax or a market mechanism with the current carbon allowance price would not likely result in significant changes in transport modes and would have a little reduction of emissions. Piattelli et al. (2002) proposed a macro-level model to study possible alternative transportation modes under a carbon tax policy. Different from most existing studies, this paper will focus on the micro-level response of individual major retailers to various carbon policies and therefore try to