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Integrated inventory control and transportation decisions under carbon emissions regulations: LTL vs. TL carriers

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ABSTRACT

This study analyzes an integrated inventory control and transportation planning problem with carbon emissions regulations. We investigate the economic order quantity model with less-than-truckload (LTL) and truckload (TL) transportation under carbon cap, cap and trade, cap and offset, and taxing policies. We find the retailer's optimal order quantity under each regulation with LTL and TL carriers. Analytical and numerical results comparing LTL and TL carriers are documented. We illustrate that the retailer's carrier preference depends on regulation parameters. The tools provided enable analyzing the effects of regulations, transportation costs and emissions on the retailer's costs and emissions with each carrier.

1. Introduction and literature review

It is well known that greenhouse gas (GHG) emissions are threatening the earth's ecology and, unless controlled, might pose great danger to the human race (Hua et al., 2011a; Benjaafar et al., 2012). Fig. 1(a) documents the global GHG emissions by economic sector in 2010 (ECOFYS, 2010). The US Energy Protection Agency (EPA) notes that the contribution of the transportation sector to national GHG emissions in 2011 was around 27% (EPA, 2013). Fig. 1(b) compares the 2011 US GHG emissions by economic sector (EPA, 2013).[1] As seen in Fig. 1(c), when different transportation modes are compared, it is noted that trucking, i.e., road transportation, constitutes the second largest GHG emission generators following passenger transportation (EPA, 2013). This implies that freight transportation by trucks dominates the GHG emissions compared to other freight transportation modes such as rail, air, and marine transportation (over 75% of GHG emissions from domestic freight transportation in the US are due to trucking activities, FHWA, 2011).

These statistics are not surprising as trucks are the most common transportation mode used for freight transportation. According to the US Department of Transportation Federal Highway Administration (FHWA), over 68% of freight tonnage is shipped by trucks and the FHWA further notes that, "By 2040, long-haul freight truck traffic in the United States is expected to increase dramatically on interstate highways and other arterials throughout the nation" and truck travel is forecasted to reach 662 million miles per day (FHWA, 2008). Similar observations are noted for the European Union countries. Forecasted growth of freight transportation from 2000 to 2020 in European countries is noted to be 50% (see, e.g., Toptal and Bingol, 2011).

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[1] Due to rounding, the totals may not sum up to 100% (EPA, 2013).

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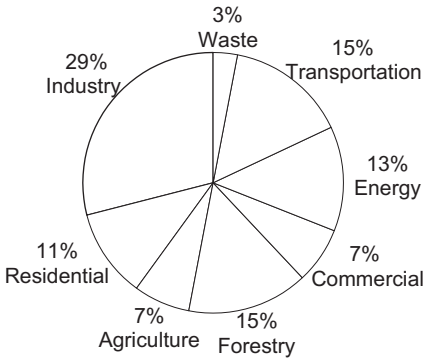
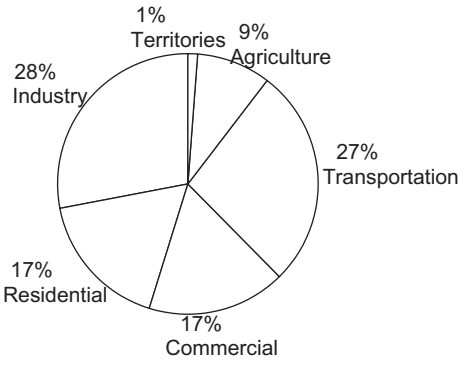
(a) Global GHG Emissions by Economic Sector in 2010



(b) US GHG Emissions by Economic Sector in 2011



(c) US GHG Emissions by Transportation Mode in 2011

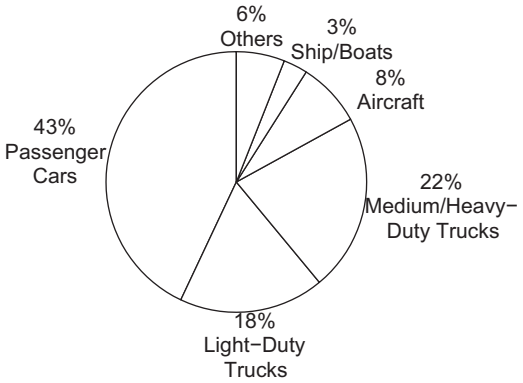


Fig. 1. GHG emissions statistics.

Given freight transportation by trucks is very common through supply chains, it is important to analyze truck transportation integrated with companies' inventory control operations under carbon emissions regulations. Ratified by 191 countries, the Kyoto Protocol (UNFCCC, 1997), for instance, set regulations on GHG emissions. The European Emissions Trading System, the New Zealand Emissions Trading Scheme, and the Regional Greenhouse Gas Initiative are some examples of governmental programs established to help companies reduce their carbon emissions. Voluntary programs such as Chicago Climate Exchange, the Montreal Climate Exchange, and many carbon offsets companies also serve to this end.

While mostly energy-intensive industries such as iron, steel, metal, cement, paper, pulp, and oil manufacturing are affected by such regulations as they account for the majority of the energy consumption in industry in many countries (IPCC, 2007), many other manufacturing, retailing, fashion apparel, health-care industries are also affected by such regulations. It is noted in Carbon Disclosure Project (2011) that emissions from supply chain operations surpass the emissions from corporate operations within the 2500 largest corporations and these corporations are estimated to generate 20% of the global emissions (see also Jira and Toffel, 2013). Specifically, supply chain operations such as warehousing activities, inventory holding, freight transportation, and logistical activities are the main emission generators throughout supply chains. Inventory appears in most industries (Tsou et al., 2010). Furthermore, inventory control policy of a company is the main determinant of levels of inventory held, warehousing activities, and freight transportation frequency; hence, it is the key controller of the emissions generated from supply chain operations. This study focuses on an integrated inventory control and freight transportation problem under four common carbon emissions regulation policies: carbon cap, carbon cap and trade, carbon cap and offset, and carbon taxing.

Under the carbon cap policy, a company plans its operations such that a predefined level of carbon emissions, referred to as carbon cap, is not exceeded. It should be noted that the carbon cap can be determined by the company's green goals as well as government agencies (Chen et al., 2013). For instance, Caro et al. (2011) note that the retailing companies Wal-mart and Tesco, and consumer goods company Unilevel set goals to reduce their emissions. Also, carbon cap policy is one of the policies considered to reduce carbon emissions in the US by the Congress of the United States, Congressional Budget Office (CBO, 2008). Under the carbon cap and trade policy, on the other hand, a company can sell its excess carbon emissions if its carbon emissions level is lower than the carbon cap or buy carbon emission permits if its carbon emissions level is higher