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Impact of fuel price and emissions on inventory policies

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ABSTRACT

The purpose of this paper is to analyze the impact of changes in fuel prices and the imposition of a carbon tax on emissions from transport on shipment lot sizes and supply chain costs. An analysis is done to show that increases in fuel prices should be dealt with differently than other costs. Further, a function to calculate future fuel prices has been developed. This function has been used to calculate transport cost in the future. The EOQ models have been modified to include increasing transport cost and a carbon tax to demonstrate its impact on various inventory policies. Due to increases in fuel prices, the cost of every subsequent order will also increase, thus resulting in an increase of average order cost for all the shipments in a production cycle. Organizations that have their vendors in relatively close proximity will be at an advantageous position in managing their supply chain costs more effectively in the future. On the other hand, organizations that have invested heavily in global supply chains will need to re-examine their supply chain strategy to overcome cost challenges. This research presents a new challenge for supply chains/logistics management strategies for organizations with global supply chains.

1. Introduction

There is a growing emphasis on the search for substitutes of fossil fuel that generate less pollution, are available in abundant quantities and as efficient as or more efficient than fossil fuel. Nowadays, newspapers in many countries are full of news and editorials about the possible depletion of the world's fossil fuel reservoirs and the future of fuel prices. Many of the available inventory management models, such as the economic order quantity (EOQ), developed over the past century were based on the false assumptions that fossil fuel is abundant and that greenhouse gas (GHG) emissions from manufacturing and logistics operations have no implicit effects [1]. Literature on EOQ, its application under varying degrees of shelf-life, yield and its limitations has been reviewed by many authors [2–5]. Despite many limitations, the EOQ is still in use and has been celebrated recently in a book and in a special issue [6–8].

One of the limitations of the EOQ model that has not been addressed in the literature is how an increase in fossil fuel prices will affect transportation cost and lot sizes. Increasing fuel prices are putting pressure on logistics and supply chain costs. Fuel cost has emerged as one of the top ten challenges in the truck transport industry in the USA [9], accounting for 35% of the total transportation cost in 2013 [10]. Andriolo et al. [11] reached a similar conclusion that transport cost is increasing and becoming an important factor in lot size and inventory decisions; they suggested including it in inventory decisions. The greater the distance traveled, the higher the cost of transportation and the bigger the impact on the environment. Oglethorpe and Heron [12] reached a similar conclusion for national food chains. They also noted that "miles per unit of consumption" is generally ignored, which is an important measure for reducing emissions.

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The long term effects of increasing fuel prices on the total cost of supply chains have not been addressed in sufficient detail. When a tax on transport emissions is considered, the total cost of supply chains will increase further. A literature review on supply chains and logistics found little evidence of theory development on the "total cost" of logistics. A survey article reviewing 683 supply chains and logistics papers found only a small fraction, 1.1%, focusing on the total cost theory [13].

This paper attempts to fill this gap in the peer reviewed literature and provides an impact of increases in fuel prices on transport cost, total order cost, and lot sizes. It further addresses the impact of a tax on GHG emitted from transportation on the total order cost. The EOQ model has been used to demonstrate the impact of increasing fuel prices and an emissions tax on the total cost. The remainder of the paper is organized as follows: Section 2 reviews the literature, briefly discusses how the demand and supply of fossil fuel affect its price, and subsequently the cost of transporting goods. Section 2 also briefly discusses transport emissions and explains the reason for treating fuel prices differently than the rest of the costs in supply chains. Section 3 discusses a model for calculating the economic order quantity (EOQ) taking into account the changes in fuel prices as a function of time and provides a solution procedure. This model is then tested in a two level-supply chain context with different coordination mechanisms. Section 4 provides illustrative numerical examples that demonstrate the application of the model. Section 5 presents analysis and discussion. Section 6 discusses managerial insights. Section 7 concludes the paper with a discussion of the implications of the model on the future of supply chains.

2. Literature review

In the context of a supply chain, transportation involves moving raw materials, semi-finished and finished products from one entity (an origin) to another (a destination). The primary mode of transportation for global supply chains is cargo shipping. Around 90% of the world trade is carried by the international shipping industry [14]. However, emissions generated from international aviation and maritime transports are ignored from national emissions inventories [15]. The price of fuel influences the cost of cargo shipping as well as the configuration of supply chains. The cost of bunker fuel in cargo shipping is about 30%, though this varies slightly based on the speed and the size of the vessel, of the total cost of transportation, which is a significant contributor to the overall cost [16]. Notteboom and Vernimmen [16] discussed the effects of high fuel prices on marine cargo liners between the Far East and Europe and found that an increase in fuel prices increases their operating cost and erodes their profitability. In a related example, Jeihani and Sibdari [17] studied the impact of gas prices on the auto industry and found that as the price of fuel increases, buyers switch to smaller cars to save on operating (fuel) cost. Some researchers have investigated the effects of transportation costs on lot size decisions. For example, Goyal and Szendrovits [18] modeled lot sizes based on the constraint of truck/container capacity and fixed transport cost. They found that a firm could experience cost savings by allowing both equal and unequal lot sizes at different stages of a production line (or a supply chain) as compared to models that require equal lot sizes alone. Swenseth and Godfrey [19] discussed inventory replenishment decisions due to price discounts on higher weight in transportation cost and found that transporting in larger quantities saves money. Russell and Krajewski [20] discussed the transport cost in a supply chain when calculating the lot size quantity based on weight discounts. In the case of partial truckloads, they found that declaring higher weights than the actual weight, cost less due to differences in rates. Ertogral et al. [21] added a step-function of the transport cost in a two-level (supplier–buyer) supply chain cost function based on volume discounts with and without over-declaration. They found a potential for savings by explicitly integrating the transportation cost into the total supply chain cost as it alters inventory (and production) decisions. However, these studies, as others in the literature, did not factor the changes in the price of fuel over time into their transportation cost equations.

Corbey and Jansen [22] studied the impact of various costs on the economic lot size quantity and emphasized the inclusion of variable costs in the calculation. Zhao et al. [23] have worked on adding transport costs whenever multiple trips per day, within cities or in close proximities, are possible. They found adding fuel cost changes the lot sizes. Most of the supply chain literature adopts a centralized policy approach by determining the joint lot sizing policy or the joint economic lot-size problem (JELSP) that minimizes the total supply chain cost. Existing literature either ignores direct fuel cost in the cost analysis or implicitly considers it a part of the fixed order costs. This indicates a need for assessing the impact of changes in fuel prices, which affect the cost of transportation, on the EOQ model. In support of this notion, readers may refer to the work of Jaber and Zolfaghari [24] and Glock [25] for reviews on the JELSP.

Transportation is a major source of GHG emissions. Offshore outsourcing and global supply chains have helped fuel the growth in emissions due to an increase in transportation needs. Davis et al. [26] observed that 23% of the global CO_2 emissions are embedded in traded goods and suggested a CO_2 emissions tax along the supply chain for reducing emissions. Chaabane et al. [27] studied production processes and transportation systems in the aluminum industry and found that the current legislation and Emissions Trading Schemes (ETS) need to be strengthened and harmonized at the global level in order to drive a meaningful environmental strategy. Jaber et al. [28] worked on the emissions in supply chains and presented a model for optimizing the cost of emissions under various scenarios. The importance of designing more environmentally responsible inventory models has been discussed by Bonney [29]. Later Bonney and Jaber [1] also discussed various challenges in including the cost of impacts on the environment in inventory management; they stressed the need for assigning a cost of environmental impact for taking meaningful decisions. The importance of the relationship between energy and inventory was discussed by Zanoni and Zavanella [30]. Benjaafar et al. [31] provided a generic model to account for emissions associated with ordering, inventory holding, and production. Chen et al. [32] further extended the work of optimizing