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Reduction carbon emissions in supply chain through logistics outsourcing

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Abstract. In this research, we consider logistics outsourcing to reduce carbon footprints by cooperating with third-party logistics service providers. Logistics outsourcing takes use of Less-Than-Truckload (LTL) shipping, and a shipment may be transported for a fraction of the cost of hiring an entire truck and trailer for an exclusive shipment. Without reducing the frequency of inventory replenishment that could lead to higher inventory level, firms can utilize LTL shipping to lower the transportation cost via outsourcing and emissions accordingly. However, LTL shipping may cause longer lead-time than those delivered by firms' own vehicles, as LTL transit times highly depend on the structure of the network of the third-party logistics provider (3PL) including terminals and connections. We develop analytical models to examine the effect of logistic outsourcing on emission reduction and associated cost.

Keywords: low carbon, outsourcing, supply chain

1. Introduction

Global warming has compelled people to reduce carbon dioxide emissions. To prevent climate change, many countries all over the world have committed to slow down carbon emissions in the coming future. Conventionally, costs, services and quality are taken into consideration; however, in the future companies should also take efforts to reduce the carbon footprint as they run

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businesses. Although now it may be just social responsibility issue for some companies, it will evolve into a financial issue for most companies in the near future. In fact, European Union Emission Trading Scheme (EU-ETS) has launched since January 2005 and currently the second Trading Period is under way which will last until December 2012. Installations are allocated emission permits by a central authority, and installations that need additional permits have to buy permits from those that require fewer permits in carbon markets. In other words, companies have to pay for the carbon dioxide emissions if they used up their permits. There were around 12,000 installations in Phase I (2005-2007) in EU-ETS, while aviation is further added in Phase II (2008-2012) and it is expected that all greenhouse gases and all sectors, especially the transport sector, will be included in it after 2012. Except financial considerations, carbon footprint is becoming another factor that may affect customer choice. Nowadays more and more consumers are concerned with the carbon footprint of products they purchase. Many companies attach carbon footprint labels to their products to display the amount of Green House Gas (GHG) emissions in goods and services throughout their entire life cycles. When consumers make shopping decisions, this measure can give them a greater insight into how much unseen pollution is caused by their purchases. A relatively smaller amount of generated CO2 can enhance brand reputation and sales appeal. Some big retailers, e.g. Tesco and Marks & Spencer, have been working on such projects. Thus, both financial and ethical incentives drive companies to reduce carbon footprints.

Across a supply chain, there are various ways to save energy and lower down GHG emissions, including raw materials selecting, using greener package, energy saving in manufacturing process and distribution & storage process, etc. Investments and innovative operational processes are usually required to implement energy saving. For example, old equipments may be replaced with new more energy-efficient ones; factories, distribution centers and retail stores can use LED lighting products, improve the efficiency of air-condition systems, and employ advanced IT system to dynamically monitor and control the energy usage. Transportation and storage activities have attracted much attention as well, for fuel is consumed greatly therein and it is believed that there is room to cut carbon emissions. Logistics sector is thought of as one of the main sources for carbon emission. Unlike carbon emissions in manufacturing, raw material selecting and packaging processes where reduction can be achieved by using greener materials for production and packaging, buying more energy-efficient machines and introducing alternative production technologies, emissions in transportation and storage process is generally determined by inventory control polices, transportation approaches and even more fuel-efficient vehicles. Its purpose is to lower GHG emissions associated with transportation and storage per item. To achieve the goal, operational tactics might be changed to save fuel and energy consumed. However, such changes could incur additional costs. Thus, a common dilemma that is often confronted by management is how to reduce carbon emissions economically in logistics.

In this research, we consider logistics outsourcing to reduce carbon footprints by cooperating with third-party logistics service providers. Logistics outsourcing takes use of Less-Than-Truckload (LTL) shipping, and a shipment may be transported for a fraction of the cost of hiring an entire truck and trailer for an exclusive shipment. Thereby, without reducing the frequency of inventory replenishment that could lead to higher inventory level, firms can utilize LTL shipping to lower the transportation cost via outsourcing. Except low cost, LTL shipping can also reduce carbon emissions on average compared to using their own transportation vehicles, as LTL carriers collect and consolidate freight from various consigners onto enclosed trailers. However, LTL shipping may cause longer leadtime than those delivered by firms' own vehicles, as LTL transit times highly depend on the structure of the network of the third-party logistics provider (3PL) including terminals and connections. If the freight is sorted and routed several times, the transportation time will be further longer. Longer leadtime is associated with higher inventory level and related costs. We develop analytical models to examine the effect of logistic outsourcing on emission reduction and associated cost.

The importance of Green SCM has been greatly addressed in literature (e.g. Kopicki et al. 1993; van Hoek 1999; Sarkis 1998 and 1999; Guide and Wassenhove 2002). Green design aims to use greener materials to replace problematic materials. Zhang et al. (1997) investigate environmentally conscious design and manufacturing and discuss the related terms on green design. However, limited research is concerned with operational decisions directly. Research on reducing carbon footprints from storage and related transportation by adjusting inventory decisions is especially rare. Recently, several works address carbon emission problems in SCM and discuss possible ways to reduce carbon footprints in logistics process. Chaabane, Ramudhin and Paquet (2011) discuss how economic and environmental objectives are balanced in the aluminum industry under different cost schemes. A few of works on analytical models of emission reduction are concerned with deterministic EOQ models by either formulating a multi-criterion model or adding carbon cost to the objective function. Zhu and Fu (2013) balance ordering policies and disruption risks in a dual-sourcing network under specific service level constraints. Wang et al. (2013) examine management strategies of reverse logistics in e-commerce environments.

2. The Model

We consider a supply chain consisting of one supplier and one buyer. The buyer employs the periodic review inventory system to control his inventory, which is frequently used in practice. He faces uncertain demand and replenishes his demand periodically. At the end of each inventory review interval, the buyer reviews his inventory level, determines an order-up-to level and places an order to the supplier. The buyer observes the demand of customers, meets the demand with on-hand inventory, and unfilled demand becomes a backorder. The supplier fulfils the order when he receives it. When goods are transported by trucks and stored in buyer's warehouse, greenhouse gases are emitted by fuel and energy consumption. We first construct a benchmark model without 3PL, where goods from supplier are conveyed by the buyer's own fleet. h and π denote the unit holding cost and backorder cost per period. Let l and c denotes the lead time and fuel price. Then without 3PL, the minimization problem of the expected average cost per period of the buyer is given as

$$\min_{I\geq 0}\ C(I)=h\int_0^I (I-x)\varphi(x)\ dx+\pi\int_I^{+\infty}(x-I)\varphi(x)\ dx \qquad (0.1)$$
$$+\frac{h}{2}E(Q)+c\left[g_0+g_1E(Q)\right]$$

In braces of (0.1), the first and second terms are overstock cost and backorder cost respectively. $\lambda_1 hE(Q_1)/2$ is the inventory holding cost during each period. $c\left[g_0+g_1E(Q)\right]$ is the fuel cost of the buyer's own fleet per period. g_0 is the fuel consumption of the unloaded (empty) vehicle and g_1 is the unit fuel consumption factor if the transportation vehicle is loaded with goods. g_0+g_1Q captures the amount of fuel consumption for a one-way delivery from the supplier to the buyer. The associated carbon emissions from transportation and storage are

$$G_1=[g_0+g_1E(Q)]\theta_1$$
$$G_2=\left[w_0+w_1E(Q)/2+\int_0^I (I-x)\varphi(x)\ dx\right]\theta_2 \qquad (0.2)$$

The optimal solution to (2.1) is

$$I^* = m + k\sqrt{v} \tag{0.3}$$

where

$$m = \mu(l+1)$$
$$v = \sigma^2(l+1)$$
$$k = \Phi^{-1}(\frac{\pi}{\pi + h}) .$$

Substituting I^* into (2.1) and noticing $E(Q_1) = \lambda_1 \mu$, we can derive the sum of the inventory and transportation costs for the benchmark model.

$$C^* = \sigma\sqrt{l+1}\left[hk + (h+\pi)\int_k^{+\infty} (y-k) d\Phi(y) \right] + \frac{h\mu}{2} + c(g_0 + g_1\mu) \tag{0.4}$$

where $k = \Phi^{-1}(\frac{\pi}{\pi + h})$

Logistics outsourcing can take advantages of LTL shipping, and the shipper, i.e. the 3PL provider, just charges a fraction of the cost of hiring an entire truck and trailer for an exclusive shipment, and the related carbon emission cost. Except the lower transportation charge, LTL shipping actually reduces average carbon emissions per item compared to using the buyer's own transportation vehicles, as LTL carriers combine demands from their multiple customers and can fully utilize truck capacities. However, LTL shipping may lead to longer leadtime than delivery by the private fleet of the buyer, and, in turn, it can lead to greater overstock and backorder cost. The longer leadtime of LTL shipping is usually caused by consolidating freights from multiple customers, as well as sorting and routing several times to enable LTL shipping. Let f denote the rate at which the 3PL provider charges the buyer, and let L denote the leadtime of inventory replenishment with 3PL, where L > l. Then with 3PL, the minimization problem of the expected average cost per period of the buyer is given as

$$\min_{I' \geq 0} \; C'(I') = h\int_0^{I'} (I'-x)\varphi(x)\,dx + \pi\int_{I'}^{+\infty} (x-I')\varphi(x)\,dx + \frac{h}{2}E(Q) + fE(Q) \tag{0.5}$$

In analogy with (0.3) and (0.4), we have

$$I'^* = m' + k\sqrt{v'} \tag{0.6}$$

where

$$m' = \mu(L+1)$$
$$v' = \sigma^2(L+1)$$
$$k = \Phi^{-1}(\frac{\pi}{\pi+h}) .$$

and

$$C'^* = \sigma\sqrt{L+1}\left[hk + (h+\pi)\int_k^{+\infty}(y-k)d\Phi(y)\right] + (\frac{h}{2} + f)\mu \quad (0.7)$$

where $k = \Phi^{-1}(\frac{\pi}{\pi+h})$

The associated carbon emissions from transportation and storage can be given as

$$G_1' = [g_0' + g_1'E(Q)]\theta_1$$
$$G_2' = \left[w_0 + w_1E(Q)/2 + \int_0^{I'}(I'-x)\varphi(x)\,dx\right]\theta_2 \quad (0.8)$$

With 3PL, fuel consumption for transportation is lower than that of the buyer's private fleet, as consolidation is employed to fully utilize truck capacities. Therefore, in our models, $g_0' < g_0$ and $g_1' < g_1$.

It can be shown that $I'^* > I^*$ as L > l. Also, it is evident that $G_1' < G_1$ and $G_2' > G_2$. It is easy to verify that as L > l, the inventory level with logistics outsourcing is larger than that without outsourcing. If special conditions (e.g. temperature control) are not required in storage, logistics outsourcing can reduce carbon emissions via consolidation. However, when special conditions are used, outsourcing leads to higher emissions from storage due to higher inventory level. It should be noted that emissions from fuel consumption are much greater than those from transportation, and reduced emissions from transportation by logistics outsourcing are usually much greater than additional emissions from storage due to higher inventory level even if special storage conditions are required. In next section, we conduct numerical experiments to examine benefits and costs of logistics outsourcing on emission reduction.

3. Numerical experiments

In numerical experiments, we set we set $\mu = 100,\ \sigma = 25,\ \ h = 0.2,\ \pi = 3,$ $l = 5,\ \ L = 10,\ \ c = 3.3,\ \ g_0 = 20,\ \ g_1 = 0.1,\ \ g_0' = 10,\ \ g_1' = 0.05,\ \ \ c = 25,$ $w_0 = 20,\ w_1 = 0.1,\ \ f = 23,\ \theta_1 = 0.011145,\ \theta_2 = 0.000653,$ as default values.

When one particular factor is analyzed, all others are fixed at the default values. We use Matlab 7 to conduct numerical experiments.

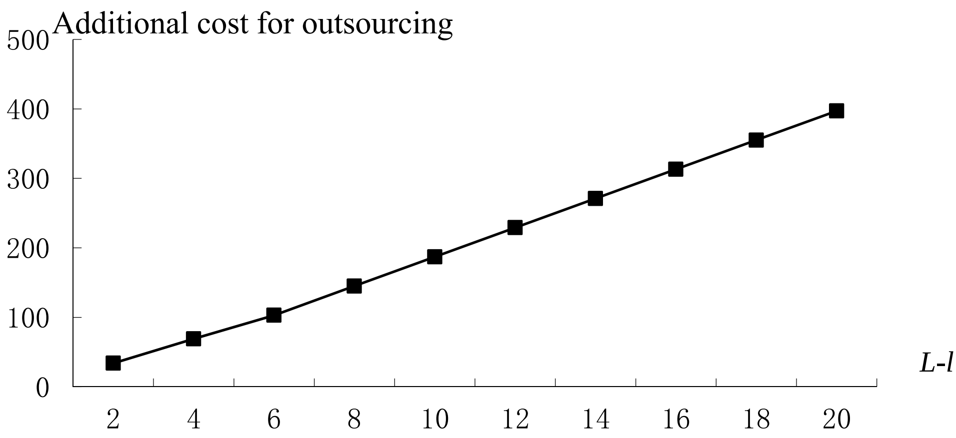

Fig.1: Additional cost for logistics outsourcing vs. the change in leadtime

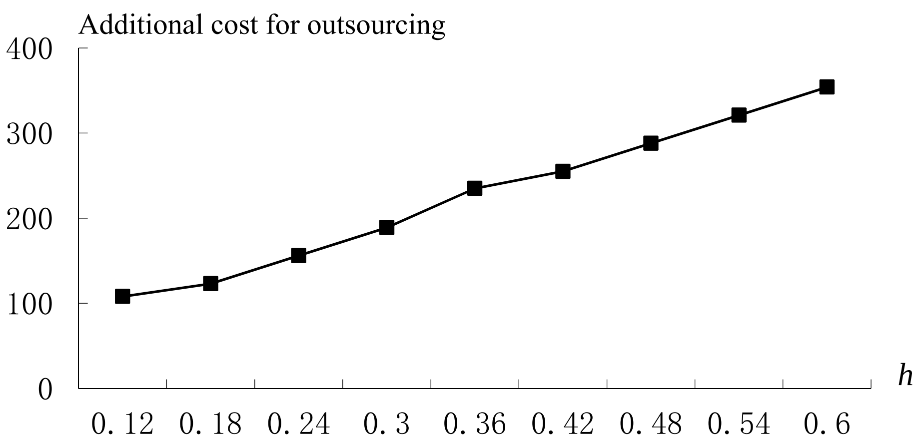

Fig.2: Additional cost for logistics outsourcing vs. unit holding cost

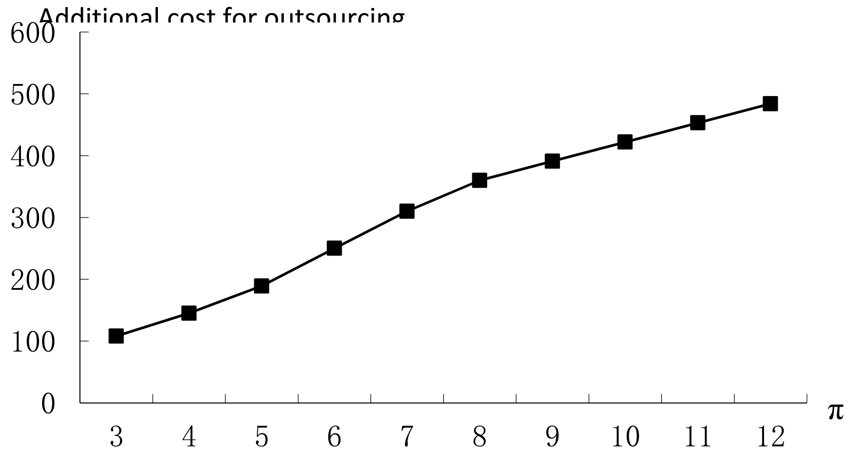

Fig.3: Additional cost for logistics outsourcing vs. unit backorder cost

In our numerical experiments, the associated cost for logistics outsourcing is affected by the lengthened leadtime, unit holding cost and unit backorder cost. For firms who want to reduce emissions through logistics outsourcing, this finding is useful to evaluate the cost incurred. Numerical experiments suggest that higher unit holding cost or backorder cost and longer leadtime caused by logistics outsourcing may lead to higher additional cost.

4. Conclusions

Our analyses show that logistics outsoucing can reduce emissions from transportation. This approach is especially effective if goods do not need temperature control to store. However, additional cost is caused by lengthened leadtime as 3PL use consolidation to reduce transportation cost. Our research shows that enhanced leadtime, unit holding cost and backorder cost may lead to higher additional cost caused by logistics outsoucing.

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