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The Impact of Carbon Policies on Closed-Loop Supply Chain Network Design

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Abstract

Due to increase in environmental concerns along with stringent government legislations, forcing industry practitioners and policy makers to take a fresh look at the impact of their supply chain activities on the environment. Various carbon regulatory mechanisms have been proposed by governmental agencies around the globe, which aims to curb the carbon emission. In this paper, optimization models based on carbon regulatory policies for a closed-loop supply chain design and logistics operations are presented. Specifically, the following three common regulatory policies are considered: strict carbon caps, carbon tax, and carbon cap-and-trade. The proposed models optimize not only costs but also emissions in the supply chain operations. The models capture: the trade-offs that exist between location and transportation modes decisions; and the trade-offs between costs and emissions in the supply chain operations. Numerical experiment illustrates different policies and their impact on the costs and the effectiveness of emission reduction. The results from the models can help policy makers to predict the impact of regulatory policies on overall emissions in the supply chain operations.

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1. Introduction

A supply chain in which forward and reverse supply chain activities are integrated is referred to as closed-loop supply chain (CLSC). There are five main reasons that motivates manufacturers to focus towards CLSC; customer awareness, social responsibilities, environmental concerns, governmental legislation, waste management. In the past, CLSC used to be an undesirable constraint but now it is an acceptable necessity, and remarkably, it will be the only remedy to sustain in the future. Supply chain which considers both economic and environmental prospective is called green supply chain, and by the integration of forward supply chain and reverse supply chain (collection, recovery, recycling of used products and safe disposals of scrapped products) is called green closed loop supply chain (GrCLSC). One dimension of mitigating environmental impacts and produce environmental friendly products is through green supply chain. The growing importance of GrCLSC stems not only from the economic benefits of product recovery but also from governmental legislative initiatives.

Supply chain activities are significant source of greenhouse gases (GHG) emissions such as carbon dioxide, methane, ozone, and other greenhouse gases. Government agencies across the world are under growing pressure to pass legislation to limit the amount of GHG emissions and pay attention to develop the environmental strategies including the Kyoto Protocol [1], the European Union Emission Trading System [2] among others. Kyoto Protocol was negotiated in 1997 by countries all over the world as a part of the United Nations Framework Convention on Climate Change to curb GHG emissions. As of May 2008, 181 countries had ratified, adhered or accepted the protocol [3].

The main objective of this paper is to propose optimization models for a CLSC design problem that is able to (1) consider both economic and environmental aspects when designing a logistics network, (2) integrate location, production technology and transportation mode selection related decisions, (3) investigate the impact of the three most common carbon regulatory policies such as carbon cap, carbon tax, and carbon cap-and-trade on supply chain operations.

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2. Literature Review

The configuration of supply chain network design (SCND) is one of the crucial strategic decisions in the SCM planning activities that have received growing attention from researchers and industries since early 20s [4]. Fleischmann et al. [5] proposed MILP formulation of CLSC network problem considering product recovery issues in the reverse flow.

Incorporating environmental performance measures in order to mitigate the environmental issues of supply chains induces green SCM [6]. According to the comprehensive review on green SCM by Srivastava [7], two types of greenness are considered in the literature: green design for products and green operations. Our research considers green operations, which are mainly composed of green production by selecting suitable technologies available to use, reverse logistics by collecting end of life products, recycling and safe disposals of scrapped products. Paksoy et al. [8] considered a CLSC network that focus on the cost of transportation activities and their GHG emissions. They investigated the trade-off between operational and environmental performance measures. Abdallah et al. [9] analysed the impact of carbon emissions on SCND and supplier selection using LCA approach. Diabat and Simichi-Levi [10] formulated a MIP for a firm to design their optimal supply chain network while meeting their carbon cap. Chaabane et al. [11] studied the impact of carbon emissions on the design of sustainable CLSC network based on LCA principles. Their model is used to evaluate the tradeoffs between economic and environmental objectives under various cost and operating strategies in the aluminium industry. Diabat et al. [12] studied the issues of facility location problem in CLSC with trading of carbon emission and a cost of procurement. Fahimnia et al. [13] developed a unified MILP model for a CLSC in which carbon foot print is evaluated based on the influence of forward and reverse supply chain, where carbon emissions are expressed in terms of dollar carbon cost.

Recently, Benjaafar et al. [14] proposed optimization models for supply chain operational decision making i.e., lot sizing and EOQ under various carbon regulatory mechanisms. They investigated the impact of these policies on operational decisions. Jin et al. [15] proposed optimization models for major retailers and investigated the impact of the carbon policies on supply chain strategic and transportation mode selection decisions.

3. Model Formulation

3.1 Problem Description

A general CLSC network under investigation is shown in Fig 1. It consists of three layers in the forward direction (manufacturing plants, distribution centers, and customers) and three layers in reverse direction (collection centers, recycling centers, and disposal centers).

In the forward chain, multiple product types $l \in L$ are produced in different manufacturing plants $p \in P$ using a set of technologies $t \in T$.

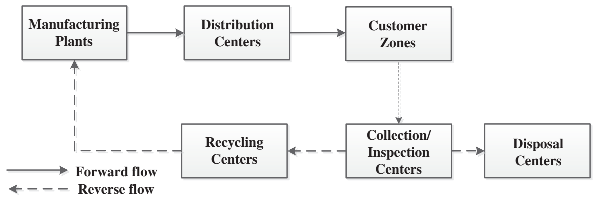

Fig. 1: A general closed-loop logistic network

Manufacturing plant has its own production cost and carbon emission rate for processing one unit of product. In each plant, a set of potential technologies are available to use differ in terms of acquisition and operation costs as well as carbon emission rate. Finished products are shipped to customer zones or markets $c \in C$ through a set of distribution centers $q \in Q$. Different transportation modes $m \in M$ are available to use for shipment of products between the facilities (plants, distribution centers, customers, collection centers, recycling centers, and disposals) with different prices and fuel efficiency rates. In the reverse supply chain network, the end of use or end of life products are collected by the collection centers $k \in K$ where they first disassembled into components, and then they are inspected and separated into recyclable and non-recyclable components. Recyclable components are sent to recycling centers $r \in R$ for further processing, recycled components are then shipped to the plants for reuse in producing new products. The non-recyclable components are destroyed at disposal centers $w \in W$.

3.2 Model Assumptions

The following assumptions will be made in the network configuration:

i. Number, capacity and potential location plants, distribution centers, collection centers, recycling centers, and disposals are known.
ii. Number, location of customer zones are known and predetermined.
iii. Demand of all products is known (deterministic).
iv. Return products rate for each customer zone and average disposal rate are known in advance.
v. Flows are permitted between two consecutive stages. Also, there are no flows between facilities at the same stage.
vi. Emissions for processing the products at facilities and emissions for shipping the products from plants to end users are determined, which is based on the type of technology used in plants and type of transportation mode is used in transport.

To describe the aforementioned CLSC network, indices, input parameters, and decision variables used in formulating the MILP models are presented in Appendix.

3.3 Model formulation of the CLSC network without carbon emission consideration

<u>Cost-only Model (M1)</u>

In the following cost only model, strategic and operational decisions are solely based on economic performance. The

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