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Multi-period planning of closed-loop supply chain with carbon policies under uncertainty

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ABSTRACT

Climate change and greenhouse gases emissions have caused countries to implement various carbon regulatory mechanisms in some industrial sectors around the globe to curb carbon emissions. One effective method to reduce industry environmental footprint is the use of a closed-loop supply chain (CLSC). The decision concerning the design and planning of an optimal network of the CLSC plays a vital role in determining the total carbon footprint across the supply chain and also the total cost. In this context, this research proposes an optimization model for design and planning a multi-period, multi-product CLSC with carbon footprint consideration under two different uncertainties. The demand and returns uncertainties are considered by means of multiple scenarios and uncertainty of carbon emissions due to supply chain related activities are considered by means of bounded box set and solve using robust optimization approach. The model extends further to investigate the impact of different carbon policies such as including strict carbon cap, carbon tax, carbon cap-and-trade, and carbon offset on the supply chain strategic and operational decisions. The model captures trade-offs that exist among supply chain total cost and carbon emissions. Also, the proposed model optimizes both supply chain total cost and carbon emissions across the supply chain activities. The numerical results reveal some insightful observations with respect to CLSC strategic design decisions and carbon emissions under various carbon policies and at the end we highlighted some managerial insights.

1. Introduction

The increase in atmospheric concentrations of greenhouse gases (GHG) emissions such as carbon dioxide, and methane has resulted in climate changes, global warming, and environmental issues. These have led to the introduction of restrictive environmental regulations by policy makers around the globe. According to the 2014 report by the Intergovernmental Panel on Climate Change, global emissions of GHGs have risen to unprecedented levels (increased by 10 billion metric tons during the period 2000–2010) despite a growing number of policies to reduce climate change (Du et al., 2016). Many countries introduced a range of carbon emissions reduction policies including mandatory carbon emission capacity, carbon cap, carbon emission tax, cap-and-trade, carbon offset, and joint implementation to curb the total amount of carbon emissions. In

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Malaysia, the government has pledged to cut 45% of its carbon emissions intensity by the year 2030 (COP21). Reducing and mitigating carbon emission proportion and in the meantime improving the energy usage efficiency are significant and necessary. Due to government legislations or mechanisms, customer awareness of environmental issues and the desire to have low carbon products, firms worldwide are undertaking carbon emission reduction initiatives to curb carbon footprint.

Most of the GHG emission reduction initiatives on the firm level are concerned with acquiring energy efficient equipment and facilities, using low pollution energy sources and implementing energy saving projects. However, it is necessary to investigate the impact of other sources of carbon emissions that are driven by firm operational activities and strategies in a complex supply chain (He et al., 2016). For instance, frequency of logistical activities, facility location, and transportation modes, will influence GHG emission of the firm as well as its supply chain activities, which in turn determines the carbon footprint of the final product (Choudhary et al., 2015).

Many countries strive to mitigate GHG emissions by passing legislation and developing market-based environmental strategies. These strategies not only help in emission reduction but also provide economic benefits to firms. Examples of these strategies are the "Kyoto Protocol, 1997", the "European Union Emission Trading System, 2009", "New Zealand Emissions Trading Scheme, 2009", and "Japan carbon tax scheme, 2012", etc. (Gao and Ryan, 2014). Kyoto Protocol was signed in by 181 countries as part of the "United Nations Framework Convention on Climate Change" to control GHG emissions. The Protocol introduced three mechanisms through which countries can cooperate to meet their emission reduction targets and decrease costs (Ramudhin et al., 2010). First, Emissions Trading or Carbon Market, allows countries that pollute more than their target to buy emission credit from countries that have excess credit i.e., pollute less in order to stay below their target or cap. Second, Clean Development mechanism that allows a country to gain carbon emissions credit if it invests in emission reduction projects in developing countries. Third, countries can also earn emissions credit through joint implementation, which allows a country to benefit by carrying out emission reduction projects in another industrialized country committed to its emission reductions.

Literature surveys conducted by Hua et al. (2011), Benjaafar et al. (2013), Palak et al. (2014) and Du et al., 2016 have identified a growing need for developing quantitative models and decision support systems for operations management, and supply chain management to address issues associated with curbing carbon emissions. Jin et al. (2014), Marufuzzaman et al. (2014), and Zakeri et al. (2015) developed optimization models for supply chain network design problems by incorporating various carbon policies to address the issue of carbon footprint in their operational decision making. However, their models are limited to either inventory management decisions, such as economic lot size and economic order quantity or conventional logistic design. In addition, Diabat and Simchi-Levi (2009), Chaabane et al. (2012), and Fahimnia et al. (2013) highlight that integrating environmental issues into production, supply chains, and logistics is a complex process. However, their works are limited to one carbon policy and considered deterministic parameters.

Increase in environmental concerns, governmental legislations, customer awareness, and social responsibilities have triggered some firms to move from conventional forward supply chains to green supply chains by recovering their end-of-life (EOL) products through re-manufacturing, repair and recycling processes. Firms realized that the issue of recycling their EOL products and reusing products residue and scrap would not only minimize environmental impact but also improve their business market status globally. For example, several major firms such as General Motors, Kodak, Walmart and Xerox are focusing on reverse logistics and recovery activities. A supply chain which integrates product recovery activities in its conventional supply chain is called closed loop supply chain (CLSC) (Abdallah et al., 2012). A large volume of the literature is available on CLSC network design (Jayaraman et al., 1999; Ko and Evan, 2007; Easwaran and Üster, 2010; Vahdani et al., 2012; Ramezani et al., 2013; Amin and Zhang, 2013; Zeballos et al., 2014; Govindan et al., 2015; Kalaitzidou et al., 2015; Gaur et al., 2016; Kumar et al., 2016; Kadambala et al., 2016; Yi et al., 2016; Tahirov et al., 2016). However, the models in the above literature are either focused on minimizing cost or maximizing profit and did not include environmental consideration under different carbon policies. The integration with environmental aspects can help policy makers to better understand how different carbon policies would reduce the negative effects of GHG. In addition, the integrated models could be used to understand the effect of policy parameters on the total cost and carbon emissions of various supply chain activities of the firm.

Consideration of uncertainties in the model parameters will represent a more realistic problem situation. Simangunsong et al. (2012) identified a comprehensive list of the sources of uncertainty and categorized them as: (1) internal organization uncertainties (e.g., manufacturing processes and product characteristics), (2) internal supply chain uncertainties (e.g., demand, supplier and supply chain configurations), and (3) external uncertainties (e.g., environmental, macroeconomic issues and disasters). Supply chain network design (SCND) has effects that last for several years, during which critical parameters such as raw material supply and demand of customers change are quite uncertain (Pishvaee et al., 2009). Reverse logistics activities are complex and tend to high degree of uncertainty. Collection rate, variety of returns, quality and quantity of returned products are highly uncertain even in a short period of time. Also, carbon emissions across the supply chain due to various activities play vital role in decisions concerning the design and planning of an optimal CLSC network. Thus, designing and planning of CLSC configuration with carbon footprint under uncertainty is highly necessary. This paper incorporates two different types of uncertainties in the model (i) uncertainty of product demand and returns, (ii) uncertainty of carbon emissions across the supply chain and investigates the impact of these uncertainties on the design and planning of a multi-period CLSC network which makes this work distinguished from existing literature. Researchers have developed methodologies to tackle uncertainty of decision-making in SCND. These include: dynamic programming, stochastic programming, robust optimization, and fuzzy programming. In particular, scenario-based stochastic programming and robust optimization could be