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Sustainable, multiperiod supply chain network model with freight carrier through reduction in pollution stock

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ABSTRACT

Sustainable supply chain management is a huge issue from both managerial and eco- nomical perspectives. This study presents a multiperiod, multitier, sustainable supply chain with freight carriers network model to address such concerns. The model comprises manufacturers, retailers, and carriers engaged in a dynamic, noncooperative game. It considers the longitudinal accumulation of pollution stock, pollution absorbtion by nature, and mitigation actions. The study examines numerical examples with an analysis of the effect of different tax rates on production, transportation, sales, and levels of pollution stock and mitigation efforts. The outcome presents important strategic reactions of decision makers to tax policies.

1. Introduction

The rapid process of world-wide industrialization has caused environmental issues, climate change, and an energy crisis, which have drawn the attention of the whole world. It is widely believed that greenhouse gas emissions are one of the main causes of climate change and the ecological environment challenges[1]. Preparing for future environmental regulations and improving market competitiveness have encouraged companies to reduce greenhouse gas emissions and improve the energy-usage efficiency that reduce the emission intensity.

For instance, Siemens has invested nearly $110 million to improve energy efficiency at its offices and factories since 2015. Siemens plans to cut its global carbon footprint in half by 2020 and to become carbon neutral by 2030 by eliminating a vast majority of carbon emissions. The company insisted that the investment would eventually pay off through savings of between $20 million to $30 million annually (Global Compact, 2015). Dell announced in 2015 that it uses packaging material made of wheat straw and suggested that this new material uses 40% less energy to produce, 90% less water, and costs less to make than traditional packaging (Fehrenbacher, 2015). According to an ESM report, Mondelez has managed to reduce CO2 emissions from its factories by 7% since 2003, which is stated to be on track with its 2020 goal of 15% deduction (O'Sullivan, 2017).

Nearly 75% of greenhouse gas emissions associated with many industry sectors come from their supply chains (Huang et al., 2009). The companies realize that emission management in pursuit of a green supply chain is an essential capability; therefore, they have increased their efforts to manage and reduce their carbon emissions. They have also realized the importance of carbon emission reduction and incorporated this objective into their operational decisions. Lowering the carbon emission proportion and improving the technology-usage efficiency to mitigate the emissions have become necessary for supply chain networks (Lou et al., 2015).

For instance, Walmart, the first retailer with a verified, science-based, target emissions-reduction plan, contrives not only to decrease its own CO2 emission but also to decrease emissions in its extended supply chain. They have encouraged and supported their

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[1] https://www.sciencedaily.com/terms/global_warming_controversy.htm.

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suppliers efforts to reduce emissions by focusing on clean energy efforts in agriculture, waste, packaging, deforestation, and product use and design (SCDigest, 2017). BT Global Services, as a British multinational telecommunications company, launched a new science-based target to cut their carbon emissions intensity by 87% and reduce their supply chain carbon emissions by 29% by 2030 from 2016/17 levels, which helps their customers cut their carbon footprints (BusinessGreen, 2018).

Environmental issues and considerations that are being imposed mainly by new legislation are becoming more of a concern to various supply chain stakeholders (Li et al., 2017; Lu et al., 2012). Supply chain stability can be exposed to risks under these issues (Dubey et al., 2017; Scholten and Fynes, 2017), and the whole network will be affected in several ways, including direct effects on production, changes in markets, and even supply chain network structure (Costantini et al., 2017; Igl and Kellner, 2017).

Freight transportation plays a central role in modern manufacturing industries (Mangan et al., 2016) and product shipment becomes a major challenge among all players of supply chain (Sarkar et al., 2016). Global freight transport additionally accounts for about 45% of total transport energy consumption (Intergovernmental, 2015). Logistics providers and freight carriers have started paying more attention to the negative externalities, including pollution, noise, and climate change risk, given the increasing worldwide concern for the environmental issues. Hence, considering them in the modeling and design of supply chains is worthy of attention (Feitó-Cespón et al., 2017; Chen and Wang, 2016; Chabot et al., 2018). The key research questions of this study are:

1. Could a sustainable supply chain model be used successfully to control and manage carbon emissions across the economy not only for production and consumption but also for transportation of products?
2. How does the incorporation of carbon emission reduction in the production and transportation decisions affect supply chain operational and strategic decisions?
3. What kind of carbon emission reduction policies can be applied to supply chain decision making?

This study's purpose is to address such concerns and shed light on how companies can profitably reduce gas emissions in their whole supply chain network. This paper mainly focuses on the development and analysis of a multiperiod, multitier, sustainable supply chain network comprising manufacturers, freight carriers, retail outlets, and customers at demand markets with a dynamic approach for pollution accumulation and reduction. The proposed dynamic supply chain planning model contributes to the sustainable supply chain-freight network modeling literature through:

- optimizing network entities' environmental and economical objectives;
- modeling both Cournot and Bertrand competition between network entities;
- considering pollution stock for both production and product shipment;
- allowing the pollutant stock to be stored, mitigated, or discharged by the manufacturers and the freight carriers; and
- considering an emission-reduction technology cost which affects emission reduction level;

The remainder of the paper is organized as follows: After Section 2 presents a survey of related literature, Section 3 introduces the multiperiod, competitive, green supply chain network model and provides the supply chain network governing equilibrium conditions and the variational inequality formulations. Additionally, Appendix A presents qualitative studies and the computational procedure that yields closed form expressions at each iteration for the variables. Section 4 presents the numerical examples. Section 5 provides the conclusion and managerial insights, and Section 6 presents our papers summary.

2. Background

The integration of supply chains and transportation networks is becoming increasingly important for companies to remain competitive and control the decisions relating to goods distribution and freight transport over the entire supply chain (Yamada et al., 2011; Ottemöller and Friedrich, 2017; Nagurney et al., 2015; Friesz et al., 2008). Additionally, considering sustainable development to meets the needs of the present without compromising the ability of future generations to meet their own needs can significantly influence the performance of global supply chains (Pan et al., 2013; Dente and Tavasszy, 2018; Haddadsisakht and Ryan, 2018).

Sustainable decision making has been investigated in supply chain management processes and associated optimization from different dimensions. For example, Nagurney et al. (2007) and Cruz (2008) developed supply chain models that included the maximization of revenue and the min- imization of environmental emissions. Relevant researches in multi-echelon supply chain models have been carried out to provide useful insight for environmental issues in the network with the focus on production-inventory control (Hammami et al., 2015; Bazan et al., 2017; Sarkar et al., 2016; Jiang et al., 2016) and tax policy scheme (Fahimnia et al., 2015; Zakeri et al., 2015). These models are either limited to a static case, which is an early step in understanding what happens in the real world, or restricted to monopoly players, which is a rare condition for supply chain management and cannot represent the competition between the supply chain entities. Our proposed model, on the other hand, considers the quantity and price competition among oligopoly market of supply chain firms and freight carriers in a multiperiod planning horizon.

Carbon emissions are generated throughout the life cycle of any product and supply chain process continuously and cumulatively. Freight carriers also are large contributors to emissions of CO2 and greenhouse gases, and mitigating their environmental impact is essential to strive for a future sustainable supply chain. The analytical-based operations management literature tends to overlook the source of emissions driven by operational decisions throughout the life cycle of products and to focus on the environmental damages (e.g., carbon emissions) associated with the decisions of procurement and inventory management (Benjaafar et al., 2013; Sarkar et al., 2016), facility location (Dekker et al., 2012; Brandenburg et al., 2014), technology selection (Drake et al., 2016), supplier

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