Letter to the editor

Bullwhip effect mitigation of green supply chain optimization in electronics industry

ABSTRACT

Technological advancement and rapid demand changes, lead to shorter life period and booming waste of electronic products. Recycling and reusing activities of electronic products has attracted much attention on the optimization of green supply chain (SC). This study employs system dynamics (SD) model to explore the effect of single strategy and combined scenarios on mitigating inventory amplification, i.e., bullwhip effect (BE) in three-echelon SC. Novel scenario simulation is designed to stimulate recovery activities of electronic waste, decrease solid material depletion and promote clean production. Main thread is as follows: establishing SD model in line with practical operation mechanism, testing the robustness of model, emulating the effect of single strategy and combined scenarios on mitigating BE and finally proposing optimal strategies on the optimization of green SC. Results show that positive recovery activities is an optimal solution in green SC among single strategies; simulated scenarios alleviate the BE largely especially the combination of higher recovery ratio and information transparency reinforcement. Initially, the emulated-mapping of this field helps graphically illustrate the potential optimized-directions and stimulate individual recovery behaviors in green SC.

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1. Introduction

1.1. Green SC background

The successful integration of economic, environmental and social sustainability goals in green SC, has pushed green SC to be the forethought of leading supply chain and operation management. Implementing green SC becomes a strategic task of industrial development worldwide (Turrisi et al., 2013). Facing governmental regulations and green trade barriers, if enterprises want to win sustainable competitive advantage, a long-term choice is to take social-economic-environmental responsibility and provide green products (Pan et al., 2015).

Issued by China's SEPA (State Environmental Protection Administration) in 2007, environmental pollution regulation of electronic products refers to information technology products, communication products, office equipment, such as computer, printer, photocopier, telephone. Electronic waste refers to disused electronic products, electronic appliances, electronic equipment and its used parts and components, including daily-disused computer, phone etc. While rapid upgrading of electronic products has brought a substantial growth of electronic waste. According to a statistical report on electronic waste by European Union (EU) in 2011, electronic waste was surging at a rate of 16%–28% per 5 years, 3 times faster than total solid waste. Electronic waste grows fastest among all the solid waste. The cyclic utilization of electronic waste has aroused the attention in the field of green SC worldwide.

China, as the manufacture and consumption superpower, is confronted with inappropriate disposal and serious pollution of electronic waste. Derived from Academy of Social Sciences, electronic products in Beijing has approached a fastigium, with electronic waste rising to 15.83 million tons million tons (Abhishek and Jinhui, 2017). In views of the incapability of natural degradation of electronic products, overdue recovery processing particularly immediate landfill or combustion, surely incurs severe contamination (Carlsson and Fuller, 2000). In China, electronic waste is mainly disposed by three ways, namely refurbishment to secondary market, simple disassembly as parts manufacturing and dumping. This disordered reverse logistic system of China brings a great waste of resources and heavy environmental pollution. Otherwise, electronic waste could be used as industrial product materials to generate social-economic-environmental value through adopting progressive technology.

Governments of many countries implement rules to regulate recycling and reusing of electronic waste, such as EU's enactment of VUEEE instruction in 2003 (Talaei et al., 2016). China has issued the first electronic waste recycling laws (Control measures for pollution control of electronic information products) in 2007. Developed countries have emphasized recycling and reusing of electronic waste and adopted many measures. Due to informal waste recycling channel and complicated operation process, reverse logistics of electronic waste in China needs to be improved. Especially, the regulatory enforcement of developed country has pushed China's export to a more severe situation. Higher technical costs and slow economic pay-back urge several brand enterprises to recycle waste and compel majorities of enterprises to focus on

forward logistics.

Hence, green SC emerges largely from the appealing for both clean production and economic benefits. Green SC is an environmentally responsible system, including eco-management of both forward logistics and reverse logistics, especially the reverse logistics. As a typical application of green SC, the reverse SC extends the forward SC by including product return, recycling/recovery, remanufacturing and resale (He, 2015). Products are recycled by the original manufacturer or through indirect channels, and then resold in primary or secondary market after necessary disposition (Ashayeri et al., 2015; Turrisi et al., 2013). Among that, one of the most serious barriers is BE, a well-known but undesirable phenomenon to incur demand amplification from a downstream site to an upstream (Lee et al., 1997). Inventory amplification due to BE is described as two opposite trends, namely falling orders happens in decreasing demand and booming orders of down-stream sectors in growing demand. BE leads to tremendous supply chain inefficiencies such as excessive inventory investment, poor customer service, lost revenues, misguided capacity plans, ineffective transportation, and missed production schedules (Giri and Sharma, 2015).

1.2. Motivation

Majorities of literature reviews on green SC management have been completed over the past decade. Some of them have been comprehensively covered entire field (Seuring and Müller, 2008), whilst others have concentrated on detailed aspects like performance measurement (Taticchi et al., 2013), supplier selection in green SC (Igarashi et al., 2013) or calculation models (Ahi and Searcy, 2013). Over decades, general focus of numerous studies on SC mainly pours on evaluating their effective performance on economical sustainability, environmental sustainability, and operational performance (Georgiadis and Besiou, 2008; Paksoy, et al., 2011; Jayaram and Avittathur, 2015; Zhou and Piramuthu, 2013). In the contrast, few works attempt to probe the SC dynamics in inventory and order amplification, let alone from the side of detailed industry. Recycling and reusing activities of waste might impact the dynamics of members' inventories and order (Adenso-Díaz et al., 2012; Turrisi et al., 2013), and also amplify or moderate detrimental time-varying phenomena, especially BE and inventory instability (Disney and Towill, 2003).

Forrester (1958) describes BE for the first time and believes that BE causes time delay, and larger demand information fluctuations. Lee et al. (2000) summarizes the causes of the BE, such as demand forecasting, supply stock, lead time and price volatility. Through simulation methods, Towill (1997) reveals that the demand information doubles its volatility from distributor to manufacturer. Zhang (2004) considers the impact of forecasting methods on BE for a simple replenishment system, describes the customer demand and an order-up-to inventory policy characterizes the replenishment decision. Chatfield and Pritchard (2013) adopts a (simulation model)">simulation model to examine the effects of stochastic lead times and information sharing on SC. They demonstrate that lead-time variability exacerbates variance amplification in a SC and information sharing is highly significant. Jaksic and Rusjan (2008) examine the influence of different replenishment policies on the occurrence of the BE. They demonstrate that certain replenishment policies could induce BE while others inherently decrease demand variability. The main causes of demand information amplification are future demand expectations that leads to over-exaggerated responses to demand changes.

Very few studies discuss the effect of the reverse logistics on BE which are quite contrasting and incomparable (e.g., Huang and Wang, 2007; Ding and Gan, 2009; Adenso-Díaz et al., 2012; Turrisi et al., 2013; Corum et al., 2014). The reasons might lie in distinguished configurations and modeling assumptions of SC. For another issue, crucial impact factors of the inventory management in SC (i.e., remanufacturing lead time, recovery ratio, SC tiers etc.) are not highlighted thoroughly. Still, non-common agreement about how different remission strategies may change SC social-economic-environmental performance is reached (e.g. Lee et al, 2000; Disney and Towill, 2003; Zhang, 2004; Agrawal et al., 2009; Jaksic and Rusjan, 2008). BE has generated attention among researchers and practitioners alike, companies have not yet succeeded incompletely taming it.

Motivated by these contrasting results and realistic significance, we list two main objectives. (1) This paper is devoted to contributing to the existing literature on reverse logistics and green SC by comparing three main BE-mitigation methods (i.e., increasing recovery ratio, information transparency reinforcement and forecast time reduction) and the combined scenarios. (2)We attempt to analyze the impact of reverse logistics on inventory fluctuation in electronic industry, to propose optimal strategies for dampening such amplification and then to decrease material consumption as well as solid waste pollution reduction.

Our final research make original contributions in two important ways. (1) It is helpful to optimize green supply chain (SC). This study proposes combined scenarios of inventory fluctuations mitigation, decreases material consumption, reduce solid waste pollution and optimize green SC. Based on clean production and green SC optimization, this study proposes BE-reducing scenarios and provides reference for green electronic industry improvement. (2) This study provides practical implications on realistic reverse logistics. The authors propose an empirical closed-loop system that accurately emulates the upstream and downstream flows in green SC and be consistent with realistic operation. Hence, the results are beneficial in motivating many firms to implement reverse logistics suitable tools for the proper management of the information and material flow in the green SC. (3) The reinforcement of foreign electronic products legislation in international trade has made the export of China's electronic products more difficult. Hence, exploration on reverse SC management of China's electronic products is critical to break green trade barriers and smoothly participate in international market competition.

The exposition is organized as bellow. An overview of SD modeling including application, modeling boundary, variables description and casual-loop diagram is described in Section 2. Section 3 introduces data source and model test. Bullwhip effect analysis in closed-loop SC is presented in Section 4. Section 5 discusses the comparison analysis of green SC optimization scenarios. Concluding remarks and further research are presented in the final section.

2. Methodology

2.1. SD model

As a prominent phenomenon in SC management, BE refers to a demand amplification phenomenon that all members make supply decisions based on the downstream demand information. This study employs SD model and Vensim software to establish a green SC and emulate the combined scenarios of reducing BE.

Originated in 1956 by Professor Forrester J.W., SD model is appropriate for analyzing the dynamic variation of system internal structure and dynamic external environment. It is operated by cause-and-effect feedback and computer simulation. SD model has a lower data sensitivity due to its basis (i.e, feedback loop). As long as parameter estimation is reasonable and falls in limited range, SD simulation show the consistent variation trend with realistic operation. SD employs given equation, parameter and initial