Journal of Cleaner Production 80 (2014) 96–105

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

A system dynamics model based on evolutionary game theory for green supply chain management diffusion among Chinese manufacturers

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ARTICLE INFO

Article history:
Received 1 December 2013
Received in revised form
31 March 2014
Accepted 23 May 2014
Available online 12 June 2014

Keywords:
Green supply chain management diffusion
System dynamics
Evolutionary game theory
Automobile manufacturers
Simulation

ABSTRACT

In this study, a system dynamics (SD) model is developed to guide the subsidy policies to promote the diffusion of green supply chain management (GSCM) in China. The relationships of stakeholders such as government, enterprises and consumers are analyzed through evolutionary game theory. Finally, the GSCM diffusion process is simulated by the model with a case study on Chinese automotive manufacturing industry. The results show that the subsidies for manufacturers are better than that for consumers to promote GSCM diffusion, and the environmental awareness is another influential key factor.

1. Introduction

With the increasing ecological problems of environmental pollution, resource depletion and energy shortage in the world, industrial and business activities that impact on the environment have been closely scrutinized by the governments of developing countries in recent years (Bilen et al., 2008; Blackman et al., 2010; Hubacek et al., 2007; Mudgal et al., 2009; Muduli et al., 2013; Govindan et al., 2012; Jindal and Sangwan, 2013; Mathiyazhagan et al., 2014; Govindan et al., 2014; Mohanty and Deshmukh, 1998; Santos et al., 2013). For the governments of these countries, especially in China, it is necessary to promote an effective method among the industries for reducing pollution and conserving resources. Under the circumstances, most industrial enterprises, particularly manufacturers, have to consider environmental factors in their internal operations management and external supply chain management. These considerations are significant because they are triggered by environmental regulations and legislations and by the green demands of consumers and markets (Zhu and Sarkis, 2004). Green supply chain management (GSCM) emerges as a comprehensive internal and external organizational environmental management approach which aims at both ecological efficiency and economic performance at every stage of the supply chain through the whole life cycle of the product (Gavronski et al., 2011; Srivastava, 2007; van Hock, 1999; Charkha and Jaju, 2014; Dweiri and Khan, 2012). Since the generation of GSCM, it has been preferred by multinational and international enterprises. For instance, Bristol–Myers, Squibb, IBM, Xerox, Ford, General Motors, and Toyota have adopted some practices of GSCM in order to lighten the increasing burden of environment issues (GEMI, 2001).

As the GSCM is widely implemented among enterprises, especially with manufacturers, the economic and environmental performances of the green strategy can improve the enterprise's operating efficiency through protecting the environment and saving resources (WEC, 2008; Azevedo et al., 2011; Chiou et al., 2011). Thus, GSCM has attracted extensive attention in China (Zhu and Sarkis, 2006), which has become the workbench of the world. A large number of manufacturing sectors in the supply chains have been transferred to China, which has provided a lot of opportunities for the development of the local economy. However, this increased development has caused more pollution and destruction on the local ecological environment. For instance, in China industrial emissions increased from 10.7 trillion cubic meters in 1995 to 51.9 trillion cubic meters in 2010; the industrial solid waste generation increased from 526 million tons in 1985 to 3.2

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http://dx.doi.org/10.1016/j.jclepro.2014.05.076
0959-6526/

billion tons in 2011. However, for most Chinese enterprises, GSCM and other environmental management practices have not been widely adopted as a result of the economic and operational obstacles such as high costs and implementation complexities (GSCC and GXS, 2009). Therefore, it is important for the government to understand how to promote effective environmental management approaches such as GSCM. Promoting GSCM in the industrial enterprises, especially among the manufacturers, will provide better management strategies for dealing with issues of coordination between economic development and environmental protection.

GSCM diffusion is the process through which GSCM is spread through certain channels over time among the manufacturers in a certain industry. In order to comprehend GSCM diffusion, one must understand the relationships among the government, manufacturers, consumers, and the influencing factors which promote the diffusion. Several scholars have studied the issue with different methodologies and theories such as statistical analysis, evolutionary game, and diffusion of innovation. These researches provide the groundwork for further studying GSCM diffusion; however, a complex relationship among various stakeholders, including governments, manufacturers, and consumers, cannot be described just by the models of game theory. In this study, the GSCM diffusion process among manufacturers is explored by analyzing the respective costs and benefits of the enterprises that adopt different green strategies and by utilizing evolutionary game theory and system dynamics (SD). By means of bringing the system dynamics into the model, this study has established the GSCM diffusion system in order to explore the influencing effects among the governments, manufacturers, and consumers more efficiently. The evolutionary game theory defines the GSCM diffusion rate among the enterprises and provides a foundation of system dynamics to model the GSCM system. The system dynamics model describes the GSCM diffusion mechanism with three modules: the GSCM diffusion module, the manufacturers' payoff module, and the consumer market module. The timing of GSCM implementation of the manufacturers decides the process of the diffusion. Manufacturers make decisions by measuring the investment and profit of the green strategy, the green preferences of the consumers, and the legislation and policies of the government. In order to solve issues of the environment and energy, the government may establish and revise polices to promote the GSCM diffusion or to change the pattern of consumption in order to influence the environmental behavior of the manufacturers.

The main goal of this paper is to describe the mechanism of GSCM diffusion among the manufacturers in developing countries, especially in China. This research contributes to the methodology by combining evolutionary game theory and system dynamics to establish an EA-SD model of GSCM diffusion. This study can provide implications for industry and governments in developing countries to establish appropriate laws and policies in order to promote GSCM implementation among domestic manufacturers.

In order to accomplish the research objectives, this paper first presents a literature review of green supply chain management, system dynamics, and evolutionary game theory in Section 2. Secondly, the problem analysis and model establishment is given in Section 3. Then the simulation of the model is discussed in Section 4. Finally, in Section 5, discussions and conclusions are given.

2. Literature review

Since the early 1990s, green supply chain management has been widely pursued in academic and business circles with the development of corporate environmental management practices, environmentally conscious manufacturing strategies, and supply chain management techniques (Sheu et al., 2005; Zhu and Sarkis, 2006). Meanwhile, the demand and application of integrating environmental factors in supply chain management practices has been heightened by the burgeoning literature on GSCM (Agarwal et al., 2011). As time goes on, GSCM practices are gradually implemented in a certain region or industry under the influence of certain factors, which is regarded as GSCM diffusion among the enterprises just like diffusion of innovation (Hazen et al., 2011). In his diffusion of innovation theory, Rogers has defined diffusion as "the process in which an innovation is communicated through certain channels over time among the members of a social system" (Rogers, 1995). According to this classic definition, we define green supply chain management diffusion as the process in which GSCM is spread through certain channels over time among the organizations of a social system. Nevertheless, studies of this theme are not broadly developed and the implications concerning implementation and diffusion of GSCM practices among interorganisational networks are not well comprehended (Srivastava, 2007; Gobbo et al., 2014). In the following paragraphs, this paper summarizes distinct streams of literature about GSCM diffusion and its influencing factors, operating mechanisms, and so forth.

Essentially, GSCM diffusion is the process over time whereby GSCM practices are adopted by the enterprises. Some researchers have defined GSCM and studied its practices in the literature. Most of the definitions place the environmental factors or related practices into supply chain management in order to achieve economic and environmental performance (Gilbert, 2001; Zhu et al., 2008b,c; Alzaman, 2014; Govindan et al., in press; Salimifard and Raeesi, 2014). For instance, Srivastava defined GSCM as "integrating environmental thinking into supply chain management, including product design, material sourcing and selection, manufacturing processes, delivery of the final products to the consumers, and end-of-life management of the product after its useful life" (Srivastava, 2007). The practices of GSCM are the foundation in the diffusion system. Some other researchers have referred to the various practices of GSCM in a supply chain. Various practices have been studied, including internal, upstream, downstream, and closed loop dimensions (Peattie and Ringler, 1994; Sarkis, 2006; Wycherley, 1999). Five sets of GSCM practices (internal environmental management, green purchasing, customer cooperation with environmental concerns, investment recovery, and eco-design practices) have been described by Zhu and Sarkis (Zhu et al., 2008a; Zhu and Sarkis, 2004, 2006). Diabat and Govindan (2011) summarized the ideas of Srivastava (2007), and referred to GSCM activities as 'green design', 'green sourcing/procurement', 'green operations' or 'green manufacturing', 'green distribution, logistics/marketing', and 'reverse logistics.'

The GSCM diffusion mechanism consists of GSCM selection and internal implementation of the enterprises and the external diffusion channels. For the implementation aspect of GSCM, the U.S. Environmental Protection Agency proposed four basic steps to implement a green supply chain: identify costs, determine opportunities, calculate benefits, and decide, implement, and monitor (EPA, 2000). Five major influential drivers exist for promoting enterprises to implement GSCM. They include regulations, customer markets, suppliers, competitors, and internal factors (Zhu and Sarkis, 2006). Under the influences of the drivers, GSCM can be transmitted through private partnerships, supply chains, professional organizations, or governmental policies (Zhu et al., 2008c). According to the knowledge diffusion, the environmental practices in supply chain management are spread through quasi-governmental and/or professional agencies, or industrial marketing relationships between smaller and larger organizations (Lai et al., 2005). From the literature, GSCM diffusion can be realized among the enterprises through two main channels which are referred to as "vertical diffusion" (supply chains and private partnerships) and "horizontal diffusion" (professional organizations or