Using game theory to describe strategy selection for environmental risk and carbon emissions reduction in the green supply chain

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ABSTRACT

This paper provides an approach in the context of green supply chain management, using game theory to analyze the strategies selected by manufacturers to reduce life cycle environmental risk of materials and carbon emissions. Through the application of the 'tolerability of risk' concept, a basis for determining the extent of environmental risk and carbon emissions reduction has been established. Currently, scant attention is given to holistic supervision of the supply chain with respect to carbon emissions by governments, and thus the starting hypothesis here is that the default strategy that manufacturers will adopt is only to reduce carbon emissions, and thereby environmental risk, in so far as this is compatible with the aim of increasing revenue. Moreover, we further hypothesize that, once necessary governmental policy has been established in the supply chain management, the strategic choices of the manufacturers would be influenced by government penalties or incentives. A case example is provided to demonstrate the insight that indicates the application of game theory. The limitations of the game model and analysis are discussed, laying a foundation for further work.

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1. Introduction

Supply chain management (SCM) has been brought into academic research since the early 1980s, covering a range of control and planning applications relating to material selection, production, transportation, distribution *etc*, as well as the potential collaboration among manufacturers, retailers and customers (Blanchard, 2007, p. 8; Harrison & Hoek, 2008, p. 6; Hines, 2004, p. 70; Oliver & Webber, 1982). With global business developing rapidly, the increasing demand for the consumption of commercial products has greatly accelerated the depletion of resources and contributed environmental pollution. Green supply chain management (GSCM) has emerged as a response to the challenge of how to improve long term economic profits and environmental performance (Sheu, Chou, & Hu, 2005). GSCM can be defined as a series of regulations and interventions in the supply chain achieved by attempting to minimize the environmental impact from the suppliers to the end users (Basu & Wright, 2008, p. 245). It is also claimed to be a "win–win" strategy, through which economic

benefits can be increased by reducing environmental impact (Zhu & Cote, 2004; Zhu, Sarkis, & Lai, 2008).

In this context, GSCM has a substantial influence on the manufacturers within supply chain network, *e.g.* increasing both opportunities and challenges in green product development, promoting innovative product design *etc* (Wang & Gupta, 2011). As a consequence, manufacturers will be encouraged, not only to consider the economic benefits, but also to provide 'environmentally sound' products having due regard to the Triple Bottom Line (TBL). With integrating clean technologies into supply chain processes, one of the major environmental concerns is the detoxification of industrial pollutants (Wang, 2009), since many common industrial materials used in manufactured products can be considered harmful or 'hazardous' to the environment to a greater or lesser extent. The definition of hazardous materials, as given by De Lisi (2006, p. 7) is "*anything which, because of its quantity, concentration, or physical, chemical, or infectious characteristics may cause, or significantly contribute to, an increase in mortality; or cause an increase in serious irreversible, or incapacitating reversible, illness: or pose a substantial present or potential hazard to human health and the environment when improperly treated, stored, transported, or disposed of, or otherwise managed*". Examples are the leaching properties of common polymers in the food supply chain, or

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formaldehyde, a common substance used in some furnishings, which can be carcinogenic. Therefore, the risk to the environment resulting from the complete supply chain involving 'hazardous' materials as defined here, and the attendant health implications, need to be carefully assessed in the context of the product life cycle. Certainly, this is scarcely considered in the literature. It follows that there is a need to consider the risk to society associated with everyday consumer products.

In addition to the immediate risk posed by 'hazardous' materials in use, it is also important in the socio-political context to discriminate within the supply chain the "carbon footprint[1]", which may be an increasingly used indicator of the public's acceptance of the product. Notably, though the environmental risk and the carbon emissions in the final disposal stage of a product are often very high compared to other stages (Lee, 2011; Zhu & Sarkis, 2006). Thus, decarbonization has become a significant challenge to the supply chain management by requiring consideration be paid to life cycle stages beyond the supply chain and consumer.

This paper proposes a game theory approach that models the likely behaviour of manufacturers in response to drivers to reduce environmental risk and carbon emissions in the context of the green supply chain. A previous study has indicated how life cycle carbon emissions could be displayed as an aid to customer choice, and therefore as a means to send an environmental signal to manufacturers (Zhao, Deutz, Neighbour, & McGuire, 2012). This paper extends the analysis to consider the perspective of manufacturers. Whilst corporations generally respond to a range of signals, from consumers, government within their supply chain, international treaties, regulations *etc* (Wang & Gupta, 2011), our study provides an initial insight into how they may respond to game scenarios with and without governmental regulations.

Game theory will be described in more detail below, but in short, allows the identification of alternative 'business' strategies. However, here the emphasis is on reducing environmental risk and carbon emissions without affecting commercial sustainability, irrespective of any governmental or inter-governmental objectives, *e.g.* international treaty. Although the green supply chain management concept has laid stress on increasing economic returns by reducing the environmental risk and impacts (Zhu et al., 2008), the extent to which the environmental risk and carbon footprint reduction should be incorporated into the management process has had limited discussion. In summary, the authors here propose an approach based on game theory to help manufacturers select appropriate strategies to reduce the environmental risk of supply chain containing 'hazardous' materials and carbon emissions in the context of 'green' supply chain management.

2. Game theory application to green supply chain

Since V-Neumann and Morgenstern (1944) published their book "The Theory of Games and Economic Behavior", game theory has been widely used as a mathematical and logical approach applied in various research fields, such as economics, marketing, supply chain management, *etc*. The solutions provided by game theory are usually arrived at by considering the interaction between the 'players' (or 'agents' in the context of the supply chain) who are involved, which can be seen as a form of "interactive decision theory" (Aumann, 2003).

Game theory is often seen as an essential tool when dealing with supply chain management problems with multiple agents (manufacturer, retailer, buyer, government *etc*), especially when there are conflicting objectives, in order to help decision makers enhance the cooperative efficiency of the partners involved (Cachon & Serguei, 2004). The application of game theory to the supply chain, especially coordination, economic stability and the supply chain efficiency have been discussed by a number of works (Esmaeili, Aryanezhad, & Zeephongsekul, 2009; Hennet & Arda, 2008; Zhang & Huang, 2010; Leng & Zhu, 2009; Li, Huang, Zhu, & Chau, 2002; Nagarajan & Sosic, 2008; Yue, Austin, Wang, & Huang, 2006). However, game theory applications to green supply chain management are still under development. Zhu and Dou (2007) have created an evolutionary game model to investigate how governmental subsidies and penalties can influence the possible actions of enterprises. The game model suggests that government should reinforce the environmental regulations by means of increasing relevant subsidies and penalties to impel enterprises to implement environmental management. A similar study can be found by Chen and Sheu (2009), derives a differential game model to design environmental regulation pricing strategies. It is evident that, with governmental regulation standards being raised, manufacturers will gradually extend their product responsibility resulting in increased product recyclability. In addition, the interaction of manufacturers and retailers has also been considered. For instance, Sheu (2011) has used the asymmetrical bargaining game model to seek negotiated solutions between manufacturers and the 'reverse logistics' suppliers under governmental financial intervention, from which the bargaining power of green supply chain members is seen to be greatly enhanced. Further, Barari, Agarwal, Zhang, Mahanty, and Tiwari (2012), who have provided a dynamic evolutionary game model to discuss the potential strategic coordination between producer and retailer by maximizing economic profits while implanting green practices, thus to achieve a 'win–win' situation between environmental and commercial benefits on the supply chain. Since the incorporation of carbon emission as an indicator for green supply chain management (Lee, 2011), game theory application has also provided an insight in this research field. A typical study has been recently reported by Nagurney and Yu (2012), who have considered developing an oligopoly game model for sustainability within fashion industrial supply chains. They investigate the oligopolistic competition among firms with different product brands, with the objective of maximizing the profits of each corporation and minimizing the corresponding carbon emissions. These previous studies, while quite useful in informing our approach, do not address the issues raised in the introduction, namely, by identifying which producers offer a sustainable economic performance with a level of environmental risk, or carbon emissions reduction, appropriate to incorporation within the management process.

3. Formulation of the game

Whilst, in theory, consumers drive the open market, *i.e.* incentivizing the sale of attractive and competitive products meeting a perceived need, Governments, for good reason, often restrict the market by legislation or regulation, sometimes with unintended consequences. This section explores one such consequence which has particular relevance to environmental management in the green supply chain, *e.g.* how governments establish a reasonable incentive and restraint mechanism to encourage manufacturers to improve their environmental performance.

The game situation can be defined by three important boundaries in the supply chain, Government|Manufacturer, and Manufacturer|Retailer|Consumer, shown in Fig. 1. It seems logical to apply game theory first to the dynamic boundary of Government|Manufacturer. Whilst an observer might conclude there is but one game, we suggest that there are, in reality, several, related, but

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