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Modeling decision processes of a green supply chain with regulation on energy saving level

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ABSTRACT

In this study, we first investigate the impact policy makers have when they set a threshold value of energy saving levels. We examine the impact on energy saving level and price of environmentally friendly products (EFP) decided by green supply chains within two different structures, i.e. vertical integration and a decentralized setting. Then, considering the tradeoff between energy savings and profits made by supply chains, we analyze decisions of the policy makers. In addition, we investigate the coordination of a supply chain by using the common wholesale pricing and profit sharing (WPPS) schemes and a lump sum transfer contract. A numerical example is used to illustrate the related issues. Observations are made, and managerial insights are indicated for the policy maker in setting threshold values of energy saving levels.

1. Introduction

Environmental problems have received increasing attention over the past few decades [1–4]. It has been proved that burning fossil fuels to create energy produces greenhouse gases and leads to global warming. Now, people around the world are joining forces and participating in environment protection activities, such as the enactment of the Kyoto Protocol in 2005, and the UN Climate Change Conference in Copenhagen in 2009. In order to reduce greenhouse gas emissions without drastically changing life styles, strategies to save energy will become increasingly important in ushering in a low-carbon economy [5,6].

Global environmental standards are bringing new challenges to firms, markets and industries, all of whom need to address energy saving and pollution reduction issues [7,8]. Also, maintaining a cleaner environment is clearly the responsibility of firms [9,10], and cleaner production methods and products are important for sustainable development [11–14]. Generally, an environmentally friendly product (EFP) entails higher production costs and a correspondingly higher retail price, and usually with lower profit margins than ordinary products [15]. Unless policy makers introduce environmentally friendly regulations, producers are more likely to choose the latter method (old-fashioned production methods and higher profit margins) in most cases. As a consequence, regulations mandating energy savings and EFPs are being implemented by policy makers in many countries [16–18]. Therefore, it is worthwhile investigating the effects of such regulations on the production decisions made by different firms.

Environmental problems are not exclusive to single firms; they include the interaction of a firm with its environment, supply chain partners, industry associations, policy makers and the media [19–21]. Investigation of green supply chain management (GSCM) finds that there are significant positive relationships between organizational learning mechanisms, organizational support and the adoption of GSCM practices. The benefits occur after controlling a number of other factors, including regulations, marketing, suppliers, cost pressures, relevant industry practices and organizational size [22]. Focusing on the components and elements of GSCM and how they serve as a foundation for a decision-making framework, Sarkis [23] explored the applicability of a dynamic non-linear multi-attribute decision model (defined as the analytical network process) for decision-making within a GSCM framework. As a matter of fact, GSCM has become a popular trend followed by many industries who want to create a cleaner environment and obtain competitive advantages.

Many models have been designed to cope with environmental problems, and some performance measures have been developed in GSCM. Shang et al. [24] highlighted the importance of green marketing as a GSCM tool, as well as being a strategic asset or a critical resource for electronics-related manufacturing firms who wish to obtain a competitive advantage. Olugu et al. [25] developed a set of key performance measures for GSCM in the automobile industry. For the forward supply chain, the most crucial measure was customer perspective, while the most applicable factor was the traditional supply chain's cost. For the reverse chain, these measures were topped by management commitment in terms of both importance and applicability. In order to support GSCM decisions, Tsoulfas and Pappis [26] defined six specific environmental performance indicator groups, including product/

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process design and production, packaging, transportation (distribution and recovery) and collection, recycling and disposal, "greening" the internal and external business environment, and other management issues. Taking into consideration previous studies as they relate to the problems we chose to investigate, we select energy saving levels, price, actual energy savings and profit as performance measures in our study.

For a decentralized supply chain, coordination between the players is a significant factor in terms of performance [27,28]. Tsoulfas and Pappis [29] dealt with the problems of identifying environmental principles for the design and operation of supply chains. The operations included in supply chains were briefly described, along with the approaches applied which were designed to improve their environmental performance. By assessing integration and supply chain management, Seuring [30] addressed the importance of the various participants along the supply chain, as well as the interaction between those participants, all of which combine to make a contribution to the future development of industrial ecology. However, extant literature has not yet examined the impact of supply chain structures and the coordination of efforts between supply chain participants on environmental performance.

Public policies are widely used to combat global warming [31]. Regulations implemented by policy makers are a possible solution. Hamza and Greenwood [32] pointed out that the major impact of regulating energy consciousness and environmental sensibility would fall upon many parties. For example, architects, building services engineers, main contractors and specialist engineering contractors would all bear the brunt of such regulations. The degree of responsibility and risk, and where they fell, would depend in part on the project's particular procurement and contractual arrangements. Hamza and Greenwood [32] sought the views of representatives of the key parties involved in these issues. Particular care was taken to select respondents who had knowledge or experience of how to comply with the new regulations. In the context of electric power supply chain networks, Nagurney et al. [33] investigated the determination of optimal carbon taxes applied to electric power plants, which provided policy makers with an insight into how to achieve the imposed reductions of carbon emissions by setting a carbon tax. The behavior of various decision-makers in the electric power supply chain network was described, along with three taxation schemes and the governing equilibrium conditions, formulated as finite-dimensional variational inequality problems. The numerical results demonstrated that the implemented carbon taxes achieved the desired goal. This indicates that public policy is effective in improving environmental performance. As a result, we investigate the impact of regulations imposed by policy makers on energy saving levels, the optimal decisions of green supply chains and the choices of the policy maker in this study.

Firstly, we analyze the impact policy makers have on both energy saving levels and the prices set by green supply chains when they set the threshold value of energy saving levels. Then, from the perspective of the policy maker, the tradeoff between energy savings and the profits of green supply chains is analyzed. We investigate the choices made by the policy makers. Moreover, the coordination of a decentralized supply chain is investigated. A numerical example is used to illustrate a number of related issues, and observations are made. Finally, conclusions are drawn, and topics for future work are suggested.

The remainder of this paper is organized as follows. In Section 2, we describe the problems of business flow and regulation as they relate to energy savings for EFPs. Then, decisions on energy saving levels and prices in both an integrated supply chain and a decentralized supply chain are investigated in Section 3. In Section 4, from the perspective of the policy maker, we analyze the optimal choices for threshold values of energy saving levels under certain conditions. Coordination of a decentralized supply chain is investigated in Section 5. A numerical example is used to illustrate the problem and some related issues are discussed in Section 6. Section 7 reveals our conclusions and suggests possible directions for future studies.

2. Description of the problem

The following notations are used in the model:

x_i	energy saving level in the ith supply chain structure ($i=I$, D, C); it is also a measure of energy saving improvement compared with a benchmark
p_i	price per unit in the ith supply chain strategy
x_0	threshold value of the energy saving level set by the policy maker
w	wholesale price per unit of the product to the retailer
v_M	variable production cost per unit of the manufacturer
v_R	variable retail cost per unit of the retailer
c	fixed cost related to the energy saving level
α	the demand responsiveness to the energy saving level
β	the demand responsiveness to the price of the product

In this study, x_i and p_i are decision variables and other variables are exogenous variables, which are known to both the manufacturer and the retailer in the supply chain.

Assumption 1. $p_i > w + v_R$ and $w > v_M$.

Assumption 2. The energy saving levels of EFPs made by the manufacturer and sold by the retailer are no less than the threshold values of energy saving levels set by policy makers. This assumption is reasonable, because there may be moral hazards from the players due to the supply of asymmetric information to the policy maker.

Assumption 3. The demand for the EFP is decided by both energy saving levels and the price. This assumption is necessary, because there may be other variables which can affect demand, such as advertising, after-sales service, etc.

The inequalities in Assumption 1 ensure that each player in a decentralized supply chain makes a positive profit. Assumption 2 ensures the efficiency of regulation. Referencing the demand functions in [34,35], we regard the energy saving level as a kind of quality characteristic in this study. According to Assumption 3, the primary demand function for the EFP in the ith supply chain structure is decided by x_i and p_i as follows:

$$D_i = a + \alpha x_i - \beta p_i \quad (1)$$

where a is potential intrinsic demand and D_i is deterministic. Obviously, the demand D_i has a positive correlation with x_i and a negative correlation with p_i.

The cost of the green supply chain is expressed as

$$C_i = v(a + \alpha x_i - \beta p_i) + f + c x_i^2 \quad (2)$$

where $v = v_M + v_R$. Here, f is a fixed cost not related to energy saving level x_i; $c x_i^2$ is a fixed cost related to x_i, and $v(a + \alpha x_i - \beta p_i)$ is the variable cost. Therefore, C_i is increasing and convex in x_i.

The business flow and regulation of a green supply chain in the social system are shown in Fig. 1, where the policy maker sets the threshold value of energy saving levels. Both the manufacturer and the retailer know the distribution of demand and they organize the production levels required to meet that demand.

In the following sections, we investigate the impact of x_0 on both the energy saving levels and the prices set by the supply