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Environmental-regulation pricing strategies for green supply chain management

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ABSTRACT

This paper demonstrates that a proper design of environmental-regulation pricing strategies is able to promote Extended Product Responsibility for green supply chain firms in a competitive market. A differential game model comprising Vidale–Wolfe equation has been established in light of sales competition and recycling dynamics as well as regulation related profit function. Analytic solutions of Markovian Nash equilibriums are provided with the necessary condition derived from Hamilton–Jacobi–Bellman equations. We found that governments should opt to gradually raise regulation standards so that rational manufacturers will gradually improve its product recyclability, and, in turn, Extended Product Responsibility will get promoted.

1. Introduction

Competitive strategies for firms and environmental-regulations for governments jointly play an important role in dictating the success of implementing Extended Product Responsibility (EPR) policies (Palmer and Walls, 1997; Reijnders, 2003). At the same time, strategic management has long been considered a significant part of business competitiveness. Most of existing reports, however, concentrate only on the impact of policies *per se*, rather than on the existence of market interaction. This paper, therefore, shed new light on recycling policy designs under a more realistic market condition by the help of a differential game model.

Existing analysis of recycling policy – including Design for Environment (DfE) incentives – are mostly based on a single company model (Fullerton and Wu, 1998; Choe and Fraser, 2001; Stavins, 2002). From the literature, however, we understand that consequence of incentive behave differently in a multiple companies competition context (Jaffe et al., 1995; Vogelsang, 2002), and thus the interactive effect of incentive policies and regulations needs to be reviewed. Moreover, product pricing and manufacturing costs mostly determine the profitability of a firm. Manufacturers accrue their profits by setting the right pricing strategies with consideration for competitor responses and product characteristics (Reijnders, 2003). Among the environmental policy literature, however, while tax or subsidy pricing is often discussed, little attention is given to product pricing and environmental friendly design policy (Ekins, 1999).

In recent years, EPR has attracted much attention and the notion of EPR has been part of the concept of green supply chain. According to Barde and Stephen (1997), EPR is defined as a strategy designed to promote the integration of environmental costs of products throughout their life cycles into the market distribution mechanism so as to reduce product harm to

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the environment. A prosperous green supply chain cannot be substantiated without the help of proper incentives and public policies (Sheu et al., 2005; Sheu, 2008). With the implementation of EPR policies in various supply chains, producer responsibilities have been extended from selling products to recycling them, meanwhile pushing waste management issues to upstream manufacturers and even the entire supply chain (Carter and Jennings, 2002).

In order to promote the concept of EPR, governments around the globe usually provide financial incentives for manufacturers and encourage them to engage in EPR practices (Palmer and Walls, 1999). Appropriate incentive mechanisms not only internalize externality by changing the cost structure for producers, but they also drive manufacturers to develop more environmentally friendly products. Moreover, although international prominence has shifted to product sustainability, the subject of product design is still seen as one of the top priorities for governments and manufacturers. When enterprises respond to strict controls regarding their social responsibility, and at the same time begin to take account of competitive pricing and manufacturing costs, it is often considered difficult for them to determine a long-term profit strategy. Existing literature has pointed out that, however, environmentally friendly designs can reduce material use, enhance business competitiveness, and have other benefits, there is no clear suggestions or practical consideration given as to how and to what extent product design can be improved (Avila, 2006).

Effect of EPR incentive on green product design reacts differently from a market with competitors. Member firms in a green supply chain, in every dynamic stage of the decision making process, attempt to estimate the actions of their rivals and then identify what corresponding strategies can be used to drive the firm toward a maximized profit situation. Such strategies, however, are expected to coincide with environmentally friendly design from the views of policy makers. To facilitate this process, we use a differential game model to derive optimal design trajectories and to illustrate how manufacturers can adopt optimal product green design and pricing strategies for pursuing maximal profit whilst also complying with social responsibility.

Moreover, given that EPR cannot be executed directly, the notion of Design for Environment (DfE) has been suggested instead (Walls, 2003; Spicer and Johnson, 2004). The DfE, however, possesses broad coverage (Calcott and Walls, 2005) and strives to integrate, in a systematic way, various aspects of environment, health, and safety into the design phase of the production process, while at the same time seeking to satisfy simple and easy disassembling design criteria (Calcott and Walls, 2005; Walls, 2003). Given such broad sentiment, this paper focuses particularly on the recyclability of product green design in the following three areas: ease of disassembly, usage of toxic materials, and reusability of resources (Calcott and Walls, 2005), i.e., design for recycling (Kriwet et al., 1995). A prevalent definition of recyclability has been known as a rate or percentage of recyclable material in a product composition (Duchin and Lange, 1994; Huisman et al., 2003). This definition of recyclability has been adopted in this paper.

There are various regulatory and financial incentive schemes. Globalized organizations – including Apple, Sony, and Matsushita – invest a large portion of their budgets in DfE activities in order to green their supply chain. The motivation that drives these firms to implement DfE (Walls, 2003) appears to lie in a combination of regulation and production cost (Palmer and Walls, 1999; Avila, 2006; Iliyana, 2006; Gottberg et al., 2006). In order to compensate for harm caused by the lack of flexibility in command and control, incentive mechanisms can be a complement to maintaining industry growth (Jaffe et al., 1995). Under these mechanisms, manufacturers are charged differently according to their product's characteristics in ease of handling. This price discrimination is expected to regulate manufacturers' environmental responsibility effectively. Among existing incentive designs, product charges or taxes are levied against products that causes environmental pollution prior to production to reflect the externality costs (Barde and Stephen, 1997). We assume that different incentives for firms largely result from differentiated processing fees charged by recycling treatment agencies providing discriminated product recyclability (Duchin and Lange, 1994). In other words, the fee schemes depend on the total amount of scraps as well as the ease of handling in waste treatment and processing.

Comparing to previous literature, we provide a distinctive feature. We extend mixed incentive strategies to a broader view. This paper finds that, for manufacturers in competition, simultaneously offering financial incentives and increasingly stringent regulation is necessary for promoting green product recyclability.

2. Competitive differential game model

In attempting to address the effectiveness of EPR instruments in a competitive environment, our model is built on top of a simplified situation in which an integrated financial incentive and regulation standard is imposed. To manifest the dynamic interaction, and for ease of illustration and analysis, we have constructed a differential game model with sales and recycling dynamics. In our model we assume that, for firms to be environmentally conscious, certain regulation standards need to be imposed to reflect current social responsibility (Foulon et al., 2002). Moreover, a certain amount of capital expenditure also needs to be invested in order to comply with government standards (Cohen, 1999; Foulon et al., 2002).

Fig. 1 illustrates the conceptual framework and the game players for constructing our differential equations. $x_i(t)$ and $\xi_i(t)$ represent the market share and recycling rate of producer i at time t, respectively. The incentive is incorporated in recycling treatment fee $u_i(t)$, which is charged by the treatment agency and depends on the product's recyclability involvement $d_i(t)$, e.g., the extent of ease of disassembly. To implement a simplified financial incentive in our model, a treatment agency directly charges manufacturers processing fees without involving other third party agencies. In the close-to-real situation, there are other agencies as intermediaries, for example, a Producer Responsibility Organization (PRO) charges EEE manufac-