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Product servicing for lifespan extension and sustainable consumption: An optimization approach

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ABSTRACT

Sustainable consumption has been defined as "the consumption of goods and services that meet basic needs and quality of life without jeopardizing the needs of future generations" (OECD, 2002). Lifespan extension of durable products underpins sustainable consumption. This paper describes a novel approach to extend product lifespans by using product servicing that conceptualizes the interactions of a producer, a policy-maker, and multiple consumer segments having different price–demand relationships. We propose a multi-period mathematical optimization model that maximizes the producer's profit while optimizing the prices of different servicing options, production quantities, and inventory levels. A computational study elicits several insights about how the optimal production (or alternatively) consumption quantities are affected by the introduction of product servicing, and the effects of various product characteristics and government incentive or penalty levels on producer's profitability and on product servicing decisions. We conclude that quantitative optimization models are useful for evaluating the impacts of different regulatory policies, assessing the benefits of offering product servicing options, and investing in design for durability and serviceability.

1. Introduction

Barber (2007) identifies four categories of initiatives to promote sustainability: consumption, investment, production, and distribution. Consumption initiatives generally involve notifying consumers about the impacts of their purchasing decisions; investment initiatives include government support of environmentally friendly products and manufacturing; distribution initiatives support marketing and advertising of green production methods, such as including environmental impact information on product labels; and production initiatives encourage the application of green production methods throughout the supply chain.

Some producers undertake real innovations in product design rather than marginal improvements. More often than not, however, the benefits of any efficiency gains disappear in the so-called rebound effect (Ehrenfeld, 2001). In this syndrome, efficiency produces more consumer surplus which leads to more consumption, counterbalancing the potential benefits of eco-efficiency. Extending product lifespans combined with eco-efficiency to achieve sustainable consumption has been proposed by Cooper (2005), who suggests that decreasing the amount of consumption and waste can only work if the framework for the relationship between the consumer and producer is drastically altered. A survey of the literature reveals no suggestions on how producers might be compensated for their lack of production and sales revenue if they invest in extending product lifespans. Our proposed framework motivates producers to institute a process for servicing products for extended periods that relies on managing demand and government incentives/penalties. The contributions of this paper are

(1) A conceptual framework of the roles that a producer, consumers and the government (policy-maker) can play to slow consumption through product servicing and government incentives.
(2) A multi-period mathematical optimization model that assists the producer in optimizing the pricing, production, and inventory decisions that maximize profit assuming multiple servicing options, multiple consumer classes (segments), and government incentives/penalties to promote extended servicing contracts.
(3) A computational study to gain insights into the impacts of different product characteristics and government penalty levels on producer's profitability and product servicing decisions.

The remainder of the paper is organized as follows: Section 2 reviews the relevant literature. Section 3 presents the conceptual

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framework for sustainable consumption through lifespan extension and product servicing. Section 4 presents the mathematical optimization model of product servicing based upon the conceptual framework. Section 5 discusses the computational study to generate insights, and Section 6 presents conclusions and suggestions for future research.

2. Related literature

2.1. The role of industries, governments, and consumers in sustainable consumption

Much of the literature on sustainable consumption focuses on the need to motivate consumers to consume more responsibly, or explores consumer choice (see for example Sanne, 2002; Jackson, 2005a; OECD, 2002). For example, Jackson (2005b) asserts that individuals can live better lives by reducing the amount of materials consumed. Eco-labeling, a recent trend, is based on recognition by government and/or the private sector that the labeled product has passed an inspection for environmental quality, i.e. eco-labels help consumers find products judged to have the least impact on the environment throughout product lifespans (Li and Tang, 2008). The expectation is that consumers will respond positively when products are made more durable, i.e. designed for longer product lifespans. O'Brien (1999) argues that governments should go beyond product eco-labeling in order to generate a change in consumer behavior and create the pull on industry for sustainable products. In fact, O'Brien argues that a policy for sustainable production should promote longer product lifespans and that manufacturers must support extended lifespans.

Murakami et al. (2010) provide an overview of the database LiVES (Lifespan Database for Vehicles, Equipment, and Structures), by the National Institute for Environmental Studies, compiled through a review of lifespan data of commodities reported in statistical surveys by public organizations, research papers, reports by industry associations, and other publications. Using LiVES, the authors model product lifespans by measuring the inflows and outflows of products in a random sampling. Charts display product lifespans and the differences for each product by product locale. For example, the authors find that the lifespan of mobile phones decreased from 4.3 years in 2006 to 2.16 years in 2009.

Most corporations seek innovation rather than durability. Bayus et al. (2003) find that a chief motivator driving companies to ignore product durability and constantly introduce upgraded products is the minimized need to identify new customers for the existing products. Once a new model of the product is introduced, demand decreases for the previous model, which in turn decreases the value of the research and development spent on this new model. Bayus et al. (2003) show that new products only promote short term profit gains and company growth but not profit persistence. Hu and Bidanda (2009) develop a quantitative model to study the tradeoffs between the costs and benefits associated with product end-of-life decisions and identify the optimal strategy to maximize the overall net profit for a manufacturing organization.

Rapid new product introduction and turnover are especially detrimental for the global electronics industry, which tends to design products that impose substantial impacts on the environment (Hu and Bidanda, 2009 and Mayers et al., 2005). Empirical research shows that electronics manufacturers frequently bring new products with poor functionality to market due to competitive pressure and market hype (e.g., the iPhone 4 (Kane and Sheth, 2010)). In fact, Fishman and Rob (2000) find that a monopolist producer who artificially shortens the useful life of each product can capture more of the value generated by its next new product.

Some literature highlights the dilemmas policy-makers face in addressing unsustainable consumption patterns and encouraging more sustainable lifestyles (Jackson, 2005b) and methods to develop sustainable consumption policies (Hertwich, 2005). Cooper (2005) and Hertwich (2005) stress the importance of Life Cycle Analysis (LCA), the study of a product's ecological footprint from "cradle to grave", to determine if reduced waste should be prioritized over lowered energy use in manufacturing, or to inform policy-making and advise consumers. See Barber (2007) for a good overview of sustainable consumption initiatives and policy-makers' efforts. O'Brien (1999) argues for incentive-based government encouragement being more effective than regulations alone in encouraging industries to promote the development of sustainable technologies. O'Brien also calls for considering voluntary negotiated agreements between government and industry on realistic and achievable targets.

Plambeck and Wang (2009) evaluate the effectiveness of two government fee schemes for electronic products to slow the rate of new products: fee-upon-sale and fee-upon-disposal. The fee-upon-sale category includes all regulations that impose a cost on the producer at point of sale. An example is California's Advanced Recovery Fee which is paid by every consumer buying a laptop, monitor, or television. The authors show that under competition a fee-upon-sale, but not a fee-upon-disposal, increases the time between product introductions by producers, which in turn increases the marginal return on expenditure and the quality improvement with each new product. As expected, the greater the fee-upon-sale, the greater the reduction in waste.

2.2. Pricing and product servicing literature survey

The literature on product servicing models generally discusses warranty pricing research, whereby the models consider the price and length of a warranty (see Glickman and Berger (1976), Teng and Thompson (1996), and Huang et al. (2007)), and for comprehensive reviews, see Murthy (1992), Murthy and Blischke (1992), and Murthy and Djamaludin (2002). There are a few papers with an explicit representation of production quantity in addition to pricing and warranty length including Lin et al. (2009) and Wu et al. (2009), but no papers offer a choice of alternative price-warranty combinations or allow customer segmentation according to warranty preferences.

The simultaneous derivation of the optimal price and production level has been examined in previous research (see Elmaghraby and Keskinocak (2003), Chan et al. (2004), and Yano and Gilbert (2005) for reviews). Chen and Sheu (2009) investigate the impact of government fees on pricing and investment in design for recyclability in a competitive market. In general, however, the literature on pricing these fees is mostly from an economics perspective in terms of impacts on price and demand. Such work usually does not incorporate the impact of operational constraints and decisions (see Palmer and Walls (1997), Fullerton and Wu (1998), Conrad (1999), Cremer and Thisse (1999), and Bansal and Gangopadhyay (2003)).

In summary, the literature review shows that sustainable consumption initiatives mostly take the form of consumer awareness campaigns through eco-labeling or voluntary extended producer responsibility activities. The excellent paper by Cooper (2005) on the topic of sustainable consumption highlights product servicing as a mechanism for extending durable products lifespans to support sustainable consumption. Our survey of the literature reveals no suggestions for how producers might be compensated for their lack of production and sales revenue if they invest in extending products' lifespans. Further, it has been