International Journal of Production Economics xxx (2017) 1–9

Contents lists available at ScienceDirect

International Journal of Production Economics

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

Reprint of "The impact of development cost on product line design and its environmental performance"☆

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ARTICLE INFO

Keywords:
Product development and design
Green product
Sustainability
Market segmentation

ABSTRACT

To address environmental problems such as pollution and climate change, many firms have endeavoured to develop green products with higher environmental quality, which includes dimensions like energy efficiency and recyclability. However, environmental quality is oftentimes associated with significant development cost. In this paper, we build and analyse mathematical models to understand how development cost affects a firm's product line design when there are two consumer segments with different willingness to pay for environmental quality. The firm can employ the mass marketing strategy and develop one standard product for all consumers, or employ the market segmentation strategy and develop two differentiated products for the two consumer segments separately. We show how various parameters, especially the development cost, affect the firm's choice on the product line length, or equivalently, between the mass marketing and market segmentation strategies, and the consequent profit and environmental performance. Furthermore, we identify different scenarios where the objective of maximizing profit may or may not lead to better environmental performance.

1. Introduction

Pollution, global warming, ozone depletion and the greenhouse effect have raised the sensitivity of environmental issues. As a result, consumers, governments and NGOs have pressured firms to develop green products. The pressures from stakeholders are not the only reasons for firms to involve in green product development. Other reasons include the opportunities of accessing new market, enhancing competitive advantages, gaining cost efficiency and improving reputation.

There are a few viewpoints about "green" products in the literature. For examples, in 2001, the Commission of the European Communities[1] defines green products as products that "use fewer resources, have lower impacts and risks to the environment and prevent waste generation already at the conception stage". Ottman et al. (2006) state that although no product is completely green, with no impact on the environment, the term "green product" or environmental friendly product commonly refers to those "that strive to protect or enhance the natural environment by conserving energy and/or resources and reducing or eliminating use of toxic agents, pollution, and waste". See Dangelico and Pontrandolfo (2010) for a comprehensive review on different definitions of green products.

According to the literature, we can classify all the attributes of a product into two broad categories, traditional quality and environmental quality (Chen, 2001). The traditional quality contains typical performance attributes including power, safety, material consistency, and convenience. The environmental quality includes those attributes affecting the environment, including energy efficiency, recyclability, and toxic minimization or elimination. On the other hand, we can group all consumers into two segments, ordinary consumers and green consumers. The two consumer segments value the traditional quality equally but green consumers have a higher willingness to pay for the environmental quality. Unlike most previous studies (e.g., Chen, 2001), this paper assumes that ordinary consumers still have a positive willingness to pay for the environmental quality. This is justified by the fact that the environmental quality consists of certain attributes appealing to all consumers such as energy efficiency (Hu et al., 2014).

DOI of original article: https://doi.org/10.1016/j.ijpe.2016.10.027.

☆ This article is a reprint of a previously published article. For citation purposes, please use the original publication details; International Journal of Production Economics, 184, pp. 122-130.

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[1] Commission of the European Communities Green Paper on Integrated Product Policy (2001) http://eurlex.europa.eu/LexUriServ/site/en/com/2001/com2001_0068en01.pdf.

https://doi.org/10.1016/j.ijpe.2017.11.005

Available online xxxx
0925-5273/© 2017 Published by Elsevier B.V.

Please cite this article in press as: Zhang, Y., et al., Reprint of "The impact of development cost on product line design and its environmental performance", International Journal of Production Economics (2017), https://doi.org/10.1016/j.ijpe.2017.11.005

In the presence of both ordinary consumers and green consumers, a firm can choose between two strategies, namely, the mass marketing strategy and the market segmentation strategy. In the former, she offers a standard product for all consumers. In other words, the product line length is one. In the latter, she offers two product versions, an ordinary product for ordinary consumers and a green product with a higher environmental quality for green consumers. In other words, the product line length is two. Of course, if there were no development cost for the environmental quality, the market segmentation strategy is better. However, achieving environmental quality often involves significant development cost, which is partially due to the need to attract specialists and purchase advanced equipment and technologies (Noci and Verganti, 1999; Cai and Li, 2008; Dangelico and Pujari, 2010). Consequently, green products are usually priced higher than ordinary products. For examples, in May 2015, Toyota priced its Camry Hybrid from $28,710, its regular Camry from $24,100, and Toyota Prius from $35,905.[2] During the same month, Ford Motors priced its Fusion SE from $24,799, Fusion SE Hybrid from $29,449, and Fusion Energi SE from $38,449.[3]

In this paper, we aim to understand how the development cost of environmental quality affects a profit-maximizing firm's choice on the product line design and the resulted financial and environmental performances. To this end, we build stylised optimization models where we assume that each product's attributes can be categorized into traditional quality and environmental quality and there are two market segments, both assumptions commonly adopted in the literature (see, e.g., Chen, 2001). However, our work is a first attempt to simultaneously consider quadratic marginal production cost and quadratic development cost, both functions of quality levels. Further, differing from previous work, our models assume that all consumers value environmental quality, although to different degrees. This is important because environmental quality does comprise quality dimensions like energy efficiency. In short, our models are more realistic for green product design.

Facing the two consumer segments, the firm can choose between the mass marketing strategy and the market segmentation strategy. Under each strategy, aiming to maximize the firm's profit, we derive the optimal levels of traditional quality and environmental quality, the optimal product selling price(s), and the resulted maximal profit. Furthermore, given those optimal decisions, we also find and compare the firm's environmental performance under the two strategies. We are particular interested in identifying scenarios where profit maximizing leads to worse environmental performances for the firm.

The rest of this paper is organized as follows. In Section 2, the related literature is reviewed. In Section 3, the model is proposed and the optimal levels of traditional quality and environmental quality, the optimal selling price(s), the maximal profit, and the total environmental performance for the mass marketing strategy and the market segmentation are derived. Furthermore, in Section 3, the environmental and economic consequences associated with each strategy are compared. Finally, our conclusions, model limitations, and future research directions are presented in Section 4.

2. Literature review

There are two streams of literature related to this paper; research in product line design and research in environmental issues related to product design. These two research streams will be reviewed below.

Managerial decisions in product line design and development have been important research topics in both the Operations Management and Marketing fields (Krishnan and Ulrich, 2001). Facing heterogeneous consumers with different preferences and willingness to pay for a particular product, a firm can choose the market segmentation strategy with quality and price discrimination. There is a vast literature aiming to understand how to design differentiated products to achieve the best possible profit for a firm. The seminal work of Mussa and Rosen (1978) is about product-line design given heterogeneous consumer preferences. They focus on how a monopolist makes decisions on qualities for a range of products. Moorthy (1984) studies the implementation of market segmentation through the consumer self-selection process. Similar to the work of Mussa and Rosen (1978), he also considers a monopolist's single-dimensional product quality decisions, but he uses a general utility function and assumes finite number of consumer segments. Moorthy and Png (1992) also apply the self-selection approach to a finite market segmentation model with the assumption of heterogeneous consumer preferences for qualities. The discrete market segment model has been further extended. Kim and Chhajed (2002) extend the results on the single attribute analysis to problems with multiple quality attributes in product design problems and assume two finite consumer segments with heterogonous consumer preferences. Krishnan and Zhu (2006) consider a quality-based model for development-intensive products in multiple market segments with different marketing and manufacturing considerations. They show that considering development costs has a significant effect on the product-line design choices. Liu and Cui (2010) try to answer an interesting question: whether channel centralisation or decentralisation will result in a longer product line? They focus on the choice between one product and two products and find that decentralisation may lead to a longer product line, which is quite counter-intuitive. Palsule-Desai et al. (2015) investigate on the production line design and positioning problem where products are differentiated on the level of add-on services only. Their work is a first attempt on the product line design for services instead of traditional manufacturing products. Aydin et al. (2015) focuses on the remanufacturing of end-of-life and returned products. Together with new products in the market, this is considered a special product line design problem. They develop algorithms to calculate the Pareto optimal solutions.

Research on the environmental impact of product development has received increasing scrutiny from both academic researchers and industry practitioners. Dangelico and Pujari (2010) propose a conceptual framework that presents different dimensions of green product innovation, firm's motivations to develop green products and the challenges they faced during green product developments. Yalabik and Fairchid (2011) examine the combined effects of consumer, regulatory, and competitive pressure on firm's green product investment. They found that competition over environmentally sensitive consumers improve the effectiveness of environmental innovations. Yalabik et al. (2014) study when a profit-maximizing manufacturing firm will become a remanufacturer and if so, when it will positively or negatively impact the environment. They find that remanufacturing may not necessarily improve the environment. Chen and Liu (2014) find that the existence of price leadership has a significant impact on design for recyclability. They discuss the ways to encourage a green firm to be the price follower to achieve more environmental friendly product design decisions. Other related research on green product design includes Shrivastava (1995) and Pujari et al. (2003).

The following two papers are most related to our work. Chen (2001) combines the merits of the above two streams of research by modelling the trade-off between traditional and environmental qualities for two consumer segments where consumers have different preferences about environmental quality. Unlike our work, Chen (2001) assumes: 1) the sum of traditional quality and the environmental quality has to be one; 2) there is a constant and identical development cost, which is not a function of quality levels. In the second paper, Krishnan and Zhu (2006) study the design of development-intensive products each with two quality dimensions. Unlike our work, Krishnan and Zhu (2006) assumes zero marginal production cost, which is appropriate only for development-intensive products such as software.

[2] http://www.toyota.ca/toyota/en/vehicles/camry-hybrid/overview
[3] http://www.ford.ca/?searchid=71700000010155675

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